AN EXAMINATION OF CRASH SCENARIOS AND THE POTENTIAL BENEFITS OF SIX ADVANCED SAFETY TECHNOLOGIES

Gene Lukianov
Objective Safety LLC
United States

Paper Number 09-0511

ABSTRACT

NHTSA published the report "Pre-Crash Scenario Typology for Crash Avoidance Research", DOT HS 810 767, in April 2007. This paper reviews the data presented in this DOT report and will examine the data for patterns which may be useful in prioritizing safety technology strategies from a frequency, economic cost and functional years lost perspective. Furthermore, techniques are developed and presented which offer weighing methodologies which could be useful in ranking anticipated benefits of various advanced safety technologies currently coming to market. The paper concludes with calculated rankings of the six advanced safety technologies, discusses the ranking results relative to a similar calculated ranking of ESC and offers some observations regarding ESC behavior and potential unexpected safety benefits of ESC.

INTRODUCTION

The DOT Report HS 810 767 "Pre-Crash Scenario Typology for Crash Avoidance Research" defined a new 37 pre-crash scenario typology for crash avoidance research based upon the 2004 General Estimates System (GES) crash database. This report also defined and provided information regarding frequency of occurrence, economic cost and functional years lost for each of the 37 pre-crash scenarios.

Crash Categories

The 37 pre-crash scenarios as defined by this DOT report were examined and a pattern emerged which indicted that similar scenarios could be grouped into broader common categories. These broader categories encompass similar situation, vehicle and driver dynamics. The benefit of combining similar scenarios is that a more global perspective can emerge regarding the kinds of crashes that occur and the associated frequency, economic cost and functional years lost. Ultimately the 37 scenarios were combined into 15 crash categories.

The 37 pre-crash scenarios as presented by the DOT Report HS 810 767 "Pre-Crash Scenario Typology for Crash Avoidance Research" are listed below. The numbering of the scenarios is reproduced as in the "Executive Summary" of the DOT report (the scenario numbering varies throughout the DOT report).

Table 1.
37 Pre-Crash Scenarios

1. Vehicle Failure
2. Control Loss With Prior Vehicle Action
3. Control Loss Without Prior Vehicle Action
4. Running Red Light
5. Running Stop Sign
6. Road Edge Departure With Prior Vehicle Maneuver
7. Road Edge Departure Without Prior Vehicle Maneuver
8. Road Edge Departure While Backing Up
9. Animal Crash With Prior Vehicle Maneuver
10. Animal Crash Without Prior Vehicle Maneuver
11. Pedestrian Crash With Prior Vehicle Maneuver
12. Pedestrian Crash Without Prior Vehicle Maneuver
13. Pedalcyclist Crash With Prior Vehicle Maneuver
14. Pedalcyclist Crash Without Prior Vehicle Maneuver
15. Backing Up Into Another Vehicle
16. Vehicle(s) Turning – Same Direction
17. Vehicle(s) Parking – Same Direction
18. Vehicle(s) Changing Lanes – Same Direction
19. Vehicle(s) Drifting – Same Direction
20. Vehicle(s) Making a Maneuver – Opposite Direction
21. Vehicle(s) Not Making a Maneuver – Opposite Direction
22. Following Vehicle Making a Maneuver
23. Lead Vehicle Accelerating
24. Lead Vehicle Moving at Lower Constant Speed
25. Lead Vehicle Decelerating
26. Lead Vehicle Stopped
27. Left Turn Across Path From Opposite Directions at Signalized Junctions
28. Vehicle Turning Right at Signalized Junctions
29. Left Turn Across Path From Opposite Directions at Non-Signalized Junctions
30. Straight Crossing Paths at Non-Signalized Junctions
31. Vehicle(s) Turning at Non-Signalized Junctions
32. Evasive Action With Prior Vehicle Maneuver
33. Evasive Action Without Prior Vehicle Maneuver
34. Non-Collision Incident
35. Object Crash With Prior Vehicle Maneuver
36. Object Crash Without Prior Vehicle Maneuver
37. Other

The regrouping of the scenarios in this paper was accomplished as follows:

- Crash scenarios differentiated by "with" or "without prior vehicle maneuver" such as scenarios 2 and 3 were grouped together into a single category because both are variations of a single scenario; loss of control, road edge departure, animal crash etc. with a variation of prior driver action.

