CHAPTER 9: SYSTEM EVALUATION

9.1 Introduction

Evaluation is an essential ingredient to good project planning and management. It is the reasoned consideration of how well project goals and objectives are being achieved. Evaluation should be considered as part of the project development process that iterates across stages of strategy formulation, detailed planning, data collection, data analysis, system design and implementation, and reporting of results.

Evaluations can be qualitative and quantitative. The most effective evaluations occur when goals and objectives are explicitly stated, are measurable, and are agreed upon by all project partners.

9.2 ITS Evaluation Guideline

The Transportation Equity Act for the 21st Century (TEA-21), ITS Evaluation Guidelines, states that projects deploying intelligent metropolitan or rural infrastructure are expected to allocate resources adequate for evaluating the impact (or impacts) their projects exert in certain major goal areas such as safety, mobility, efficiency, productivity, energy and the environment. These above-listed goal areas are contained in the 1992 ITS Strategic Plan.

9.2.1 ITS goal areas

ITS projects should be evaluated according to their impact on these goal areas.

- Traveler Safety
- Traveler Mobility
- Transportation System Efficiency
- Productivity of Transportation Providers
- Conservation of Energy and Protection of the Environment
- Others as may be appropriate to unique features of a project

Each of these goal areas can be associated with outcomes of deployment that lend themselves to measurement. The association of goal areas and measures is depicted in the

Table 9-1 where each of the National ITS Program goal areas is presented, along with key measures of effectiveness (MOE's) associated with each goal.

Table 9-1: MOE's of ITS Goal Areas

Goal Area	Measure of Effectiveness
Safety	Reduction in the overall crash rate Reduction in the rate of crashes resulting in fatalities Reduction in the rate of crashes resulting in injuries Improvement in surrogate measures
Mobility	Reduction in travel time delay Reduction in travel time variability Improvement in surrogate measures
Efficiency	Increases in Freeway and Arterial Throughput or Effective Capacity
Productivity	Cost Savings
Energy and Environment	Decrease in Emissions Levels Decrease in Energy Consumption
Customer Acceptance	Improvement in Customer Satisfaction

9.2.2 System Performance Evaluation

The size and the experimental nature of this project would lead to focusing on some main parts of those goals, namely the safety goal (reducing crashes and crash risks) and its direct implication on productivity or cost savings in lives and damages. Other goals are implicitly and positively related to the main goal which is reduction of accidents, that is, when the number of crashes are less it is logical to expect reduction in travel delays, higher throughput of the road, less emissions and energy consumption and improvement in users satisfaction, at least during the time period between accident occurrence and clearance.

9.3 Safety

One of the most "predictable / expected" consequences, as well as the main objective, of installing the warning system is reducing the number of the head-on collision occurrences by discouraging violations.

Surrogate measures might provide one indicator of the safety gains of ITS systems if the field survey period is meant to be relatively short. That is, the use of the warning system may reduce the **violation rate**, which in turn, is expected to **reduce the risk** of an accident occurring. Violation rate reduction could be assessed through field surveys that compare the rate of violation on the basis of "before" and "after" activating the system for an extended period of time (six months for example).

However, when evaluating the performance of the project in terms of the **number of head-on accidents** reduced, a **field** comparison can be made between the number of crashes in the period before and the period following the implementation of the detection and warning system. In this case, care should be given to the length of the study period and the collection of data in both time periods.

It should also be noted that, due to the random nature of crash occurrences, it may not be possible to prove statistically that there was a significant difference between the number of crashes in the "before" and "after" periods unless the field evaluation extended over a lengthy period of time (2-3 years).

However, to overcome the difficulty of time when evaluating the impact of the system, we may rely on the simulation output when comparing the number of head-on collisions in "**with** the system" and "**without** the system" **simulation cases**. This approach enables us to assess the safety impact of deploying a detection and warning system, and consequently to make estimations about other impacts mainly in the productivity goal area.

9.3.1 Risk Comparison Tools

In the "Without System" case, the only stimulus that can affect the decision of the violator while he/she is committing the illegal action, as well as the driver of vehicle C, is when they see each other. In the “With System”, another stimulus can affect the violator behavior is the warning display when it is activated before the two vehicles reveal to each other.

Following the stimulus and the perception-reaction period, and as we have explained before, there are three actions that could be taken by the violator once he/she perceives the oncoming vehicle C or the warning message. Since we cannot tell which one of those actions will be finally adopted in each violation maneuver, we ended up with analyzing all three actions for all the 890 annual violations simulated in both directions. The outcome of every violation tested for every action type is either 0 or 1 indicating that no crash or a crash occurred for that violation associated with the action specified.

That kind of analysis would allow us to view risks associated with violations from two angles:

1- Assess the crash risks of each action and then tell which action is the riskiest move after we test all the violations. That is, for the 890 violations, we are going to determine which action among the three will cause the highest number of crashes, and which one the least.

2- Assess the risk level of every violation in term of possible crashes that could occur pending on the actions taken, so a violation could be 0,1,2, or 3 crashes when it is tested for the three possible actions.

The outcomes of every violation when tested for the three actions serve as risk indicators for that violation. For example, when a violation ends up with three crashes as it is tested with the three actions, we may conclude that we have a case with an “unavoidable crash” fate, whatever the action taken by vehicle A driver. This case represents the highest risk indicator. Whereas the zero possible crash result means that there is no collision regardless of the action adopted by vehicle A driver, indicating the lowest (or risk free) risk indicator.

Actually, those two assessments would help as an effective tool when comparing the “with” and “ without” cases.

Table 9-2: Crash Outcomes of Actions by Directions (Without System)

Crashes	Action1 Crashes			Action2 Crashes			Action3 Crashes			All Actions Crashes		
Direction Run #	E	W	E+W	E	W	E+W	E	W	E+W	E	W	E+W
1	206	120	326	152	54	206	297	71	368	655	245	900
2	217	120	337	158	63	221	294	70	364	669	253	922
3	199	120	319	153	69	222	310	61	371	662	250	912
4	228	126	354	166	67	233	301	64	365	695	257	952
5	194	132	326	143	69	212	301	61	362	638	262	900
6	206	129	335	152	58	210	298	74	372	656	261	917
7	209	116	325	139	61	200	307	69	376	655	246	901
8	219	120	339	158	64	222	291	66	357	668	250	918
9	215	130	345	148	74	222	305	68	373	668	272	940
10	180	128	308	130	58	188	309	78	387	619	264	883
11	235	121	356	170	80	250	316	49	365	721	250	971
12	194	117	311	143	59	202	301	73	374	638	249	887
13	204	119	323	152	67	219	296	56	352	652	242	894
14	226	121	347	165	55	220	293	75	368	684	251	935
15	199	112	311	149	55	204	301	71	372	649	238	887
16	220	112	332	162	57	219	283	70	353	665	239	904
17	208	117	325	153	54	207	295	75	370	656	246	902
18	206	122	328	152	58	210	298	75	373	656	255	911
19	208	122	330	154	65	219	306	67	373	668	254	922
20	207	129	336	165	67	232	301	70	371	673	266	939
21	208	129	337	156	74	230	307	60	367	671	263	934
22	231	134	365	166	65	231	323	75	398	720	274	994
Average	**210**	**123**	**333**	**154**	**63**	**217**	**302**	**68**	**370**	**665**	**254**	**919**
Percent	**31.6%**	**48.3%**	**36.2%**	**23.1%**	**24.9%**	**23.6%**	**45.3%**	**26.8%**	**40.2%**	**100.0%**	**100.0%**	**100.0%**
St. Dev.	**13.2**	**6.2**	**14.7**	**9.8**	**7.2**	**13.7**	**8.7**	**7.2**	**10.0**	**23.9**	**10.0**	**27.9**

N.B. Action 1: Make full stop Action 2: Return to right lane behind vehicle B Action 3: continue takeover maneuver

Table 9-3: Crash Risk Indicator In Term Of Possible Crashes by Direction (Without System)

	Violations With Crash Risk Indicator 0			Violations With Crash Risk Indicator 1			Violations With Crash Risk Indicator 2			Unavoidable Crash Violations (Crash Risk Indicator 3)			Total Violations		
Direction / Run #	**E**	**W**	**E+W**	**E**	**W**	**E+W**	**E**	**W**	**E+W**	**E**	**W**	**E+W**	**E**	**W**	**E+W**
1	258	41	299	269	13	282	193	116	309	0	0	0	720	170	890
2	258	35	293	257	17	274	203	118	321	2	0	2	720	170	890
3	248	37	285	282	16	298	190	117	307	0	0	0	720	170	890
4	234	36	270	278	13	291	207	119	326	1	2	3	720	170	890
5	264	34	298	274	10	284	182	126	308	0	0	0	720	170	890
6	257	35	292	272	12	284	189	120	309	2	3	5	720	170	890
7	249	37	286	287	20	307	184	113	297	0	0	0	720	170	890
8	252	39	291	268	13	281	200	117	317	0	1	1	720	170	890
9	249	24	273	275	20	295	195	126	321	1	0	1	720	170	890
10	272	29	301	277	18	295	171	123	294	0	0	0	720	170	890
11	223	38	261	276	15	291	218	116	334	3	1	4	720	170	890
12	264	34	298	274	23	297	182	113	295	0	0	0	720	170	890
13	257	43	300	275	13	288	187	113	300	1	1	2	720	170	890
14	248	39	287	261	12	273	210	118	328	1	1	2	720	170	890
15	260	43	303	271	17	288	189	109	298	0	1	1	720	170	890
16	257	38	295	261	25	286	202	107	309	0	0	0	720	170	890
17	258	39	297	268	16	284	194	115	309	0	0	0	720	170	890
18	257	30	287	272	25	297	189	115	304	2	0	2	720	170	890
19	243	33	276	287	20	307	189	117	306	1	0	1	720	170	890
20	243	32	275	281	13	294	196	122	318	0	3	3	720	170	890
21	243	33	276	284	13	297	192	122	314	1	2	3	720	170	890
22	211	29	240	298	9	307	211	131	342	0	1	1	720	170	890
Average	**250**	**35**	**286**	**275**	**16**	**291**	**194**	**118**	**312**	**0.68**	**0.73**	**1.41**	**720**	**170**	**890**
Percent	**34.8%**	**20.8%**	**32.1%**	**38.2%**	**9.4%**	**32.7%**	**27.0%**	**69.3%**	**35.1%**	**0.1%**	**0.4%**	**0.2%**	**100.0%**	**100.0%**	**100.0%**
St. Dev.	**13.9**	**4.7**	**15.4**	**9.5**	**4.6**	**9.6**	**11.0**	**5.6**	**12.8**	**0.9**	**1.0**	**1.5**			

9.3.2 Crashes Output of The "Without System" Simulation

Twenty-two runs were made to represent a total of 22 years of system operation analysis. An average was taken for all runs output to represent the number of crashes as well as the risk levels on yearly basis under the actual prevailing conditions.

Table 9-2 exhibits the crash outcome of every action when tested for all the violations. An average was calculated for the 22 annual runs in both directions.

The figures in the table suggest that decelerating and merging back behind vehicle B is the safest move to make in order to avoid a crash. It also seems that this is true in either direction where action 2 crashes percent is the lowest among the three possible actions in both east or westbound directions (23.1% and 24.9 % respectively).

Action 3 seems to be the riskiest action to make in the eastbound whereas action 1 is the riskiest in westbound directions, most probably due to the differences of the geometric conditions of the two sides of the hill (in grade and length) knowing that the differences in speeds and in violating vehicle types percentages are relatively small.

Table 9-3 exhibits the risk levels that the violations are exposed to, presented in terms having 0,1,2 and 3 (unavoidable crash) risk indicators. The table reveals high annual number of **possible** crashes reflecting the risky nature of overtaking maneuver with an uncleared passing distance. Actually, what is happening in reality suggests that human intelligence-under prevailing conditions of road, vehicle and human factor- is almost capable of making the right decision about what would be the safest action among the three to make in order to avoid a possible head-on collision. However, it could happen -as the table suggests- that all of the three actions would lead to an "unavoidable crash" where collision in this case is considered **certain**.

So, in terms of **unavoidable** crashes, Table 9-3 shows that an average of 1.41 unavoidable crashes would result from the controlled simulated violations per year, a figure, which is very close to the actual fact of 0.71 head-on crash per year (5 reported crashes in the last 7 years).

The lower rate observed in project site could be simply explained by the "uncontrolled" or "unpredictable" conditions or actions that either vehicle A, B or C or their drivers can come up at those critical moments, such as driver A runs out the road or makes a forced merging with B (etc..), an action that was not “predicted or controlled” by our model in one hand , and that could lead to another type of crashes observed such as rear-end, side swipe or fixed object collision, on the other hand.

Another information that the table provides is that the rate of unavoidable crashes in the westbound is larger than the eastbound one even though the estimated annual number of violations is much less (almost one quarter). In fact, the table shows that the eastbound direction is much less riskier than the westbound. This conclusion is expressed, in addition to the unavoidable crashes percent (0.1% vs. 0.4%), by also the high percent of westbound riskier violations, i.e. violations with possible two head-on crashes outcomes (69.3% and) when compared to the eastbound percentages (27.0%).

Moreover, one out of every three of eastbound violations is at no risk (or 0 possible crashes) versus one out of five in the westbound direction.

In both directions combined (E+W), the figures show that almost equal percentages of violations might face risk levels of zero, one and two possible crashes pending on the action taken. Also, Two violations per thousand (or 0.2%) have the risk of inescapable crashes under the prevailing conditions.

It is worth indicating here that unlike all the other parameters presented in the table, the unavoidable crashes parameter (or crash risk indicator 3) has Mean- Standard deviation ratio greater than one, reflecting actually the volatile nature of this random variable.

9.3.3 Crashes Output of The “With System” Simulation

Surprisingly, all simulations output showed a consistent and robust outcome of low risk levels when a detection and warning system is deployed.

In fact, Table 9-4 shows that it is virtually impossible to have a head-on crash if the violator responded to the warning message when displayed and perceived either by making full stop (action1) or by setting back and resuming the right lane behind vehicle B (action 2). This outcome could be explained by the very early warning that the system sends to the violator; early enough to allow him take the appropriate corrective action in obeying the law and discontinuing the illegal maneuver.