- Scenarios 23, 24, 25 and 26 were grouped together as all four pre-crash scenarios were variations of a particular theme; a rear end crash with some difference regarding the exact state of the lead vehicle.

- Pre-crash scenarios involving turning in various directions at signalized and non-signalized junctions were grouped together because all are variations of an intersection crash.

- Running red lights and stop signs were grouped together since both involve the driver not acting appropriately regarding a traffic control device requiring a full stop.

- Pedestrian and pedalcyclist crashes were grouped together as all encompass a personal injury outside the vehicles.

- Pre-crash scenarios of vehicles turning, parking-same direction, changing lanes and drifting were grouped together into traveling and turning together because all the vehicles are on parallel paths.

- Pre-crash scenarios of vehicles turning at or crossing paths at signalized or non-signalized junctions were grouped together since these crashes occurred at intersections and at either oblique or perpendicular impacts between vehicles.

Ultimately the 37 pre-crash scenarios were grouped together to form 15 crash categories as shown in Table 2.

Table 2.
15 Crash Categories

1.	VEHICLE FAILURE
2.	LOSS OF CONTROL
3.	RUNNING RED LIGHTS AND STOP SIGNS
4.	ROAD EDGE DEPARTURE
5.	ANIMAL CRASH
6.	PEDESTRIAN AND PEDALCYCLIST CRASH
7.	BACKING UP
8.	TRAVELING AND TURNING TOGETHER
9.	TRAVELING IN OPPOSITE DIRECTIONS
10.	REAR END COLLISION
11.	CRASH AT INTERSECTION
12.	EVASIVE MANEUVER
13.	NON-COLLISION INCIDENT
14.	RUNNING INTO OBJECT
15.	OTHER

Two pre-crash scenarios were moved from their original sequence in the DOT report HS 810 767 to revised locations.

Scenario 8, Road Edge Departure while Backing Up, was moved from the Road Edge Departure category into the Backing Up category because it is a low speed event. The other road edge departure scenarios, Road Edge Departure with/without Prior Vehicle Maneuver (6, 7), are both events that happen at significant forward velocity while scenario 8 is a slow speed event. It fits more appropriately in the Backing Up category.

Scenario 22, Following Vehicle Making a Maneuver, was moved from the Rear End Collision category to the Traveling and Turning Together category because it is a scenario that occurs during a relatively constant vehicle velocity situation and not during a decelerating/accelerating situation as would happen at an intersection where rear end crashes generally occur.

Table 3 containing the complete 37 pre-crash scenarios as sorted and rearranged into the 15 crash categories is included in the Appendix.

Though not mentioned in the DOT report, the 37 pre-crash scenarios were ordered in the sequence as presented above in the executive summary of the DOT report with the two exceptions mentioned. Otherwise, the pre-crash scenario numbers change in the DOT report. This grouping was not expanded

upon within the DOT report. It was not attributed to previous efforts and may have been an intermediate step in the development of the 37 pre-crash scenarios. The author believes these 15 crash categories are important to consider in vehicle safety research because they allow a more global level of focus and prioritization than is practical with the 37 pre-crash scenarios. The 37 pre-crash scenarios offer a more detailed perspective regarding crash scenarios. Both a global and detailed focus is appropriate to consider for research.

The 15 crash categories summarize the possible variations of travel direction and kinds of crash situations that occur on-road in a broad sense: Drivers end up running into each other while traveling in the same direction, while traveling on opposing head-to-head paths and while on generally perpendicular paths, they run red lights and stops signs. Drivers run into things, other people, animals, objects or the vehicle ahead of them. Drivers lose control of their vehicles or "fall off the road" for no apparent reason. Sometimes drivers have an incident while backing up or parking. Drivers attempt evasive action and end up crashing. Vehicles experience mechanical failures that can initiate a crash or sometimes a non-collision event happens that precipitates a crash. Finally, an "other" category is maintained for situations that may not fit the prior categories. An examination of what kinds of crashes occur can provide useful research direction in addition to the other classical questions of who, when, where, how and why.