Table 9-4: Actions Outcomes by Directions (With System)

Crashes	Action1 Crashes			Action2 Crashes			Action3 Crashes			All Actions Crashes		
Direction / Run #	E	W	E+W	E	W	E+W	E	W	E+W	E	W	E+W
1	0	0	0	0	0	0	297	71	368	297	71	368
2	0	0	0	0	0	0	294	70	364	294	70	364
3	0	0	0	0	0	0	310	61	371	310	61	371
4	0	0	0	0	0	0	301	64	365	301	64	365
5	0	0	0	0	0	0	301	61	362	301	61	362
6	0	0	0	0	0	0	298	74	372	298	74	372
7	0	0	0	0	0	0	307	69	376	307	69	376
8	0	0	0	0	0	0	291	66	357	291	66	357
9	0	0	0	0	0	0	305	68	373	305	68	373
10	0	0	0	0	0	0	309	78	387	309	78	387
11	0	0	0	0	0	0	316	49	365	316	49	365
12	0	0	0	0	0	0	301	73	374	301	73	374
13	0	0	0	0	0	0	296	56	352	296	56	352
14	0	0	0	0	0	0	293	75	368	293	75	368
15	0	0	0	0	0	0	301	71	372	301	71	372
16	0	0	0	0	0	0	283	70	353	283	70	353
17	0	0	0	0	0	0	295	75	370	295	75	370
18	0	0	0	0	0	0	298	75	373	298	75	373
19	0	0	0	0	0	0	306	67	373	306	67	373
20	0	0	0	0	0	0	301	70	371	301	70	371
21	0	0	0	0	0	0	307	60	367	307	60	367
22	0	0	0	0	0	0	323	75	398	323	75	398
Average	**0**	**0**	**0**	**0**	**0**	**0**	**302**	**68**	**370**	**302**	**68**	**370**
Percent	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**
St. Dev.							**8.7**	**7.2**	**10.0**	**8.7**	**7.2**	**10.0**

N.B. Action 1: Make full stop Action 2: Return to right lane behind vehicle B Action 3: continue takeover maneuver

Table 9-5: Crash Risk Indicator In Term Of Possible Crashes by Direction (With System)

	Violations With Crash Risk Indicator 0			Violations With Crash Risk Indicator 1			Violations With Crash Risk Indicator 2			Unavoidable Crash Violations (Crash Risk Indicator 3)			Total Violations		
Direction / **Run #**	**E**	**W**	**E+W**	**E**	**W**	**E+W**	**E**	**W**	**E+W**	**E**	**W**	**E+W**	**E**	**W**	**E+W**
1	423	99	522	297	71	368	0	0	0	0	0	0	720	170	890
2	426	100	526	294	70	364	0	0	0	0	0	0	720	170	890
3	410	109	519	310	61	371	0	0	0	0	0	0	720	170	890
4	419	106	525	301	64	365	0	0	0	0	0	0	720	170	890
5	419	109	528	301	61	362	0	0	0	0	0	0	720	170	890
6	422	96	518	298	74	372	0	0	0	0	0	0	720	170	890
7	413	101	514	307	69	376	0	0	0	0	0	0	720	170	890
8	429	104	533	291	66	357	0	0	0	0	0	0	720	170	890
9	415	102	517	305	68	373	0	0	0	0	0	0	720	170	890
10	411	92	503	309	78	387	0	0	0	0	0	0	720	170	890
11	404	121	525	316	49	365	0	0	0	0	0	0	720	170	890
12	419	97	516	301	73	374	0	0	0	0	0	0	720	170	890
13	424	114	538	296	56	352	0	0	0	0	0	0	720	170	890
14	427	95	522	293	75	368	0	0	0	0	0	0	720	170	890
15	419	99	518	301	71	372	0	0	0	0	0	0	720	170	890
16	437	100	537	283	70	353	0	0	0	0	0	0	720	170	890
17	425	95	520	295	75	370	0	0	0	0	0	0	720	170	890
18	422	95	517	298	75	373	0	0	0	0	0	0	720	170	890
19	414	103	517	306	67	373	0	0	0	0	0	0	720	170	890
20	419	100	519	301	70	371	0	0	0	0	0	0	720	170	890
21	413	110	523	307	60	367	0	0	0	0	0	0	720	170	890
22	397	95	492	323	75	398	0	0	0	0	0	0	720	170	890
Average	**419**	**102**	**520**	**302**	**68**	**370**	**0**	**0**	**0**	**0**	**0**	**0**	**720**	**170**	**890**
Percent	**58.1%**	**59.9%**	**58.5%**	**41.9%**	**40.1%**	**41.5%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**100.0%**	**100.0%**	**100.0%**
St. Dev.	**8.7**	**7.2**	**10.0**	**8.7**	**7.2**	**10.0**									

Let us recall that the system needs only 0.2 seconds to detect the violation and display the message that will be read by the violator in one second and perceived in less than one second, that is a total of about 2 seconds before the violator make up his mind about how to respond.
The early warning that usually takes place in the first two seconds at the beginning of a detected violation gives the violator a precious time gain to make a move and avoid a possible crash. This time gain can be seen as the difference between the 2 seconds time period needed in the "with system" case and the late time period till drivers of A and C see each other and start taking actions in the "without system" case.
It remains that action 3 is the only action that could put the situation in jeopardy and lead to a possible head-on crash. If so, this means that the violator is so persistent (or stubborn!), so that he/she takes his chances in attempting to complete the risky maneuver. Such kind of drivers are usually aggressive and risk takers in such situations, and are unaware of the tragic circumstances that could be resulted from their irresponsible actions.
Here comes the enforcement system, which can play the role of the "awaken eye" over those hindering the lives of the others. The low camera system installed and activated by the control system to capture the violating vehicle license plate, in addition to role as an evidence material is a tool aiming at putting more pressure on the violator in order to affect his/her decision and force him/her not continues the risky takeover.

Based on the crash analysis by action type above, and as Table 9-5 indicates for all the 22 years runs, the entire violations risks were either 0 or 1 possible crash and no single violation showed a higher risk level including the unavoidable crashes. The risk indicator 1 results from action 3 only as we have seen before, and this is true for both east and west directions.
More than half of violations are at zero risk levels: 58.1% eastbound, 59.9 % westbound, and 58.5 % combined. The rest of the violations are at 1 possible crash risk level associated with a possible wrong action that could be taken by the violator, as we will see later.
The low risk indicator results means that head-on collisions could be virtually eliminated if the human intelligence responded correctly to the early warning of the system and took the appropriate action.

Finally Figures 9-1 and 9-2 summarize the evaluation findings between the "without " and "with" cases, in terms of number of crashes by action type and crash risk analysis.

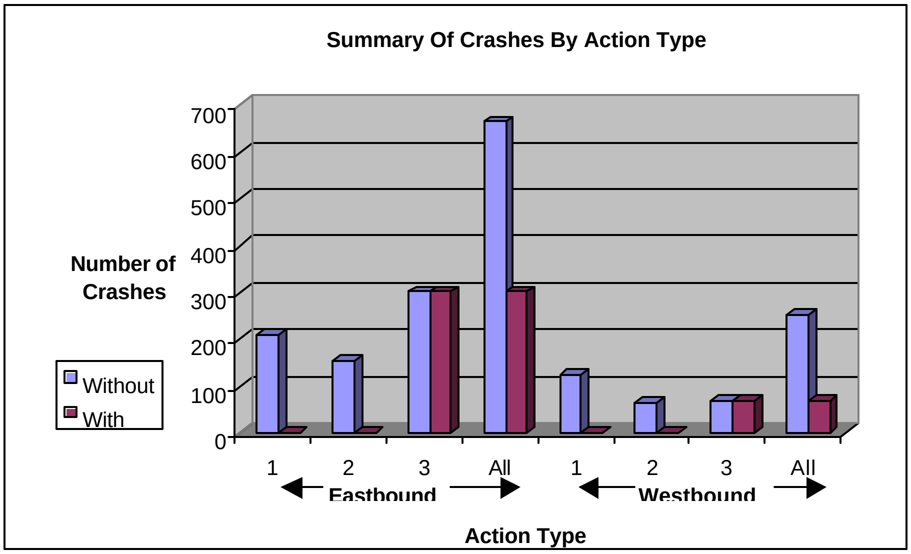

Figure 9-1: Crash Summary By Action Type

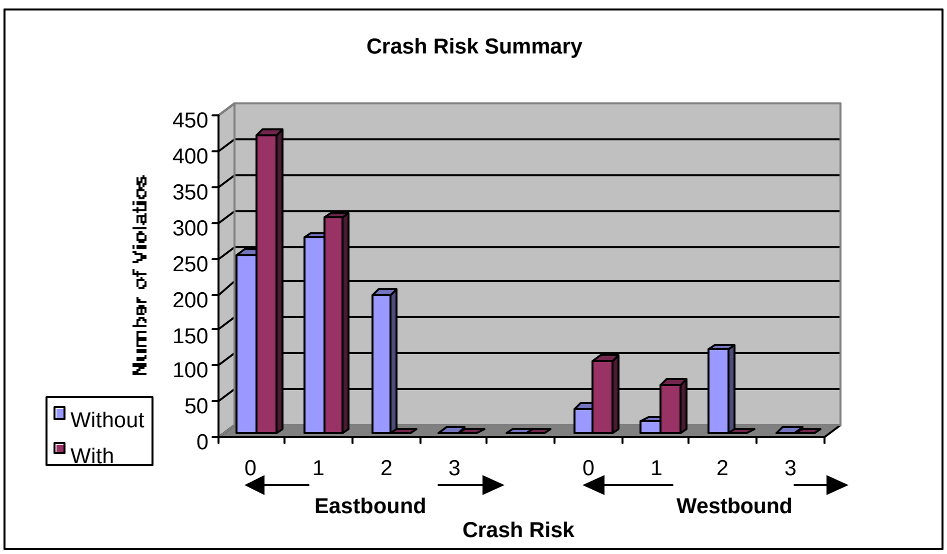

Figure 9-2: Crash Risk Summary

9.3.4 Accident Severity

Another important aspect that we can examine in the system evaluation is the comparison of accidents severity between the "with " and " without" system cases. One way of doing that, is by comparing the speeds of the vehicles A and C at the moment of collision for both cases. Tables 9-6 and 9-7 summarize the average results of the 22 runs.

As one may expect, the average crashes speeds are the lowest for actio n1: 27 mph for vehicle A and 17 for vehicle C in both directions, with slight differences between the two directions (without the system case). This is simply explained by the two drivers attempt to decelerate and make full stop.

Table 9-6: Crashes Speed of Vehicles A and C (Without Case)

		Action1 Crashes			Action2 Crashes			Action3 Crashes		
		E	W	E+W	E	W	E+W	E	W	E+W
Vehicle A	Av. Min	0	3	1	1	6	2	65	65	65
	Av. Max	50	51	51	50	51	50	65	65	65
	Av. Mean	25	31	27	27	31	28	65	65	65
	Av. St. Dev.	11	10	11	10	10	10	0	0	0
Vehicle C	Av. Min	0	0	0	0	0	0	0	0	0
	Av. Max	48	52	50	48	51	49	45	52	47
	Av. Mean	15	20	17	16	19	17	6	25	9
	Av. St. Dev.	12	13	12	12	13	13	10	13	11

Table 9-7: Crashes Speed of Vehicles A and C (With Case)

		Action1 Crashes			Action2 Crashes			Action3 Crashes		
		E	W	E+W	E	W	E+W	E	W	E+W
Vehicle A	Av. Min	0	0	0	0	0	0	65	65	65
	Av. Max	0	0	0	0	0	0	65	65	65
	Av. Mean	0	0	0	0	0	0	65	65	65
	Av. St. Dev.	0	0	0	0	0	0	0	0	0
Vehicle C	Av. Min	0	0	0	0	0	0	0	0	0
	Av. Max	0	0	0	0	0	0	45	52	47
	Av. Mean	0	0	0	0	0	0	6	25	9
	Av. St. Dev.	0	0	0	0	0	0	10	13	11

However, that does not deny the possibility of having more severe accidents as Table 9-6 shows where maximum crash speeds recorded are of 51mph for vehicle A and 50 mph for vehicle C. That could happen when both vehicles are revealed to each other too late to reduce their speeds before they hit each other.

Action 2 results are very close to those of action 1, as both vehicles decelerate but with an intension of A driver to return to the right lane.

On the contrary, the highest crash speeds are observed when action 3 is considered. The average crash speed is a fixed 65 mph for A as the driver continues the takeover maneuver at the highest speed. For vehicle C it is an average of 6 mph for eastbound violations, and 25 mph westbound violations. That means that in addition to the riskier nature of the westbound violations (as we have seen earlier), they are even more severe when a crash occurs. Also, an average maximum reported crash speed for vehicle C was as high as 45 mph for the eastbound, and 52 for the westbound violations.

Actions 1 and 2 of Table 9-7 reflect the zero-crash outcomes when the system is deployed and drivers obey the warning message. However, action 3 figures reflect the disobedience outcome in terms of crash speeds. Similar to the previous risk evaluation, crash speeds of action 3 in the "without the system" case are quite identical of those observed in the "without the system". This is true based on the fact that the warning displays had no effect on the vehicle A driver behavior, and hence, had no effect on his/her speed which remained unchanged at 65 mph.

Finally, a separate crash speed analysis was made for violations with crash risk level 3 (or unavoidable crashes), that is, the violations that would face crash whatever the action they might take. Table 9-8 summarizes the results of the analysis by possible action type.

Table 9-8: Average Speeds Of Vehicles A and C in The Unavoidable Crashes

	Action 1		**Action 2**		**Action 3**		**All Actions**	
	VehA	vehB	VehA	vehB	VehA	vehB	VehA	vehB
Mean	41	33	41	33	65	37	49	35
St. Dev.	5	11	5	11	0	10	12	11

As the table reveals the crash speed are quite high and this is expectable for such high-risk violations. Actually this result reflects the fact that having A and C unable to avoid crash, means that both vehicles -when they saw each other- were close and running at high speed in a way they couldn't help it whatever the action that might be taken. Here, let us remember that all fatalities on Route 114 resulted from head-on collisions only, and every head-on crash resulted in human injuries.

9.4 Sensitivity analysis

A sensitivity analysis aims at evaluating the system performance under varying values of some input parameters. This would help in determining what are the critical factors that play major role in collision occurrences and severity and to what extent. It helps also in assessing how robust the performance of the system is as these parameters vary.

Eleven tests have been conducted in the sensitivity analysis. In every test, the value of one input parameter only has been changed from its original value, and then 10 years runs have been made after which the output average is compared with that of the original scenario in terms of number of crashes by action type, crash risk indicator and the severity of crashes. It is worth noting here that in every sensitivity test we are going to compare the average values of some parameters such as the number of crashes by action type, number of violations for the different crash risk indicators, crashes speed of vehicles A and C between those of the original case and of the sensitivity tests. However, due to the stochastic nature of the simulations, these parameters values will be associated with degree of significance represented by the alpha (a) values resulting from the statistical two-tail t-test for the means of the original case and the sensitivity test case, where (1- a) represents the confidence level of testing the hypothesis of having two equal means.

Based on above, for alpha value where ($a/2 \leq 2.5\%$) means that we are 95% confident that the variation of a parameter mean is significant. Similarly, for another alpha value such ($a/2 \leq 5\%$) reflects that we are less confident (or 90% confident) that the two means are not equal, and so on.

For the sake of presenting the results of a typical analysis, we will show in the first two sensitivity tests all tables and graphs depicting all changes of outcomes due the modification of one parameter, even though some of those changes could not be significant. In other tests, we might skip some of those tables or graphs that do not show any significant modifications.

At the end of the analysis, a recap table will summarize all sensitivity tests by presenting only the significant changes of simulations outcomes.

9.4.1 <u>Test 1:</u> Decrease Mean Desired Spacing

In the original scenario, we assumed that vehicle A at t = o will be located behind B at a distance that randomly falls between the mean desired spacing (d_d) and the minimum headway (d_{ABmin}) between vehicles A and B.

In this test we have decreased the mean desired spacing (d_d) by 10 and 20%, keeping every thing else constant. This assumption actually could be resulted from the variations of other traffic parameters such as traffic density.

Anyway, assuming all other parameters constant, the results of the changes occurred are shown in Tables 9-9 and 9-10 to the averages of the runs crash output, and crash risks. Every parameter in the test scenario is compared to that similar in the original scenario with the percent change and the alpha value associated with that change. The same results are depicted in Figures 9-3 and 9-4.

Figure 9-3 shows that in the eastbound direction there is an increase in actions 1 and 2 crashes offset by a decrease in action 3 crashes. However, in the westbound direction, the changes of action 1 crashes seem less significant than those of actions 2 and 3 (see Table 9-9). The shorter headway distance between vehicles A and B could explain the pattern of those changes. This would enable A to overtake more easily B when action 3 is taken. On the other hand, shorter headway poses other difficulties in terms of the oncoming vehicle C that might surprise A when only action 1 and 2 are taken. Adding all action types crashes, the overall number of crashes in the "without system" is almost equal to that of the original case and this is true for both directions.

In the "with system" case, the system proved to be effective for actions 1 and 2 with no crashes at all. However, as the only crashes that can occur in this case are resulting from action 3, and since action 3 crashes are less with shorter headway, it appears that the overall results are better when traffic flow is higher than the original case.

In terms of crash risks, and as table 9-10 and Figure 9-4 shows for the "without system" case, there is a redistribution of crash risks indicators, where crash risks indicators 0 and 2 increases at the expense of crash risk indicator 1. The number of unavoidable crashes, which is an average 1.4 crashes per year in the original case, doesn't significantly change at

Table 9-9: Crashes By Action in Decrease of Desired Spacing (dd) Sensitivity Test

		Without						
	Action	Original Mean	**(-10%)**			**(-20%)**		
			Mean	% Change	**a/2**	Mean	% Change	**a/2**
Eastbound	1	210	219	4%	6.6%	237	13%	0.0%
	2	154	167	9%	0.1%	184	20%	0.0%
	3	302	275	-9%	0.0%	242	-20%	0.0%
	All	665	662	-1%		664	0%	
Westbound	1	123	127	4%	7.4%	127	4%	8.0%
	2	63	73	16%	0.0%	76	21%	0.0%
	3	68	58	-15%	0.1%	54	-21%	0.0%
	All	254	259	2%		257	1%	
		With						
	Action	Original Mean	**(-10%)**			**(-20%)**		
			Mean	% Change	**a/2**	Mean	% Change	**a/2**
Eastbound	1	0	0			0		
	2	0	0			0		
	3	302	275	-9%	0.0%	242	-20%	0.0%
	All	302	275	-9%		242	-20%	
Westbound	1	0	0			0		
	2	0	0			0		
	3	68	58	-15%	0.1%	54	-21%	0.0%
	All	68	58	-15%		54	-21%	

Table 9-10: Violations by Crash Risk Indicator in Decrease of Desired Spacing Test

		Without						
	Crash Risk	Original Mean	**(-10%)**			**(-20%)**		
			Mean	% Change	**a/2**	Mean	% Change	**a/2**
Eastbound	0	250	266	6%	0.6%	278	11%	0.0%
	1	275	247	-10%	0.0%	222	-19%	0.0%
	2	194	206	6%	0.7%	220	13%	0.0%
	3	0.68	0.60	-12%	79.0%	0.60	-12%	80.0%
Westbound	0	35	35	-2%	67.0%	37	4%	47.1%
	1	16	13	-18%	10.5%	11	-33%	0.2%
	2	118	122	3%	10.7%	121	2%	21.6%
	3	0.73	0.70	-4%	93.5%	1.60	120%	5.3%
		With						
	Crash Risk	Original Mean	**(-10%)**			**(-20%)**		
			Mean	% Change	**a/2**	Mean	% Change	**a/2**
Eastbound	0	419	445	6%	0.0%	478	14%	0.0%
	1	302	275	-9%	0.0%	242	-20%	0.0%
	2	0.0	0			0.0		
	3	0.0	0			0.0		
Westbound	0	102	112	10%	0.1%	116	14%	0.0%
	1	68	58	-15%	0.1%	54	-21%	0.0%
	2	0.0	0			0.0		
	3	0.0	0			0.0		

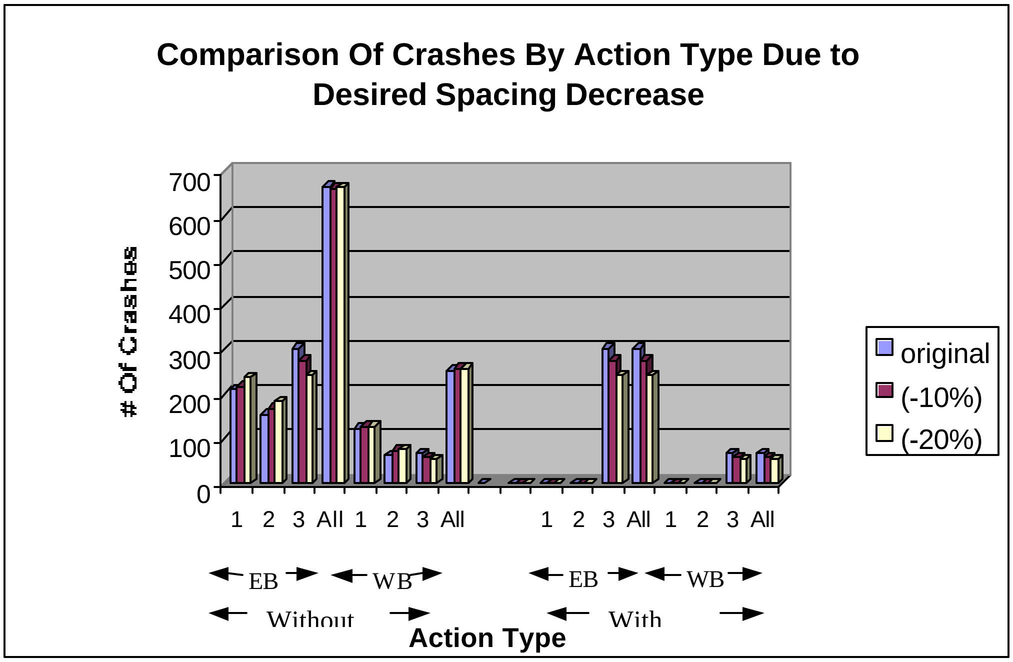

Figure 9-3: Number of Crashes by Action Type and Due To Desired Spacing Decrease

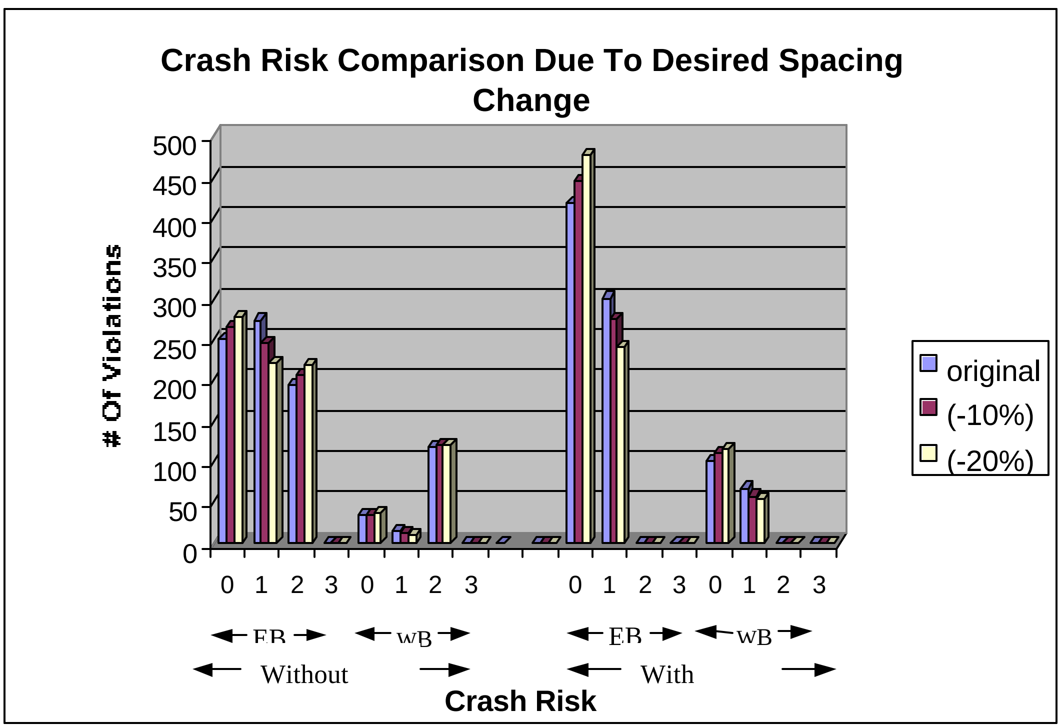

Figure 9-4: Crash Risk Indicator Comparison Due To Desired Spacing Decrease

10% decrease in mean desired spacing. However, it rises up to 2.3 crashes when the mean desired spacing decreases by 20% mainly because of the increase of the westbound unavoidable crashes from 0.73 to 1.6.

On the other hand, for "with system" the risk free indicator 0 increases as risk indicator 1 decreases. Like the original scenario, the system eliminate all crash risks of 2 and 3, hence it virtually keeps eliminating the possibility of the unavoidable crashes with the increase of traffic volume.

In terms of severity of crashes, Table 9-11 shows that there is almost no significant change in crash speeds of vehicles A and C between the original scenario and desired spacing decrease scenario (without case) for both directions, based on the assumption that such decrease would not affect the average speed and speed distribution of the traffic.

Table 9-11: Crashes Speed Comparison of Vehicles A and C (Without Case)

			Vehicle A Crash Speed (mi/hr)					**Vehicle C Crash Speed (mi/hr)**				
	Action Type		**Original**	**(-10%)**	**a/2**	**(-20%)**	**a/2**	**Original**	**(-10%)**	**a/2**	**(-20%)**	**a/2**
East-bound	Action 1	Mean	25	25	9.1%	25	69.3%	15	14	17.7%	14	31.06%
		Max	50	49	24.3%	50	71.0%	48	48	58.1%	47	33.07%
	Action 2	Mean	27	26	0.4%	27	4.4%	16	15	1.6%	15	8.52%
		Max	50	49	24.3%	50	71.0%	48	48	90.3%	47	51.16%
	Action 3	Mean	65	65		65		6	6	4.3%	6	10.73%
		Max	65	65		65		45	46	87.3%	43	23.20%
West-bound	Action 1	Mean	31	30	23.8%	31	98.0%	20	20	94.6%	20	61.01%
		Max	51	52	61.2%	52	87.5%	52	52	68.7%	54	46.37%
	Action 2	Mean	31	31	7.1%	30	2.2%	19	19	82.9%	19	83.08%
		Max	51	51	97.6%	50	44.1%	51	48	16.8%	51	81.75%
	Action 3	Mean	65	65		65		25	26	43.1%	27	0.39%
		Max	65	65		65		52	52	77.2%	54	21.41%

9.4.2 <u>Test 2:</u> Increase Maximum speed

In this test we have increased the maximum speed that vehicle A can reach from 65 mph in the original scenario up to 70 and 75 mph, keeping all other parameters constant. Referring to the data collection chapter, such high speeds have been observed and recorded by the machine counters although their percents were small (1%).

Tables 9-12 and 9-13 shows the changes that occurred to the averages of the runs crash output and crash risks. The same results are depicted in Figures 9-5 and 9-6.
Figure 9-5 shows that there is a high increase in actions 1 and 2 crashes offset by a decrease in action 3 crashes. A higher maximum speed of vehicle A, requires longer time and distance to decelerate and make full stop or merge behind B, which poses more chances to collide with the oncoming C. In the same time, a higher passing speed would enable A to overtake more easily B when action 3 is taken. Adding all action types crashes, the number of crashes of all types in the "without system" is greater than that of the original case up to 37% eastbound and 17% westbound.
In the "with system" case, actions 1 and 2 remain still at zero crash. However, as the higher speed suits more action 3 maneuvers, the overall results are better with 46% and 42% less action 3 crashes than the original case for east and west bounds respectively.

These high increases of crashes are reflected in terms of crash risks. and as Table 9-13 and Figure 9-6 shows for the "without system" case, there is a sharp decrease in crash risks indicators 0 and 1 offset with high increase at of crash risk indicator 2 and 3. The number of unavoidable crashes in the eastbound direction doesn't significantly change at the 70 mph maximum speed unlike the other direction, which goes up from to 0.73 to 2.1 average annual crashes. However, the number of unavoidable crashes rises up to 3.9 per year in both when maximum speed goes up to 75 mph.