It may be wise to be cautious in the assumption that the data record available is infallible and that all accident facts were interpreted and recorded properly. The broader picture is probably reasonably accurate, however, the details can become murky. A difference between a rear end crash and a sideswipe crash is clear to recording authorities. The fact of a rear end crash is pretty obvious, but was the forward vehicle accelerating or traveling at a steady speed? That question is unlikely to be answered with as high a degree of accuracy by observers or authorities investigating the incident and filling out the paperwork. An argument can be made to use a variety of data sets each set providing some definition of the problem while also introducing some level of noise and confusion.

Examination of the 15 crash categories provides a more global perspective of the data than presented in the DOT Report HS 810 767. The 15 crash categories provide an information base that may be used to examine the relative importance of each category and provide a framework within which the benefits of some technologies may be assessed.

The raw data for the 15 crash categories in terms of frequency of occurrence, economic cost and functional years lost as defined in the DOT report is presented in Table 4.

Crash Category Data Examination

Tables 5 through 7 present the data for the 15 crash categories sorted in terms of frequency, economic cost and functional years lost. The 15 crash category data was sorted in descending order and the Pareto principle (80/20 rule) [1] was applied to identify the categories that would account for the top 80% (approximately) of the frequency of occurrence, economic cost and functional years lost.

Table 5 sorts the crash category data in descending order of frequency. The top 80% of crashes are:

- Rear End Collision 27.5%
- Crash at Intersection 19.3
- Traveling and Turning Together 13.3
- Loss of Control 10.6
- Road Edge Departure 6.8

Table 6 sorts the crash category data in descending order of economic cost. The top 80% of crashes are:

- Rear End Collision 21.7%
- Crash at Intersection 21.6
- Loss of Control 14.8
- Traveling and Turning Together 8.6
- Road Edge Departure 8.5
- Running Red Lights and Stop Signs 6.6

Table 7 sorts the crash category data in descending order of functional years lost. The top 80% of crashes are:

- Crash at Intersection 19.9%
- Loss of Control 19.0
- Rear End Collision 15.2
- Road Edge Departure 11.0
- Traveling in Opposite Directions 8.6
- Pedestrian and Pedalcyclist Crash 7.9

Table 4.
Crash Categories: Frequency, Economic Cost and Functional Years Lost

CATEGORY	CATEGORY DESCRIPTION	37 DOT CRASH SCENARIO NUMBERS	Frequency	Freq %	Eco Cost: Millions	Eco Cost %	Func Years Lost: Thous	Func Y L %
1	VEHICLE FAILURE	1	42,000	0.71	1,051	0.88	26	0.94
2	LOSS OF CONTROL	2, 3	632,000	10.63	17,766	14.82	527	19.03
3	RUNNING RED LIGHTS and STOP SIGNS	4, 5	302,000	5.08	7,937	6.62	163	5.89
4	ROAD EDGE DEPARTURE	6, 7	402,000	6.76	10,149	8.47	304	10.98
5	ANIMAL CRASH	9, 10	328,000	5.52	1,752	1.46	26	0.94
6	PEDESTRIAN, PEDALCYCLIST CRASH	11, 12, 13, 14	98,000	1.65	6,689	5.58	218	7.87
7	BACKING UP	8, 15	197,000	3.31	1,297	1.08	15	0.54
8	TRAVELING AND TURNING TOGETHER	16, 17, 18, 19, 22	791,000	13.31	10,275	8.57	184	6.64
9	TRAVELING IN OPPOSITE DIRECTIONS	20, 21	139,000	2.34	7,350	6.13	238	8.60
10	REAR END COLLISION	23, 24, 25, 26	1,632,000	27.46	25,961	21.66	422	15.24
11	CRASH AT INTERSECTION	27, 28, 29, 30, 31	1,144,000	19.25	25,874	21.59	550	19.86
12	EVASIVE ACTION	32, 33	69,000	1.16	1,547	1.29	40	1.44
13	NON-COLLISION	34	46,000	0.77	592	0.49	13	0.47
14	RUNNING INTO OBJECT	35, 36	85,000	1.43	842	0.70	22	0.79
15	OTHER	37	36,000	0.61	764	0.64	21	0.76
		TOTALS	5,943,000	100	119,846	100	2,769	100