Table 9-12: Number of Crashes by Action in Increase of Maximum Speed Test

		Without						
	Action	Original Mean	Max-sp70			Max-sp75		
			Mean	% Change	a/2	Mean	% Change	a/2
Eastbound	1	210	323	54%	0.0%	403	92%	0.0%
	2	154	264	71%	0.0%	345	124%	0.0%
	3	302	210	-30%	0.0%	162	-46%	0.0%
	All	665	796	20%		910	37%	
Westbound	1	123	141	15%	0.0%	147	20%	0.0%
	2	63	96	51%	0.0%	111	75%	0.0%
	3	68	48	-29%	0.0%	40	-42%	0.0%
	All	254	285	12%		297	17%	
		With						
	Action	Original Mean	Max-sp70			Max-sp75		
			Mean	% Change	a/2	Mean	% Change	a/2
Eastbound	1	0	0			0		
	2	0	0			0		
	3	302	210	-30%	0.0%	162	-46%	0.0%
	All	302	210	-30%		162	-46%	
Westbound	1	0	0			0		
	2	0	0			0		
	3	68	48	-29%	0.0%	40	-42%	0.0%
	All	68	48	-29%		40	-42%	

Table 9-13: Violations by Crash Risk Indicator in Increase of Maximum Speed Test

		Without						
	Crash Risk	Original Mean	Max-sp70			Max-sp75		
			Mean	% Change	a/2	Mean	% Change	a/2
Eastbound	0	250	233	-7%	0.1%	199	-21%	0.0%
	1	275	179	-35%	0.0%	134	-51%	0.0%
	2	194	308	58%	0.0%	386	99%	0.0%
	3	0.68	0.60	-12%	80.0%	1.30	91%	6.1%
Westbound	0	35	26	-26%	0.0%	22	-39%	0.0%
	1	16	5	-72%	0.0%	3	-84%	0.0%
	2	118	137	16%	0.0%	143	22%	0.0%
	3	0.73	2.10	189%	0.1%	2.60	258%	0.0%
		With						
	Crash Risk	Original Mean	Max-sp70			Max-sp75		
			Mean	% Change	a/2	Mean	% Change	a/2
Eastbound	0	419	510	22%	0.0%	558	33%	0.0%
	1	302	210	-30%	0.0%	162	-46%	0.0%
	2	0.0	0			0.0		
	3	0.0	0			0.0		
Westbound	0	102	122	19%	0.0%	131	28%	0.0%
	1	68	48	-29%	0.0%	40	-42%	0.0%
	2	0.0	0			0.0		
	3	0.0	0			0.0		

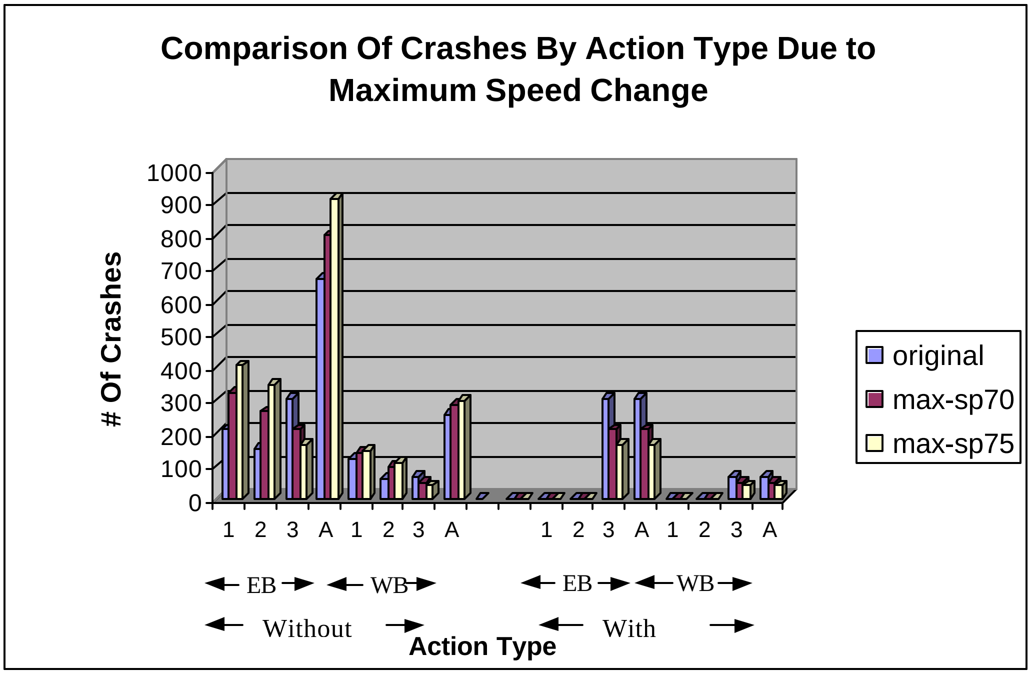

Figure 9-5: Number of Crashes by Action Type and Due To Increasing Maximum Speed

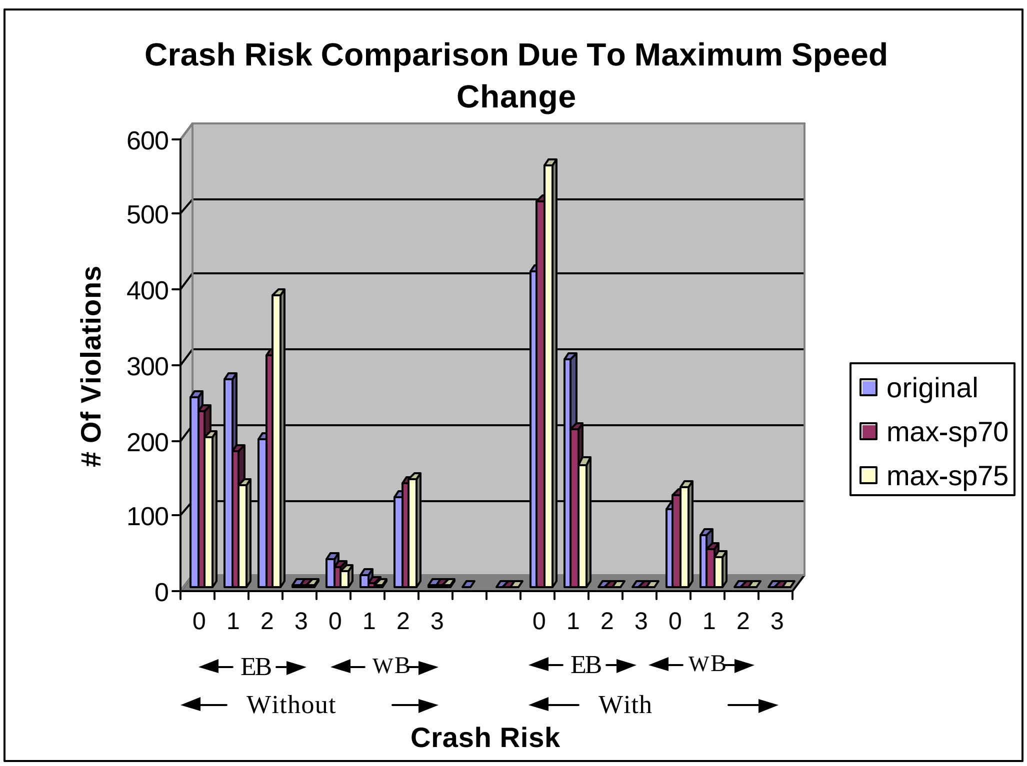

Figure 9-6: Violations by Crash Risk Indicator Comparison Due To Increasing Maximum Speed

For "with system" analysis, the risk free indicator 0 increases as risk indicator 1 decreases as the higher speed favors the action 3 maneuvers. Also, the system keeps eliminating all crash risk indicators of 2 and 3, hence it virtually eliminates the possibility of having unavoidable crashes as maximum speed of vehicle A increases.

In terms of severity of crashes, Table 9-14 shows that there are significant increase in crash speeds means of both vehicles A and C between the original scenario and the maximum speed increase scenario in both directions. And this is true for all action types. Actually this is quite expected, because higher speed would leave less time to brake and avoid crashes whatever the action is taken.

Table 9-14: Crashes Speed Comparison of Vehicles A and C (Without Case)

		Vehicle A Crash Speed (mi/hr)					Vehicle C Crash Speed (mi/hr)				
Action Type		Original	Max-sp70	a/2	Max-sp75	a/2	Original	Max-sp70	a/2	Max-sp75	a/2
Action 1	Mean	25	32	0.0%	38	0.0%	15	16	0.8%	17	0.00%
	Max	50	59	0.0%	63	0.0%	48	51	7.9%	54	0.01%
Action 2	Mean	27	33	0.0%	40	0.0%	16	17	0.8%	18	0.00%
	Max	50	59	0.0%	63	0.0%	48	51	3.9%	54	0.01%
Action 3	Mean	65	70		75		6	7	0.0%	8	0.00%
	Max	65	70		75		45	44	34.4%	47	42.86%
Action 1	Mean	31	36	0.0%	42	0.0%	20	20	34.4%	22	0.00%
	Max	51	58	0.0%	63	0.0%	52	56	7.1%	58	0.46%
Action 2	Mean	31	36	0.0%	42	0.0%	19	19	66.9%	21	0.24%
	Max	51	56	0.0%	63	0.0%	51	55	7.7%	56	3.13%
Action 3	Mean	65	70		75		25	28	0.3%	30	0.00%
	Max	65	70		75		52	55	14.4%	58	0.08%

9.4.3 <u>Test 3:</u> Decrease Driving Under Influence DUI Percent

In this sensitivity test, the percentage of the violators under Influence of alcohol was decreased from 20% in the original scenario to 15 and 10% of the total violators' population.

As Tables 9-15 and 9-16 show, almost all changes that occurred to the averages of the runs crash output and crash risks were insignificant when the DUI percent was decreased to 15%. However, minor significant decrease of 5% and 7% occurred in action 1 and action2 crashes of the "without" case eastbound direction only, when the percent was further decreased till 10%. This result could be explained by the less number of possible violators driving under the influence of alcohol or drug, as those are slower in reacting than the regular drivers.

Those slight variations in the crash outcome are reflected in the crash risk with a slight decrease of 6% in the number of eastbound violations with crash risk indicator 2. Unavoidable crashes didn't seem significantly reduced by the minor crash reductions.

In the "with system" case, there were no significant changes in crashes number or risks when we compared the test outcome is compared to those of the original scenario.

Table 9-15: Number of Crashes by Action in Decrease of DUI Percent Test

		Without						
	Action	Original Mean	**DUI_15%**			**DUI_10%**		
			Mean	% Change	**a/2**	Mean	% Change	**a/2**
Eastbound	1	210	209	-1%	81.2%	199	-5%	3.8%
	2	154	153	-1%	79.7%	143	-7%	1.0%
	3	302	294	-2%	8.0%	301	0%	97.4%
	All	665	656	-1%		643	-3%	
Westbound	1	123	125	2%	26.7%	124	2%	45.9%
	2	63	66	5%	25.3%	66	4%	32.6%
	3	68	66	-3%	38.1%	66	-3%	38.1%
	All	254	258	1%		256	1%	
		With						
	Action	Original Mean	**DUI_15%**			**DUI_10%**		
			Mean	% Change	**a/2**	Mean	% Change	**a/2**
Eastbound	1	0	0			0		
	2	0	0			0		
	3	302	294	-2%	8.0%	301	0%	97.4%
	All	302	294	-2%		301	0%	
Westbound	1	0	0			0		
	2	0	0			0		
	3	68	66	-3%	38.1%	66	-3%	38.1%
	All	68	66	-3%		66	-3%	

Table 9-16: Violations by Crash Risk Indicator in Decrease of DUI Percent Test

		Without						
	Crash Risk	Original Mean	DUI_15%			DUI_10%		
			Mean	% Change	a/2	Mean	% Change	a/2
Eastbound	0	250	256	2%	30.2%	259	4%	9.3%
	1	275	273	-1%	59.0%	279	1%	24.3%
	2	194	191	-2%	46.2%	182	-6%	0.6%
	3	0.68	0.40	-41%	38.6%	0.10	-85%	5.6%
Westbound	0	35	34	-4%	46.3%	34	-3%	58.9%
	1	16	16	-3%	74.8%	16	0%	97.9%
	2	118	120	2%	34.7%	119	1%	57.8%
	3	0.73	0.60	-18%	70.4%	0.60	-18%	70.4%
		With						
	Crash Risk	Original Mean	DUI_15%			DUI_10%		
			Mean	% Change	a/2	Mean	% Change	a/2
Eastbound	0	419	426	2%	8.0%	419	0%	97.4%
	1	302	294	-2%	8.0%	301	0%	97.4%
	2	0.0	0			0.0		
	3	0.0	0			0.0		
Westbound	0	102	104	2%	38.1%	104	2%	38.1%
	1	68	66	-3%	38.1%	66	-3%	38.1%
	2	0.0	0			0.0		
	3	0.0	0			0.0		

The variations of crashes speeds are shown in Table 9-17. The table reveals that slights decrease in vehicle A average crash speed occurred in the westbound direction for actions 1 and 2 in both 15% and 10% tests. Vehicle C crash speeds remained almost the same as in the original scenario.

Table 9-17: Crashes Speed Comparison of Vehicles A and C (Without Case)

			Vehicle A Crash Speed (mi/hr)					Vehicle C Crash Speed (mi/hr)				
	Action Type		Original	DUI 15%	a/2	DUI 10%	a/2	Original	DUI 15%	a/2	DUI 10%	a/2
East-bound	Action 1	Mean	25	25	6.4%	25	9.1%	15	14	27.5%	14	24.23%
		Max	50	49	23.9%	50	79.9%	48	48	69.3%	48	98.90%
	Action 2	Mean	27	26	2.8%	27	39.7%	16	15	15.4%	15	26.26%
		Max	50	49	23.9%	50	79.9%	48	48	98.2%	48	72.00%
	Action 3	Mean	65	65		65		6	6	46.2%	6	64.59%
		Max	65	65		65		45	44	49.7%	45	86.25%
West-bound	Action 1	Mean	31	30	3.5%	29	0.2%	20	20	79.5%	20	94.65%
		Max	51	52	75.2%	52	75.2%	52	52	68.7%	52	68.65%
	Action 2	Mean	31	30	2.2%	30	0.2%	19	19	83.8%	19	72.80%
		Max	51	51	77.8%	51	77.8%	51	48	19.2%	48	19.22%
	Action 3	Mean	65	65		65		25	26	70.6%	26	70.63%
		Max	65	65		65		52	52	73.4%	52	73.42%

9.4.4 Test 4: Increasing DUI Impairment effect

We have seen previously that an additional 0.5 seconds time lag penalty (or delay) was considered for violators driving under influence. This delay was added to the PRT and reading times for the designated DUI violators as the impairment affects their capabilities to perceive and react, which poses them on higher crash risks than the regular drivers. Actually the half second value adopted for DUI impairment was derived for study conducted on low or moderate BAC of less than or equal to 0.10%, knowing that the legal threshold is 0.08% BAC. Here, we are going to consider the impact of the higher BAC by taking 1 and 1.5 seconds time lag delay for the impaired drivers.

As one may expect, Table 9-18, which summarizes the simulations outcome, reveals that in the "without scenario" there is a considerable rise in the number of accidents resulting from actions 1 and 2 by 15% and 17% respectively, when the impairment delay rises and worsens with higher impairment effect of 1.5 seconds.

In terms of crash risks, Table 9-19 shows that there is a significant increase in crash indicator 2 and huge jumps of the unavoidable crashes in both directions from 1.4 to 5.7 crashes per year. Such increases come at the expense of crash risk indicator 1 in the eastbound and the free risk indicator in the westbound direction, signaling a higher dangerous driving conditions resulting from higher impaired violators. The system seems helpful even under these conditions, as it remains successful in preventing any crash resulting from actions 1 and 2, as its early warning provides enough time for the slower reacting drivers to take proper actions to prevent accidents.

Table 9-18: Number of Crashes by Action in Decrease of DUI Impairment Effect Test

		Without						
	Action	Original Mean	**DUI-eff-1sec**			**DUI-eff-1.5sec**		
			Mean	% Change	**a/2**	Mean	% Change	**a/2**
Eastbound	1	210	222	6%	3.1%	242	15%	0.0%
	2	154	160	4%	15.5%	180	17%	0.0%
	3	302	298	-1%	25.6%	283	-6%	10.0%
	All	665	680	2%		705	6%	
Westbound	1	123	127	4%	6.6%	128	4%	3.3%
	2	63	68	8%	10.2%	69	9%	2.8%
	3	68	65	-4%	33.0%	68	0%	93.9%
	All	254	260	3%		265	4%	
		With						
	Action	Original Mean	**DUI-eff-1sec**			**DUI-eff-1.5sec**		
			Mean	% Change	**a/2**	Mean	% Change	**a/2**
Eastbound	1	0	0			0		
	2	0	0			0		
	3	302	298	-1%	25.6%	283	-6%	10.0%
	All	302	298	-1%		283	-6%	
Westbound	1	0	0			0		
	2	0	0			0		
	3	68	65	-4%	33.0%	68	0%	93.9%
	All	68	65	-4%		68	0%	

Table 9-19: Violations by Crash Risk Indicator in Decrease of DUI Impairment Effect Test

		Without						
	Crash Risk	Original Mean	**DUI-eff-1sec**			**DUI-eff-1.5sec**		
			Mean	% Change	**a/2**	Mean	% Change	**a/2**
Eastbound	0	250	248	-1%	64.5%	245	-2%	28.9%
	1	275	265	-4%	1.4%	249	-9%	0.0%
	2	194	206	6%	1.7%	223	15%	0.0%
	3	0.68	1.00	47%	34.6%	3.20	369%	0.0%
Westbound	0	35	34	-4%	44.6%	32	-11%	4.4%
	1	16	14	-16%	10.4%	14	-11%	27.4%
	2	118	121	3%	18.1%	122	3%	9.8%
	3	0.73	1.70	134%	2.8%	2.50	244%	0.0%
		With						
	Crash Risk	Original Mean	**DUI-eff-1sec**			**DUI-eff-1.5sec**		
			Mean	% Change	**a/2**	Mean	% Change	**a/2**
Eastbound	0	419	422	1%	25.6%	437	5%	10.0%
	1	302	298	-1%	25.6%	283	-6%	10.0%
	2	0.0	0			0.0		
	3	0.0	0			0.0		
Westbound	0	102	105	3%	33.0%	102	0%	93.9%
	1	68	65	-4%	33.0%	68	0%	93.9%
	2	0.0	0			0.0		
	3	0.0	0			0.0		

Also, slower reacting drivers means more severe collisions as vehicle A impaired divers fail to brake early enough to reduce the speed of their vehicles heading towards vehicle C. Table 9-20 shows that the severity of crashes come mainly from higher vehicle A crash speeds in terms of mean speed and maximum crash speed observed. Whereas vehicles C crash speeds didn't prove to be significantly higher than those obtained from the original case.

Table 9-20: Crashes Speed Comparison of Vehicles A and C (Without Case)

			Vehicle A Crash Speed (mi/hr)					Vehicle C Crash Speed (mi/hr)				
	Action Type		Original	DUI_effe 1 sec.	a/2	DUI_effe 1.5 sec.	a/2	Original	DUI_effe 1 sec.	a/2	DUI_effe 1.5 sec.	a/2
East-bound	Action 1	Mean	25	28	0.0%	29	0.0%	15	15	92.8%	15	50.01%
		Max	50	55	0.0%	57	0.0%	48	50	16.0%	48	94.35%
	Action 2	Mean	27	29	0.0%	31	0.0%	16	16	81.3%	16	49.40%
		Max	50	54	0.2%	57	0.0%	48	50	15.0%	48	95.18%
	Action 3	Mean	65	65		65		6	6	47.9%	6	79.54%
		Max	65	65		65		45	47	46.2%	44	41.59%
West-bound	Action 1	Mean	31	31	5.5%	33	0.0%	20	19	66.8%	20	33.40%
		Max	51	54	0.3%	58	0.0%	52	54	37.8%	54	27.25%
	Action 2	Mean	31	33	1.5%	34	0.0%	19	19	92.6%	20	38.05%
		Max	51	53	9.3%	58	0.0%	51	52	50.3%	53	20.81%
	Action 3	Mean	65	65		65		25	25	90.6%	25	74.30%
		Max	65	65		65		52	55	9.5%	54	29.41%

9.4.5 <u>Test 5:</u> Overtaking B Ahead on the Slope

In the original scenario we assumed that violators take decision, start acceleration and launch their illegal passing at the sag area of the curve. This assumption actually is practically the most effective way to take advantage of the longer sight distance and higher acceleration that the sag provides. In addition all violations reported in the field support this conclusion as they all started either in the sag or very close to the curve crest when violators had the capability to see the downward side of the road hill.

On the other hand, such scenario cannot eliminate the possibility of having violations that could start in the middle part of the upward slope of the road. Hence, we are going to test the impact of a new modification to our original scenario by assuming that violations could take place, as vehicle B is randomly located in the first 500 feet of the upward slope.

The crashes outcome of the simulation runs is summarized in Table 9-21 and presented in Figure9-7. It shows that, for the “without” system case, there is sharp increase in crashes resulting from actions 1 and 2 in the eastbound directions whereas there is a decrease in the number of crashes resulting from the same actions in the westbound directions. An explanation of this result could be by the relatively short upward slope of the westbound directions, which enables violators to shortly be close to the crest then capable of overview the other side of the road curve, hence, have enough time to make full stop or resume their right lane early before they hit the oncoming vehicles.

Action 3 shows a considerable increase in the number of crashes for both directions. The total possible crashes increased sharply in the eastbound by around 260 crashes (or 39%), and significantly by around 40 crashes (or 15%) in the westbound violations.

For the “with” system case, like other tests, all actions 1 and 2 are risk free, and still the system can provide them with early warning to correct their actions. Unfortunately, this is not true for action3, which turn the “with system” case less efficient as those reckless violators start their maneuvers from riskier places and disobey the warning messages.

Table 9-21: Number of Crashes by Action in Slope Overtaking Test

		Without			
	Action	Original Mean	Test		
			Mean	% Change	a/2
	1	210	347	65%	0.0%
	2	154	193	25%	0.0%
	3	302	384	27%	0.0%
Eastbound	All	665	924	39%	
	1	123	100	-18%	0.0%
	2	63	37	-42%	0.0%
	3	68	79	16%	0.0%
Westbound	All	254	216	-15%	
		With			
	Action	Original Mean	Test		
			Mean	% Change	a/2
	1	0	0		
	2	0	0		
	3	302	384	27%	0.0%
Eastbound	All	302	384	27%	
	1	0	0		
	2	0	0		
	3	68	79	16%	0.0%
Westbound	All	68	79	16%	

Table 9-22: Violations by Crash Risk Indicator in Slope Overtaking Test

		Without			
	Crash Risk	Original Mean	Test		
			Mean	% Change	a/2
	0	250	121	-52%	0.0%
	1	275	275	0%	89.4%
	2	194	322	66%	0.0%
Eastbound	3	0.68	1.70	149%	2.6%
	0	35	51	43%	0.0%
	1	16	24	51%	0.0%
	2	118	94	-21%	0.0%
Westbound	3	0.73	1.40	93%	12.2%
		With			
	Crash Risk	Original Mean	Test		
			Mean	% Change	a/2
	0	419	336	-20%	0.0%
	1	302	384	27%	0.0%
	2	0.0	0		
Eastbound	3	0.0	0		
	0	102	91	-11%	0.0%
	1	68	79	16%	0.0%
	2	0.0	0		
Westbound	3	0.0	0		

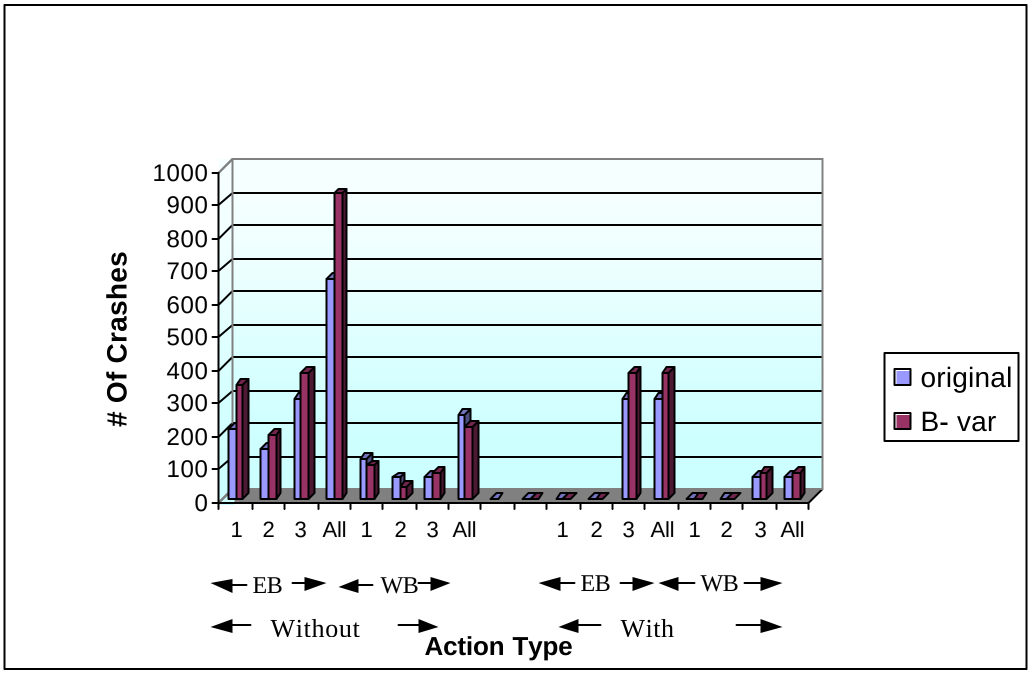

Figure 9-7: Number of Crashes by Action Type and Due To Slope Overtake

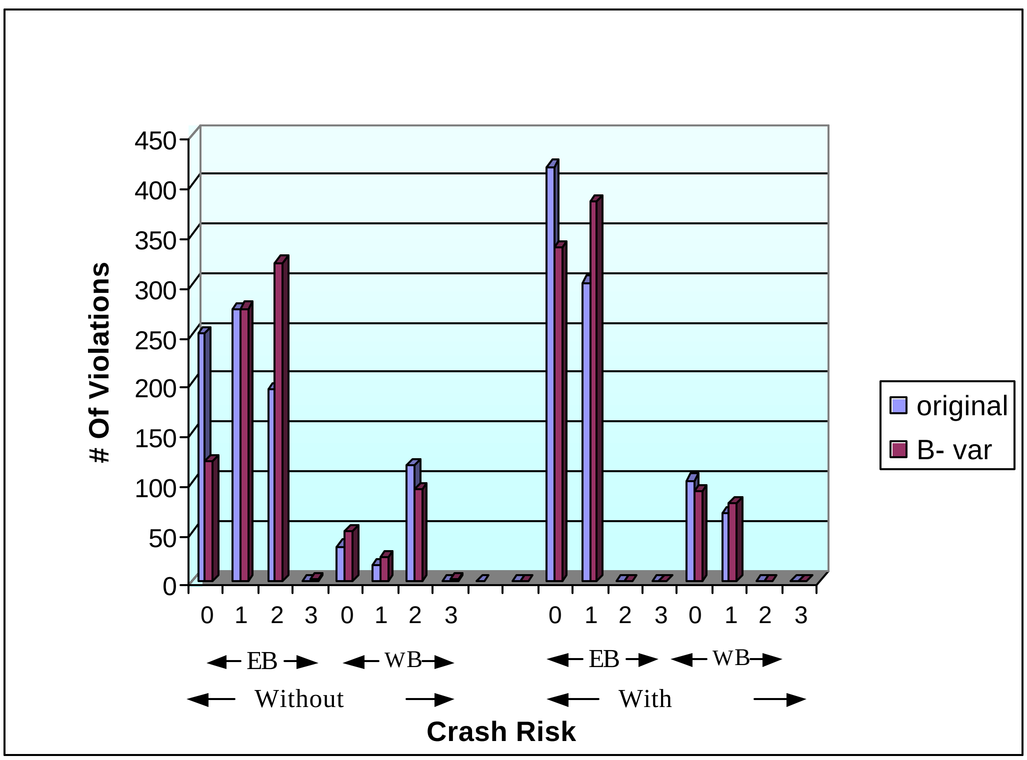

Figure 9-8: Violations by Crash Risk Indicator Comparison Due To Slope Overtake

In terms of crash risks, as Table 9-22 and Figure 9-8 present, there is sharp decrease of the number of the eastbound violations enjoying crash risk free in favor of a high increase with those violations at crash risk 2 and 3 (unavoidable crashes). On the westbound directions, the redistribution of the crash risk shows significant decrease in crash brisk indicator 2 in favor of the crash risk indicators 0 and 1. The unavoidable crashes in this direction reveals an increase from 0.73 to 1.4 annual crashes, but still not proven significant.