Table 5.
Data Sorted by Frequency

SORTED BY FREQUENCY		37 DOT CRASH SCENARIO NUMBERS	Frequency		Freq %	Eco Cost: Millions		Eco Cost %	Func Years Lost: Thous		Func Y L %
CATEGORY	CATEGORY DESCRIPTION										
10	REAR END COLLISION	23, 24, 25, 26	1,632,000	1	27.46	25,961		21.66	422		15.24
11	CRASH AT INTERSECTION	27, 28, 29, 30, 31	1,144,000	2	19.25	25,874		21.59	550		19.86
8	TRAVELING AND TURNING TOGETHER	16, 17, 18, 19, 22	791,000	3	13.31	10,275		8.57	184		6.64
2	LOSS OF CONTROL	2, 3	632,000	4	10.63	17,766		14.82	527		19.03
4	ROAD EDGE DEPARTURE	6, 7	402,000	5	6.76	10,149		8.47	304		10.98
5	ANIMAL CRASH	9, 10	328,000		5.52	1,752		1.46	26		0.94
3	RUNNING RED LIGHTS and STOP SIGNS	4, 5	302,000		5.08	7,937		6.62	163		5.89
7	BACKING UP	8, 15	197,000		3.31	1,297		1.08	15		0.54
9	TRAVELING IN OPPOSITE DIRECTIONS	20, 21	139,000		2.34	7,350		6.13	238		8.60
6	PEDESTRIAN, PEDALCYCLIST CRASH	11, 12, 13, 14	98,000		1.65	6,689		5.58	218		7.87
14	RUNNING INTO OBJECT	35, 36	85,000		1.43	842		0.70	22		0.79
12	EVASIVE ACTION	32, 33	69,000		1.16	1,547		1.29	40		1.44
13	NON-COLLISION	34	46,000		0.77	592		0.49	13		0.47
1	VEHICLE FAILURE	1	42,000		0.71	1,051		0.88	26		0.94
15	OTHER	37	36,000		0.61	764		0.64	21		0.76
		TOTALS	5,943,000		100	119,846		100	2,769		100

Table 6.
Data Sorted by Economic Cost

SORTED BY ECONOMIC COST		37 DOT CRASH SCENARIO NUMBERS	Frequency		Freq %	Eco Cost: Millions		Eco Cost %	Func Years Lost: Thous		Func Y L %
CATEGORY	CATEGORY DESCRIPTION										
10	REAR END COLLISION	23, 24, 25, 26	1,632,000	1	27.46	25,961	1	21.66	422		15.24
11	CRASH AT INTERSECTION	27, 28, 29, 30, 31	1,144,000	2	19.25	25,874	2	21.59	550		19.86
2	LOSS OF CONTROL	2, 3	632,000	4	10.63	17,766	3	14.82	527		19.03
8	TRAVELING AND TURNING TOGETHER	16, 17, 18, 19, 22	791,000	3	13.31	10,275	4	8.57	184		6.64
4	ROAD EDGE DEPARTURE	6, 7	402,000	5	6.76	10,149	5	8.47	304		10.98
3	RUNNING RED LIGHTS and STOP SIGNS	4, 5	302,000		5.08	7,937	6	6.62	163		5.89
9	TRAVELING IN OPPOSITE DIRECTIONS	20, 21	139,000		2.34	7,350		6.13	238		8.60
6	PEDESTRIAN, PEDALCYCLIST CRASH	11, 12, 13, 14	98,000		1.65	6,689		5.58	218		7.87
5	ANIMAL CRASH	9, 10	328,000		5.52	1,752		1.46	26		0.94
12	EVASIVE ACTION	32, 33	69,000		1.16	1,547		1.29	40		1.44
7	BACKING UP	8, 15	197,000		3.31	1,297		1.08	15		0.54
1	VEHICLE FAILURE	1	42,000		0.71	1,051		0.88	26		0.94
14	RUNNING INTO OBJECT	35, 36	85,000		1.43	842		0.70	22		0.79
15	OTHER	37	36,000		0.61	764		0.64	21		0.76
13	NON-COLLISION	34	46,000		0.77	592		0.49	13		0.47
		TOTALS	5,943,000		100	119,846		100	2,769		100