The crash risk analysis for the "with system" case reflect directly action3 outcome, thus reducing risk free violations in favor of crash risk 1. However, the system proved to keep up high performance with zero violations at high risks indicators of 2 and 3

Table 9-23: Crashes Speed Comparison of Vehicles A and C (Without Case)

			Vehicle A Crash Speed (mph)			Vehicle A Crash Speed (mph)		
	Action Type		**Original**	**Test**	a/2	**Original**	**Test**	a/2
East-bound	Action 1	Mean	25	27	0.0%	15	16	0.1%
		Max	50	52	14.3%	48	52	0.3%
	Action 2	Mean	27	29	0.0%	16	18	0.0%
		Max	50	52	20.4%	48	51	0.4%
	Action 3	Mean	65	65		6	11	0.0%
		Max	65	65		45	51	0.4%
West-bound	Action 1	Mean	31	30	1.6%	20	18	2.6%
		Max	51	52	65.2%	52	51	55.0%
	Action 2	Mean	31	30	0.3%	19	18	3.9%
		Max	51	48	3.4%	51	45	0.7%
	Action 3	Mean	65	65		25	23	0.3%
		Max	65	65		52	53	31.8%

Finally, small changes occurred to the severity of crashes with a generally significant slight increase of crashes speed for vehicles A and C in the eastbound directions and a slight decrease in some of the westbound direction parameters as Table 9-23 shows.

9.4.6 Test 6: Increase Detection and Verification Time

Detection and verification time (or time lag 1 +2) is the time that the system needs to detect violators and verify the wrong way direction through 3 consecutive pictures. For the whole process requires 0.2 seconds before a warning message is displayed on the warning panel. In this sensitivity test we increased the detection time from 0.2 to 0.6 and 1 second consecutively in order to assess its impact on the system performance.

Actually such significant increase in detection and verification time does not come from a lack of credibility of the equipment itself rather than the special geometric conditions of the project site, namely the existence of many driveways along the roadway that require leaving some gaps between the detection zones.

It is worth noting here that time lag 1+2 is a parameter used only in “with system” simulation cases. Therefore, we expect to have no impact on the “without system” case. In fact, Tables 9-24 and 9-25 show no significant changes (all a/2 are greater than 2.5%) in the output parameters of the “without” case for both crashes by action type and crash risk indicators, and this is true for both directions.
As for the “with system” case, Tables 9-24 and 25 demonstrate that the system performance is robust in terms of eliminating all crash possibilities related to crash types 1 and 2, hence eliminating all crash risk indicators 2 and 3. However, since crashes resulting from action type 3 are not influenced by the modifications of the system parameters, the sensitivity test output does not show also any significant changes in the “with system” case.

Finally, based on the above, we may expect as well no significant changes in the crashes severity as Table 9-26 proves.

Table 9-24: Number of Crashes by Action in Increase of Detection Time Test

		Without						
	Action	Original Mean	0.6 sec detect			1 sec detect		
			Mean	% Change	a/2	Mean	% Change	a/2
Eastbound	1	210	214	2%	48.2%	215	2%	31.2%
	2	154	156	2%	51.5%	158	3%	23.6%
	3	302	304	1%	42.3%	298	-1%	24.9%
	All	665	674	1%		671	1%	
Westbound	1	123	124	1%	63.7%	124	1%	46.5%
	2	63	65	3%	45.4%	65	3%	52.0%
	3	68	67	-2%	54.3%	68	0%	93.9%
	All	254	255	1%		258	1%	
		With						
	Action	Original Mean	0.6 sec detect			1 sec detect		
			Mean	% Change	a/2	Mean	% Change	a/2
Eastbound	1	0	0			0		
	2	0	0			0		
	3	302	304	1%	42.3%	298	-1%	24.9%
	All	302	304	1%		298	-1%	
Westbound	1	0	0			0		
	2	0	0			0		
	3	68	67	-2%	54.3%	68	0%	93.9%
	All	68	67	-2%		68	0%	

Table 9-25: Violations by Crash Risk Indicator in Increase of Detection Time Test

		Without						
	Crash Risk	Original Mean	0.6 sec detect			1 sec detect		
			Mean	% Change	a/2	Mean	% Change	a/2
Eastbound	0	250	244	-3%	27.0%	249	-1%	77.7%
	1	275	279	1%	31.7%	272	-1%	55.4%
	2	194	197	1%	52.2%	198	2%	33.6%
	3	0.68	0.60	-12%	82.3%	0.50	-27%	57.6%
Westbound	0	35	36	1%	89.4%	34	-3%	55.3%
	1	16	15	-8%	37.3%	15	-6%	54.6%
	2	118	119	1%	76.0%	119	1%	48.6%
	3	0.73	1.20	65%	20.9%	1.20	65%	19.3%
		With						
	Crash Risk	Original Mean	0.6 sec detect			1 sec detect		
			Mean	% Change	a/2	Mean	% Change	a/2
Eastbound	0	419	416	-1%	42.3%	423	1%	24.9%
	1	302	304	1%	42.3%	298	-1%	24.9%
	2	0.0	0			0.0		
	3	0.0	0			0.0		
Westbound	0	102	103	1%	54.3%	102	0%	93.9%
	1	68	67	-2%	54.3%	68	0%	93.9%
	2	0.0	0			0.0		
	3	0.0	0			0.0		

Table 9-26: Crashes Speed Comparison of Vehicles A and C (Without Case)

			Vehicle A Crash Speed (mi/hr)					Vehicle C Crash Speed (mi/hr)				
	Action Type		Original	0.6 sec detect	a/2	1 sec detect	a/2	Original	0.6 sec detect	a/2	1 sec detect	a/2
East-bound	Action 1	Mean	25	25	37.1%	25	97.0%	15	14	37.1%	15	69.12%
		Max	50	49	37.1%	53	2.6%	48	48	94.2%	49	34.09%
	Action 2	Mean	27	27	23.9%	27	78.5%	16	16	39.3%	16	50.61%
		Max	50	49	37.1%	53	2.6%	48	48	73.8%	49	29.20%
	Action 3	Mean	65	65		65		6	6	64.6%	6	94.25%
		Max	65	65		65		45	45	71.1%	45	92.05%
West-bound	Action 1	Mean	31	31	81.3%	30	44.7%	20	20	32.3%	20	58.08%
		Max	51	52	61.5%	51	73.6%	52	54	33.8%	54	45.03%
	Action 2	Mean	31	31	23.9%	31	36.0%	19	20	35.6%	20	47.57%
		Max	51	50	67.0%	51	76.0%	51	53	32.6%	53	36.12%
	Action 3	Mean	65	65		65		25	26	67.5%	25	74.30%
		Max	65	65		65		52	55	10.9%	54	29.41%

9.4.7 Test 7: Increase Reading Time

Reading time (or time lag 3) is the average time that the violator needs to read the warning message displayed on the warning panel, which is considered 1 sec in the analysis of the original case. In this sensitivity test we are going to rise the reading time up to 1.3 and 1.6 seconds consecutively in order to assess its impact on the system performance.

Similar to the detection and verification sensitivity test, the reading time lag 3 parameter is used only in "with system" case. Therefore, we do not expect having any impact on the "without system" case outcome.

Tables 9-27 and 9-28 show also no significant changes (all a/2 are greater than 2.5%) in the "without" case entire output parameters and for both directions. The tables show also that system performance in the "with system" case, was not affected by 60% higher reading time.

Finally, crash severity show no significant changes in crash speeds for vehicles A and C as Table 9-29 reveals.

Table 9-27: Number of Crashes by Action in Increase of Reading Time Test

		Without						
	Action	Original Mean	Read-1.3sec			Read-1.6sec		
			Mean	% Change	a/2	Mean	% Change	a/2
Eastbound	1	210	207	-1%	57.9%	209	0%	84.4%
	2	154	149	-3%	21.0%	153	0%	86.8%
	3	302	301	0%	89.5%	301	0%	82.7%
	All	665	658	-1%		663	0%	
Westbound	1	123	125	2%	25.0%	124	1%	46.5%
	2	63	67	5%	26.4%	65	3%	52.0%
	3	68	66	-4%	43.0%	68	0%	93.9%
	All	254	258	1%		258	1%	
		With						
	Action	Original Mean	Read-1.3sec			Read-1.6sec		
			Mean	% Change	a/2	Mean	% Change	a/2
Eastbound	1	0	0			0		
	2	0	0			0		
	3	302	301	0%	89.5%	301	0%	82.7%
	All	302	301	0%		301	0%	
Westbound	1	0	0			0		
	2	0	0			0		
	3	68	66	-4%	43.0%	68	0%	93.9%
	All	68	66	-4%		68	0%	

Table 9-28: Violations by Crash Risk Indicator in Increase of Reading Time Test

		Without						
	Crash Risk	Original Mean	Read-1.3sec			Read-1.6sec		
			Mean	% Change	a/2	Mean	% Change	a/2
Eastbound	0	250	254	1%	47.7%	250	0%	97.9%
	1	275	275	0%	87.3%	277	1%	51.0%
	2	194	190	-2%	31.3%	192	-1%	61.8%
	3	0.68	0.60	-12%	80.0%	0.50	-27%	57.6%
Westbound	0	35	34	-3%	53.8%	34	-3%	55.3%
	1	16	15	-7%	51.2%	15	-6%	54.6%
	2	118	120	2%	42.9%	119	1%	48.6%
	3	0.73	1.10	51%	29.5%	1.20	65%	19.3%
		With						
	Crash Risk	Original Mean	Read-1.3sec			Read-1.6sec		
			Mean	% Change	a/2	Mean	% Change	a/2
Eastbound	0	419	419	0%	89.5%	419	0%	82.7%
	1	302	301	0%	89.5%	301	0%	82.7%
	2	0.0	0			0.0		
	3	0.0	0			0.0		
Westbound	0	102	104	2%	43.0%	102	0%	93.9%
	1	68	66	-4%	43.0%	68	0%	93.9%
	2	0.0	0			0.0		
	3	0.0	0			0.0		

Table 9-29: Crashes Speed Comparison of Vehicles A and C (Without Case)

			Vehicle A Crash Speed (mi/hr)					Vehicle C Crash Speed (mi/hr)				
	Action Type		Original	Read-1.3sec	a/2	Read-1.6sec	a/2	Original	Read-1.3sec	a/2	Read-1.6sec	a/2
East-bound	Action 1	Mean	25	26	42.9%	25	37.1%	15	15	54.8%	14	37.08%
		Max	50	50	59.3%	52	25.3%	48	47	36.2%	47	48.11%
	Action 2	Mean	27	28	39.3%	27	21.7%	16	16	96.4%	15	15.00%
		Max	50	50	53.7%	52	25.3%	48	47	54.2%	47	76.68%
	Action 3	Mean	65	65		65		6	6	32.2%	6	64.59%
		Max	65	65		65		45	44	52.0%	44	47.17%
West-bound	Action 1	Mean	31	30	14.0%	30	44.7%	20	19	22.8%	20	58.08%
		Max	51	51	89.2%	51	73.6%	52	53	57.7%	54	45.03%
	Action 2	Mean	31	31	26.2%	31	36.0%	19	19	52.9%	20	47.57%
		Max	51	50	65.8%	51	76.0%	51	52	43.7%	53	36.12%
	Action 3	Mean	65	65		65		25	25	54.0%	25	74.30%
		Max	65	65		65		52	53	62.8%	54	29.41%

9.4.8 Test 8: Widening Speed Difference Threshold

In this sensitivity test, we are going to widen the speed difference threshold between vehicles A and B from 5-10 mph uniformly distributed speed margin to 5-15 and 5-20 mph speed margin, reflecting the fact that some vehicles (like heavy vehicles) could run slower than the average regular speed practiced by other vehicles. One implication of this assumption is the need to lower the mean of vehicles B speed distribution adopted in the original case analysis to reflect the slower speed condition of vehicles B population.
The shortcoming of this scenario is that we know the speed distribution of all traffic classes, but we don't know exactly the distribution neither of violating vehicles A nor of those vehicles B being taken over.
Tables 9-30 and 9-31 exhibit the results of the test simulation runs.
As one may expect, A wider difference between the speed of vehicles A and B makes the taking over maneuver faster and less riskier, and this is reflected by the sharp drop of action 3 crashes by around 70-80% as Table 9-33 shows. However, we notice in the same time is significant increase in the number of action 2 crashes. This could be explained by the fact that as vehicle A accelerates and overtakes B easily and then sees vehicle C, it will take longer time for A to reduce its speed and then setback and resume its original lane behind B, hence, A will be more exposed to the risk of colliding with C before it makes a safe merging.

Table 9-30: Number of Crashes by Action in Widening Speed Threshold Test

		Without						
	Action	Original Mean	**(5-15) Thresh.**			**(5-20) Thresh.**		
			Mean	% Change	**a/2**	Mean	% Change	**a/2**
Eastbound	1	210	217	3%	20.0%	221	5%	2.9%
	2	154	200	30%	0.0%	233	51%	0.0%
	3	302	165	-45%	0.0%	66	-78%	0.0%
	All	665	581	-13%		520	-22%	
Westbound	1	123	122	0%	84.9%	119	-3%	14.5%
	2	63	89	41%	0.0%	101	60%	0.0%
	3	68	38	-44%	0.0%	20	-71%	0.0%
	All	254	249	-2%		240	-6%	
		With						
	Action	Original Mean	**(5-15) Thresh.**			**(5-20) Thresh.**		
			Mean	% Change	**a/2**	Mean	% Change	**a/2**
Eastbound	1	0	0			0		
	2	0	0			0		
	3	302	165	-45%	0.0%	66	-78%	0.0%
	All	302	165	-45%		66	-78%	
Westbound	1	0	0			0		
	2	0	0			0		
	3	68	38	-44%	0.0%	20	-71%	0.0%
	All	68	38	-44%		20	-71%	

Table 9-31: Violations by Crash Risk Indicator in Widening Speed Threshold Test

		Without						
	Crash Risk	Original Mean	**(5-15) Thresh.**			**(5-20) Thresh.**		
			Mean	% Change	**a/2**	Mean	% Change	**a/2**
Eastbound	0	250	346	38%	0.0%	416	66%	0.0%
	1	275	167	-39%	0.0%	76	-72%	0.0%
	2	194	206	6%	2.0%	228	17%	0.0%
	3	0.68	0.70	3%	95.7%	0.00	-100%	2.3%
Westbound	0	35	42	18%	0.2%	49	37%	0.0%
	1	16	9	-43%	0.0%	4	-78%	0.0%
	2	118	118	0%	94.1%	118	0%	88.0%
	3	0.73	1.40	93%	12.2%	0.30	-59%	22.4%
		With						
	Crash Risk	Original Mean	**(5-15) Thresh.**			**(5-20) Thresh.**		
			Mean	% Change	**a/2**	Mean	% Change	**a/2**
Eastbound	0	419	556	33%	0.0%	654	56%	0.0%
	1	302	165	-45%	0.0%	66	-78%	0.0%
	2	0.0	0			0.0		
	3	0.0	0			0.0		
Westbound	0	102	132	30%	0.0%	150	48%	0.0%
	1	68	38	-44%	0.0%	20	-71%	0.0%
	2	0.0	0			0.0		
	3	0.0	0			0.0		

The overall number of crashes seems to be less as the speed threshold margin widens especially is the eastbound direction.

In terms of crash risks resulting from the redistribution of crashes by the different action types, Table 9-31 shows that risk free indicator increased mainly at the expense of risk indicator 1. Risk indicator 2 showed higher average number of violations in the eastbound but remained stable in the westbound.

The number of unavoidable crashes showed no significant changes in the first test. When the margin become wider enough in the second test with 20 mph maximum speed difference, the average annual number dropped to zero in the eastbound direction. The westbound direction did not show any significant changes in the unavoidable crash number.

For the "with" system case, crashes resulting from actions 1 and 2 remain risk free, whereas action 3 crashes dropped as overtaking became easier and faster, reflecting lower risk indicator 1.

For crash severity, Table 9-32 shows that there is no or slight significant modifications in the crash speed means.

Table 9-32: Crashes Speed Comparison of Vehicles A and C (Without Case)

			Vehicle A Crash Speed (mi/hr)					Vehicle C Crash Speed (mi/hr)				
	Action Type		Original	(5-15) Thresh.	a/2	(5-20) Thresh.	a/2	Original	(5-15) Thresh.	a/2	(5-20) Thresh.	a/2
East-bound	Action 1	Mean	25	26	46.5%	26	7.1%	15	15	94.0%	16	1.59%
		Max	50	54	1.5%	50	85.5%	48	49	65.0%	50	25.81%
	Action 2	Mean	27	26	0.8%	26	0.7%	16	15	7.0%	16	95.68%
		Max	50	54	1.5%	50	85.5%	48	49	43.2%	50	15.49%
	Action 3	Mean	65	65		65		6	5	0.3%	4	0.00%
		Max	65	65		65		45	44	47.9%	37	0.00%
West-bound	Action 1	Mean	31	30	25.1%	30	1.4%	20	19	31.2%	19	24.38%
		Max	51	53	10.2%	52	44.7%	52	52	87.9%	50	30.24%
	Action 2	Mean	31	31	7.7%	30	0.1%	19	18	26.0%	19	34.59%
		Max	51	52	19.9%	52	40.2%	51	51	99.4%	50	65.32%
	Action 3	Mean	65	65		65		25	26	63.3%	27	7.77%
		Max	65	65		65		52	51	67.3%	47	1.29%

9.4.9 <u>Test 9:</u> Increase Minimum Emergency Merging Distance

In the original scenario, a 10-feet minimum emergency merging distance was adopted to simulate a safe merging of vehicle A in the following two actions cases:

a- In action 2, when vehicle A is decelerating and reaches a speed below that of vehicle B, and wants to resume the right lane behind B.

b- In action 3, when vehicle is accelerating at a speed higher than B and determined to continue overtaking and merging ahead of B.

In this sensitivity test, we are going to increase this minimum emergency merging distance up to 15 and 20 feet, reflecting a more cautious (or risk averse) driver's behavior, or simply a less responding capability. Table 9-33 shows that increasing this distance to 15 feet has no significant impact on the number of crashes by all action types. However, raising it again up to 20 feet will increase significantly action 3 crashes by 3 %.

Surprisingly, Table 9-34 shows that crash risk indicator 3 was very sensitive to that change which lead the number of unavoidable crashes to increase from 1.41 to 4 annual crashes in both directions.

It is worth noting here that although the westbound crashes increases due to raising the minimum merging distance from 10 to 15 feet did not prove to be significant, table 9-34 shows that in the redistribution of crash risk, the unavoidable crashes we significantly increased from 0.73 to 1.6 crashes per year.

System wise, early warning messages are still effective in avoiding all actions 1 and 2 possible crashes. Crash risk free violations were decreased by 2% for the sake of crash risk indicator1; this is mainly because of the increase of action-3 crashes when the minimum merging distance was set 20-ft.

Finally, simulation output did show no significant changes in the mean crash speed for all action types.

Table 9-33: Number of Crashes by Action in Increasing Merging Distance Test

		Without						
	Action	Original Mean	15-ft Merge			20-ft Merge		
			Mean	% Change	**a/2**	Mean	% Change	**a/2**
Eastbound	1	210	211	1%	82.8%	213	1%	55.7%
	2	154	153	0%	86.6%	158	2%	34.8%
	3	302	306	1%	22.2%	311	3%	0.5%
	All	665	670	1%		682	3%	
Westbound	1	123	124	1%	46.5%	125	2%	25.0%
	2	63	65	3%	42.8%	68	7%	13.6%
	3	68	70	2%	56.4%	69	1%	86.4%
	All	254	259	2%		262	3%	
		With						
	Action	Original Mean	**15-ft Merge**			**20-ft Merge**		
			Mean	% Change	**a/2**	Mean	% Change	**a/2**
Eastbound	1	0	0			0		
	2	0	0			0		
	3	302	306	1%	22.2%	311	3%	0.5%
	All	302	306	1%		311	3%	
Westbound	1	0	0			0		
	2	0	0			0		
	3	68	70	2%	56.4%	69	1%	86.4%
	All	68	70	2%		69	1%	

Table 9-34: Violations by Crash Risk Indicator in Increasing Merging Distance Test

		Without						
	Crash Risk	Original Mean	15-ft Merge			20-ft Merge		
			Mean	% Change	**a/2**	Mean	% Change	**a/2**
Eastbound	0	250	247	-1%	54.1%	242	-3%	8.4%
	1	275	277	1%	62.4%	276	0%	83.9%
	2	194	195	0%	85.4%	201	3%	16.3%
	3	0.68	1.20	76%	14.2%	1.50	120%	1.6%
Westbound	0	35	34	-5%	35.1%	34	-5%	32.0%
	1	16	15	-7%	47.5%	14	-15%	16.8%
	2	118	120	2%	39.1%	120	2%	30.8%
	3	0.73	1.60	120%	2.2%	2.50	244%	0.0%
		With						
	Crash Risk	Original Mean	**15-ft Merge**			**20-ft Merge**		
			Mean	% Change	**a/2**	Mean	% Change	**a/2**
Eastbound	0	419	414	-1%	22.2%	409	-2%	0.5%
	1	302	306	1%	22.2%	311	3%	0.5%
	2	0.0	0			0.0		
	3	0.0	0			0.0		
Westbound	0	102	100	-2%	56.4%	101	0%	86.4%
	1	68	70	2%	56.4%	69	1%	86.4%
	2	0.0	0			0.0		
	3	0.0	0			0.0		

9.4.10 <u>Test 10:</u> Risk Taker Violators

In this scenario, we are going to narrow the merging conditions when violators want to resume the right lane, whether behind vehicle B (action2) or ahead of B (action3). Actually such assumption might reflect the behavior of the more risk taker violators, or those who badly want to avoid the head-on crashes, and maybe prefer to have a side swipe or rear end crashes instead (although those won't occur under the conditions explained above).

Such behavior will be translated into two modifications in the merging conditions set for the original case, which are:

1- Decrease the minimum difference between the speeds of vehicles A and B, when A is braking and trying to setback behind B (action2), from 5 to 2 mph.
2- Narrow the minimum emergency merging distance from 10 to 5 feet.

We notice here that this test requires dual parameter modifications. Actually, in order to identify the impact of each one on the combined outcome, we did first only one modification, which is decreasing the speed difference from 5 to 2mph. The test outcome did not show any significant difference with that of the original case as Tables 9-35 and 9-36 reveals.

The next step was to introduce the second modification, which is shortening the minimum emergency merging distance from 10 to 5 feet. The combined effect of the dual modifications is depicted in Tables 9-37 and 9-38.

We may notice that the tables show that, in the "without" case, there are no significant changes in the westbound direction. However, some significant decreasing by 4% has been seen concerning action 3 crashes in the eastbound direction, which might slightly improve the risk free indicator and reduce the number of unavoidable crashes from 0.68 to 0.1 crashes per year. However, this improving trend did not prove to be significant at the 95% confidence level (**a/2** = 5.6 and 4.6% > 2.5%)

However, In the "with" system case, the reduction of action 3 crashes was directly translated into higher number of eastbound free risk violations at the expense of the risk indicator 1.

In terms of crash severity, reducing the dual modification had no significant impact on the crash speeds

Table 9-35: Number of Crashes by Action in Decrease of Merging Speed Difference Test

		Without			
	Action	Original Mean	2mph Speed Difference		
			Mean	% Change	a/2
	1	210	211	1%	79.7%
	2	154	155	0%	85.0%
	3	302	295	-2%	4.6%
Eastbound	All	665	661	-1%	
	1	123	124	1%	64.8%
	2	63	66	4%	36.9%
	3	68	67	-2%	66.4%
Westbound	All	254	256	1%	
		With			
	Action	Original Mean	2mph Speed Difference		
			Mean	% Change	a/2
	1	0	0		
	2	0	0		
	3	302	295	-2%	4.6%
Eastbound	All	302	295	-2%	
	1	0	0		
	2	0	0		
	3	68	67	-2%	66.4%
Westbound	All	68	67	-2%	

Table 9-36: Violations by Crash Risk Indicator in Decrease of Merging Speed Difference Test

		Without			
	Crash Risk	Original Mean	2mph Speed Difference		
			Mean	% Change	a/2
	0	250	256	2%	22.5%
	1	275	267	-3%	3.7%
	2	194	196	1%	67.9%
Eastbound	3	0.68	0.50	-27%	57.6%
	0	35	35	-2%	70.7%
	1	16	16	-3%	77.7%
	2	118	119	1%	77.1%
Westbound	3	0.73	1.20	65%	20.9%
		With			
	Crash Risk	Original Mean	2mph Speed Difference		
			Mean	% Change	a/2
	0	419	425	2%	4.6%
	1	302	295	-2%	4.6%
	2	0.0	0		
Eastbound	3	0.0	0		
	0	102	103	1%	66.4%
	1	68	67	-2%	66.4%
	2	0.0	0		
Westbound	3	0.0	0		

Table 9-37: Number of Crashes by Action in The Dual Modification Test

		Without			
	Action	Original Mean	2mph+5ft Merging		
			Mean	% Change	a/2
	1	210	211	1%	79.7%
	2	154	153	-1%	78.1%
	3	302	289	-4%	0.1%
Eastbound	All	665	653	-2%	
	1	123	124	1%	64.8%
	2	63	65	2%	54.4%
	3	68	65	-5%	21.0%
Westbound	All	254	253	0%	
		With			
	Action	Original Mean	2mph+5ft Merging		
			Mean	% Change	a/2
	1	0	0		
	2	0	0		
	3	302	289	-4%	0.1%
Eastbound	All	302	289	-4%	
	1	0	0		
	2	0	0		
	3	68	65	-5%	21.0%
Westbound	All	68	65	-5%	

Table 9-38: Violations by Crash Risk Indicator in The Dual Modification Test

		Without			
	Crash Risk	Original Mean	2mph+5ft Merging		
			Mean	% Change	a/2
	0	250	260	4%	5.3%
	1	275	267	-3%	2.5%
	2	194	193	-1%	78.1%
Eastbound	3	0.68	0.10	-85%	5.6%
	0	35	35	-1%	88.1%
	1	16	18	9%	37.8%
	2	118	117	-1%	57.2%
Westbound	3	0.73	0.80	10%	83.9%
		With			
	Crash Risk	Original Mean	2mph+5ft Merging		
			Mean	% Change	a/2
	0	419	431	3%	0.1%
	1	302	289	-4%	0.1%
	2	0.0	0		
Eastbound	3	0.0	0		
	0	102	105	3%	21.0%
	1	68	65	-5%	21.0%
	2	0.0	0		
Westbound	3	0.0	0		

9.4.11 <u>Test 11:</u> Cooperative Driver of Vehicle B

In all previous simulation runs, both in original analysis and in sensitivity tests, we have assumed that vehicle B is neutral, that is, the driver of B is either indifferent or unaware of what is going around him. Therefore no interaction was input from his part in the maneuvers analysis, except his steady run along the right lane of the road.

What is happening in real life is sometimes quite different: Some drivers might try to help, especially when the situation is critical, by decelerating and allowing the violator to pass them and make a safe merging, while others provoked drivers might try to tease the violator by accelerating although in the critical situations the goodwill prevails.

Anyway, we are going to rely on the good faith of vehicles B drivers and assume that they have the cooperating mood, thus they will decelerate as soon as vehicle A reaches the same location point of vehicle B. (i.e. $X_A = X_B$).

A (– 0.5g) deceleration rate will be considered for vehicle B when it brakes. This value is the midpoint between the values of (-0.45g) and (-0.55g) means adopted for the "expected" and "surprised" drivers respectively.

Table 9-39 shows that in the "without" case, there is significant decrease in the eastbound action 3 crashes due the cooperation of vehicle B driver by allowing smoother merging for vehicle A. The westbound direction a similar result trend did not prove to be significant.

The redistribution of crash risks presented in Table 9-40 shows significant improvement only in the eastbound direction, where the number of violations enjoying risk free indicator increased at the expense of risk indicators 1 and 3. The latter shows dramatic drop in the average number of unavoidable crashes from 0.68 to 0.

Like the other sensitivity tests, the "With" system case remains robust in avoiding all risks of having crashes resulting from actions 1 and 2. In addition, it shows same improvement in action 3 crash result as the "without" case. This is reflected through the significant 5% improvement in risk free violations at the expense of the 7% decrease in the risk indicator 1 violations.

As far as crash severity is concerned, Simulation output analysis did not show any significant changes to the crash speeds compared with those of the original case.