Table 7.
Data Sorted by Functional Years Lost

		37 DOT									
SORTED BY FUNC. YEARS LOST		CRASH SCENARIO									
CATEGORY	CATEGORY DESCRIPTION	NUMBERS	Frequency		Freq %	Eco Cost: Millions		Eco Cost %	Func Years Lost: Thous		Func Y L %
11	CRASH AT INTERSECTION	27, 28, 29, 30, 31	1,144,000	2	19.25	25,874	2	21.59	550	1	19.86
2	LOSS OF CONTROL	2, 3	632,000	4	10.63	17,766	3	14.82	527	2	19.03
10	REAR END COLLISION	23, 24, 25, 26	1,632,000	1	27.46	25,961	1	21.66	422	3	15.24
4	ROAD EDGE DEPARTURE	6, 7	402,000	5	6.76	10,149	5	8.47	304	4	10.98
9	TRAVELING IN OPPOSITE DIRECTIONS	20, 21	139,000		2.34	7,350		6.13	238	5	8.60
6	PEDESTRIAN, PEDALCYCLIST CRASH	11, 12, 13, 14	98,000		1.65	6,689		5.58	218	6	7.87
8	TRAVELING AND TURNING TOGETHER	16, 17, 18, 19, 22	791,000	3	13.31	10,275	4	8.57	184		6.64
3	RUNNING RED LIGHTS and STOP SIGNS	4, 5	302,000		5.08	7,937	6	6.62	163		5.89
12	EVASIVE ACTION	32, 33	69,000		1.16	1,547		1.29	40		1.44
5	ANIMAL CRASH	9, 10	328,000		5.52	1,752		1.46	26		0.94
1	VEHICLE FAILURE	1	42,000		0.71	1,051		0.88	26		0.94
14	RUNNING INTO OBJECT	35, 36	85,000		1.43	842		0.70	22		0.79
15	OTHER	37	36,000		0.61	764		0.64	21		0.76
7	BACKING UP	8, 15	197,000		3.31	1,297		1.08	15		0.54
13	NON-COLLISION	34	46,000		0.77	592		0.49	13		0.47
		TOTALS	5,943,000		100	119,846		100	2,769		100

It is noteworthy to observe that 8 of the 15 crash categories cover 80% of the occurrences in terms of frequency, economic cost and functional years lost. This data offers a potential prioritization point of view. If progress is made in regards to reducing the frequency and severity of these 8 crash categories, a significant savings of life and economic cost can be expected.

In the functional years lost viewpoint, two categories appear that do not appear in the frequency and economic cost analysis. Traveling in Opposite Directions and Pedestrian/Pedalcyclist Crash categories rise in significance. Head on collisions and collisions with people outside the vehicle are crash categories that do not happen often but tend to involve severe injury and therefore rise in importance in the functional year lost analysis.

A closer examination of the data shows that within this prioritization two or three categories stand out from the rest in magnitude. In frequency sorting, Rear End Collisions and Crashes at Intersections stand out above the others. In economic cost and functional years lost sorting both also stand out however Loss of Control also appears. After these three categories there is a distinct drop in magnitudes of occurrence for the remaining categories. The top two categories in frequency account for 47 percent of the total occurrences. The top three categories in economic cost account for 58 percent of the total. In functional years lost the top three categories account for 54 percent of the total.

The 15 crash categories presented in this paper offer an opportunity to focus attention upon specific incidents which encompass similar situation, vehicle and driver dynamics and may benefit from a particular advanced safety technology. This data can be used to structure further research into a specific crash category from a driver behavior point of view, from a vehicle technology point of view and from a transportation infrastructure point of view. This data provides a framework to focus resources upon the areas where the most benefit may be achieved for the effort committed.