Table 9-39: Number of Crashes by Action in Cooperating Vehicle B Test

		Without			
	Action	Original Mean	Cooperating B		
			Mean	% Change	a/2
	1	210	218	4%	11.7%
	2	154	157	2%	49.1%
	3	302	279	-7%	0.0%
Eastbound	All	665	653	-2%	
	1	123	124	1%	64.8%
	2	63	66	4%	36.9%
	3	68	65	-5%	21.8%
Westbound	All	254	254	0%	
		With			
	Action	Original Mean	Cooperating B		
			Mean	% Change	a/2
	1	0	0		
	2	0	0		
	3	302	279	-7%	0.0%
Eastbound	All	302	279	-7%	
	1	0	0		
	2	0	0		
	3	68	65	-5%	21.8%
Westbound	All	68	65	-5%	

Table 9-40: Violations by Crash Risk Indicator in The Cooperating Vehicle B Test

		Without			
	Crash Risk	Original Mean	Cooperating B		
			Mean	% Change	a/2
	0	250	264	5%	1.2%
	1	275	260	-6%	0.0%
	2	194	197	1%	52.3%
Eastbound	3	0.68	0.00	-100%	2.3%
	0	35	35	-1%	83.7%
	1	16	17	3%	73.4%
	2	118	118	0%	97.7%
Westbound	3	0.73	0.60	-18%	72.6%
		With			
	Crash Risk	Original Mean	Cooperating B		
			Mean	% Change	a/2
	0	419	441	5%	0.0%
	1	302	279	-7%	0.0%
	2	0.0	0		
Eastbound	3	0.0	0		
	0	102	105	3%	21.8%
	1	68	65	-5%	21.8%
	2	0.0	0		
Westbound	3	0.0	0		

9.4.12 Sensitivity Tests Conclusions

The simulation model in hand, offered a powerful tool to understand the phenomena of the short-sight overtaking maneuvers taking place at vertical curves of two-lane rural roads. It allows also testing and recognizing what are the most important parameters that could affect the outcome of the risky passings, namely in terms of crash risks and severity of crashes.

Table 9-41 recapitulates the significant changes of the simulations outcomes due to the various sensitivity tests elaborated previously. The (+) sign denotes a significant (at 95% confidence level) increase of the parameter outcome due to the outmost modification made in the designated test. Conversely, the (-) sign denotes a significant decrease in that outcome parameter. A blank cell denotes no significant changes to the original case outcome.

The table reveals that the tests, in which the simulation outcomes are sensitive the most:

1- Test 2: Increasing maximum speed of A.
2- Test 5: Overtaking B ahead on the slope.
3- Test 8: Widening speed difference threshold between vehicles A and B.
4- Test 4: Increasing DUI impairment effect for higher BAC levels.

On the other way, the tests that showed the least impact (actually no impact) on the final outcomes are:

1- Test 6: Increase Detection and verification time.
2- Test 7: Increase reading time.

Finally, the detection and warning system specially designed to fight against the violations leading to severe head-on crashes proved capable to bring risk free situation as long as drivers obey to the warning messages. However, disobedience might hold some risk of having crashes. In this case more pressures, like the lower cameras to capture violator license plate, should be put in order to enforce a good driving behavior.

Table 9-41: Significant Changes Observed Due To Sensitivity Tests

			Test Number																					
			"Without" Case											"With" Case										
Parameter	Dir.	Type/ Indic.	1	2	3	4	5	6	7	8	9	10	11	1	2	3	4	5	6	7	8	9	10	11
Crashes by Action Type	Eastbound	1	+	+		+	+																	
		2	+	+	-	+	+			+														
		3	-	-			+			-	+	-	-	-	-			+			-	+	-	-
	Westbound	1		+			-																	
		2	+	+			-			+														
		3	-	-			+			-				-	-			+			-			
Crash Risk Indicator	Eastbound	0	+	-			-			+			+	+	+			-			+	-	+	+
		1	-	-		-				-		-	-	-	-			+			-	+	-	-
		2	+	+	-	+	+			+														
		3				+				-	+													
	Westbound	0		-			+			+				+	+			-			+			
		1	-	-			+			-				-	-			+			-			
		2		+			-																	
		3		+		+					+													
Vehicle A Mean Crash Speed By Action Type	Eastbound	1		+		+	+																	
		2		+		+	+			-														
		3		+																				
	Westbound	1		+	-	+	-			-														
		2	-	+	-	+	-			-														
		3		+																				
Vehicle C Mean Crash Speed By Action Type	Eastbound	1		+			+			+														
		2		+			+																	
		3		+			+			-														
	Westbound	1		+																				
		2		+																				
		3		+			-																	

test 1 : decrease mean spacing
test 2 : increase max. speed
test 3 : decrease DUI percent
test 4 : increase DUI effect
test 5: overtaking B on slope
test 6: increase detection & verification time
test 7: increase reading time
test 8: widening speed difference threshold
test 9: increase min. me rging distance
test 10: risk taker violator
test 11: cooperative driver B

9.5 Productivity: Cost savings

The aim of deploying the detection and warning system is to reduce the number and severity of head-on crashes and save lives. Such deployment implicates some costs to be paid; as well as some benefits to be generated. These two accrued cash flow components will be offset in order to assess the viability of project from economic viewpoint.

9.5.1 Costs Of The System

Like any other transportation improvement, there are many elements that constitute the total cost of deploying the ITS system. These cost elements could be grouped into two major components:

1- The acquisition cost (capital cost), which includes the costs of purchasing and installing the equipment, in addition to all related engineering study and consultancy fees.

2- Operating & maintenance costs, which include the annual costs of operating the system and maintaining it at the required level of performance.

9.5.1.1 Capital Cost

The capital investment costs of the system are based on the quotations provided by the equipment manufactures. Table 9-42 summarizes the different elements of system acquisition costs totaling around 63,100 dollars.

Table 9-42: System Acquisition costs ($)

Item	Description	Qty	Unit	Unit Price	Sub Total
1	Video Cameras (Autoscope Solo Pro)	8	Each	3375.0	27,000
2	Data Cable	2500	Feet	1.0	2,500
3	L Mounting Bracket	8	Each	71.25	570
4	Camera Junction Box	8	Each	75.0	600
5	Mini Hub	1	Each	618.75	619
6	Panel Cable Set	2	Each	1050.0	2,100
7	Interface	3	Each	57.0	171
8	6-Pair Twisted Pair Cable	2500	Feet	0.3	750
9	Cabinet	1	Each	8233.0	8,233
10	Warning Signs	4	Each	500.0	2,000
11	Lower Enforcement Cameras Costs	2	Each	1600.0	3,200
12	Video Cameras Poles Installation	8	Each	600.0	4,800
13	Lower Cameras installation Costs	2	Each	300.0	600
14	Engineering Fees				10,000
				Total	**63,143**

The total capital cost estimated above covers the minimum requirements needed for a proper installation and functioning of the system. Of course, more sophisticated equipment could be added to the system such as LED warning signs, powerful communication system with the regional control center and digital enforcement cameras. Such enhancements, however, will not add much on the system functions performance, which are mainly detecting and warning violating vehicles.

9.5.1.2 Operation and Maintenance Cost

Operation and maintenance cost are current expenses required to ensure proper functioning of the system. Maintenance costs of equipment are usually estimated as a certain percent (10-20%) of the acquisition cost to be paid to manufacturer's company. As electronic systems are usually provided with one-year warranty, Maintenance costs will accrue starting from the second year of installing the equipment.

Operation costs consist of electric power bills, low cameras films purchase and development and additional human resources to be provided to maintain, monitor and follow up the system output. Table 9-43 summarizes the annual O&M costs.

Table 9-43: Annual Operation and Maintenance Costs ($)

Electricity bills	500
Films acquisition and development	850
Follow up manpower resources (25% of full time operator salary + fringe benefits)	10,000
Annual operation costs (sum of above)	11,350
Annual maintenance costs (15% of acquisition costs)	7,161
Total operations and maintenance costs	18,511

9.5.2 Benefits Of The System

The system is expected to generate tangible benefits, which are derived from the reduction of losses (mainly lives, injuries and properties) resulting from crash occurrences. Those benefits should be identified, quantified and monetized on annual basis to be offset against the costs.

In a lot of cost-benefit analysis studies, it is hard sometimes to quantify some elements or even assign money values for them. We may think of the human pain, injured suffering or driver's comfort, gas emissions and pollution, etc.

In this analysis, we are going to ignore such elements and focus only tangible costs (or benefits) related to the loss of productivity and to the consumption of resources, namely:

1- **Loss of life:** As we have seen in the literature review section 2.1.6, each fatality resulted in lifetime economic costs to society of over $830,000. Over 85 percent of this cost is due to lost workplace and household productivity. Therefore, we are going to assume $ 705,000 as the economic value of productivity loss resulting from one crash fatality.

2- **Injury loss:** Losses due to injuries depend on how severe they are. The scale could range from minor injury to a critical one that would leave the person hit permanently disable. The estimated average cost for each **critically injured** survivor (or Maximum Abbreviated Injury Scale MAIS level 5 injuries) is $706,000 -- nearly as high as for a fatality. Medical costs and lost productivity accounted for 84 percent of the cost for these (around 593,000). As we don't know exactly the level of severity of injuries resulting from the crashes that occurred on route 114, and to keep our estimations in the safe side, we are going to assume an average cost of $ 50,000 per injured person.

3- **Property Loss:** Previously in the accidents analysis section 4.3.1, we have found that the average property cost per vehicle involved is $14,500, a figure that will be inserted in the average cost per crash calculation sheet presented in Table 9-44.

Table 9-44: The Actual Cost Per Crash on Route 114 ($)

Cost Element	Unit Cost	Rate Per Crash	Cost Per Crash
Average fatality cost	705,000	1.4	987,000
Average injury cost	50,000	3	150,000
Average property damages cost	14,500	2	29,000
Total costs per crash			1,166,000

The average cost of one crash is derived from the unit costs estimated, multiplied by the observed average rate of units resulting from one crash on route 114.

The actual average economic cost of one crash is around 1.17 million dollars mostly due to human life loss consequences. Hence, once the system succeeds in preventing a crash, a total benefit is accrued from the avoided crash and amounts the $1.17 million loss that would have been paid by the national economy should a head-on collision occur on that road.

Finally, The total benefits that could be generated by the system depend on when and how many crashes it would prevent over the 10-year lifetime of the project. The simulation in this case provides a useful tool to make such estimation:

In fact, the "without the system" runs constitute the base case which simulates violations under present conditions over the next ten years without introducing any improvement. The base case runs provide us with some predictions about the number of unavoidable head-on crashes distributed over the project 10 years analysis horizon, knowing that crash occurrences prediction relies fully on the randomness nature of a lot of the analysis parameters.

On the other hand, the "with system" runs showed a very robust crash-free simulation results even with several sensitivity tests, as we have seen earlier. Consequently, all crashes costs cashflow forgone could be considered as economic benefits accrued to the national economy.

Now, referring to Table 9-3 earlier in section 9.3.1, we may consider that the first 10 rows of the table represent the 10-year analysis period runs of the project. The average number of the unavoidable crashes predicted by the simulation is 1.41per year. However, this figure is almost as twice as the actual average number observed which is 0.71 crash per year. Therefore, an adjustment should be made to the value of crashes avoided by almost the half in order to reflect a more realistic estimation about the benefits generated by the system.

Table 9-45 exhibits the procedure of estimating the adjusted value of benefits generated by the system.

Table 9-45: Adjusted Benefits Generated By The System ($)

Year	Avoided Crashes	Crashes Cost	Adjusted Benefits
1	0	0	0
2	2	2332000	1166000
3	0	0	0
4	3	3498000	1749000
5	0	0	0
6	5	5830000	2915000
7	0	0	0
8	1	1166000	583000
9	1	1166000	583000
10	0	0	0

9.5.3 Financial Analysis and The Economic Indicators

Economic indicators are tools frequently used in financial analysis to evaluate the productivity or the feasibility of the project investment. Benefit-Cost ratio (or BCR) is the indicator the most recommended for public funded projects, whereas the Net Present Value (NPV) is widely preferred for private investments. The Internal Rate of Return (IRR) can be used for both types of investments.

The financial analysis of the costs and benefits cashflows over the lifetime period of the project is depicted in Table 9-46, where we may note the following:

- The first year is considered as year 0 where the system is installed and put directly in service.
- In that year only operation costs are accrued since the system is under warranty and no pay is required for the maintenance.
- The benefits are accrued whenever a crash predicted by the simulation is avoided.
- Net benefits are expressed either as cash inflow or cash outflow (negative value between parenthesis).
- The discount factor used to determine the present value of the cashflow is based on a 10% discount rate.

Table 9-46: Financial Analysis Of Cashflows ($)

Year	Capital Investment	Operation & Maintenance Cost	Total Cost	Total Benefits	Net Benefits	Discount Factor@ 10%	Net Benefits Present Value
0	63,143	11,350	74,493	0	(74,493)	1.000	(74,493)
1		18,511	18,511	1166000	1,147,489	0.909	1,043,171
2		18,511	18,511	0	(18,511)	0.826	(15,299)
3		18,511	18,511	1749000	1,730,489	0.751	1,300,142
4		18,511	18,511	0	(18,511)	0.683	(12,644)
5		18,511	18,511	2915000	2,896,489	0.621	1,798,492
6		18,511	18,511	0	(18,511)	0.564	(10,449)
7		18,511	18,511	583000	564,489	0.513	289,672
8		18,511	18,511	583000	564,489	0.467	263,338
9		18,511	18,511	0	(18,511)	0.424	(7,851)
						BCR	**38.9**
						IRR	**1449%**
						MIRR	**65%**

9.5.3.1 The Economic Indicators

As the table reveals, the system pays back its costs from the second year of operations. In fact, the estimated 1.166 million dollars benefits generated by the system from preventing the first predicted crash would cover the entire lifetime costs of the system. The table shows also a very high BCR of 38.9 is resulting from avoiding the head-on crashes over the next 10 years. A benefit-cost ratio greater than one would mean that the project is economically feasible since the present value of the benefits generated surpasses- here in large margin- those of costs paid.

This outcome could be expressed in another way, by determining the rate of return IRR that the estimated cash flows would yield. The calculation sheet shows that it is extremely high nearly 1450%, which is far beyond of any "regular" investment return one could imagine. Therefore, a "modified" internal rate of return MIRR will be used where the early benefits generated will be assumed reinvested at the same rate of 10%. This would yield 65 % of MIRR, which still a high and lucrative rate of return.

As a conclusion, as far as human life is concerned, one would wonder how moral or ethical it is to put money against human life, pain and suffer in order to compare then make a decision to install or not such safety system. Actually, this is one of many disputed questions that economists still cannot answer yet. Anyway, we are just trying to draw a certain framework to say that even for a most conservative approach, it is worth to "invest" some money in this system even to prevent one crash only!