Severity Index and Cost Index

The data in this study was used to calculate a "Severity Index" and a "Cost Index" which provide an indication of functional years lost per incident as well as an economic cost per incident. The Severity Index is the division of the total functional years lost by the frequency of occurrence for a particular category. The Severity Index can be considered to be the average functional years lost per incident within a category. The Cost Index is the division of total economic cost by the frequency of occurrence for a particular crash category. The Cost Index can be considered to be the average economic cost per incident within a category.

Table 8 presents the Severity Index in descending order and the Cost Index for the 15 crash categories.

Table 8.
Severity Index and Cost Index

CATEGORY	CATEGORY DESCRIPTION	Severity Index Years/Inc.	Cost Index: Dollars/Inc.
6	PEDESTRIAN, PEDALCYCLIST CRASH	2.22	68255
9	TRAVELING IN OPPOSITE DIRECTIONS	1.71	52878
2	LOSS OF CONTROL	0.83	28111
4	ROAD EDGE DEPARTURE	0.76	25246
1	VEHICLE FAILURE	0.62	25024
15	OTHER	0.58	21222
12	EVASIVE ACTION	0.58	22420
3	RUNNING RED LIGHTS and STOP SIGNS	0.54	26281
11	CRASH AT INTERSECTION	0.48	22617
13	NON-COLLISION	0.28	12870
14	RUNNING INTO OBJECT	0.26	9906
10	REAR END COLLISION	0.26	15907
8	TRAVELING AND TURNING TOGETHER	0.23	12990
5	ANIMAL CRASH	0.08	5341
7	BACKING UP	0.08	6584

The Severity Index and the Cost Index can be used to compare the categories on a per incident basis. The Severity Index and the Cost Index can also be applied to the pre-crash scenarios from the DOT Report HS 810 767 for in-depth examinations of the 37 pre-crash scenarios.

Examination of the Severity Index reveals that there are distinct steps in the data: Pedestrian and Pedalcyclist Crashes and Traveling in Opposite Directions have a Severity Index of 2.22 and 1.71 years lost per occurrence. The categories Loss of Control, Road Edge Departure, Vehicle Failure, Other, Evasive Action, Running Red Lights and Stop Signs, and Crash at Intersection occupy a bracket of approximately 0.50 to 0.80 years lost per occurrence. The categories of Non-Collision, Running into Object, Rear End Collision and Traveling and Turning Together occupy a bracket of approximately 0.20 to 0.30 years lost per occurrence while the categories Animal Crash and Backing Up occupy a bracket of years lost below 0.10 years. Table 9 summarizes this information.

The maximum level of Severity Index is observed in the crash categories Pedestrian and Pedalcylist Crash and Traveling in Opposite Directions which is supported by the fact that pedestrians and pedalcyclists are unprotected when impacted by a vehicle and can be expected to sustain significant injury. Traveling in Opposite Directions is a category that encompasses head on crashes, one of the most severe crashes possible due to the relative velocity between vehicles.

Table 9.
Severity Index Range

Crash Category	Severity Index Functional Years Lost/Incident
Pedestrian and Pedalcyclist Crash	1.71 – 2.22
Traveling in Opposite Directions	
Loss of Control	0.50 – 0.80
Road Edge Departure	
Vehicle Failure	
Other	
Evasive Action	
Running Red Lights and Stop Signs	
Crash at Intersection	
Non-Collision	0.20 – 0.30
Running into Object	
Rear End Collision	
Traveling and Turning Together	
Animal Crash	< 0.10
Backing Up	

The Cost Index basically parallels the Severity Index except in the categories Rear End Collision and Traveling and Turning Together. These two categories have a higher Cost Index ranking than Severity Index ranking and are suspected to incur proportionally more property damage than human injury compared to the other categories therefore the higher Cost Index ranking.

The Severity Index offers a prioritization methodology that indicates where the probability of the most severe injury can be expected given that a crash occurs. However, it does not include a frequency of occurrence perspective that is necessary when considering the overall consequence to society. A few rare severe occurrences may not outweigh more frequent but less severe incidents. Both severity and frequency must be considered.

Potential Benefits of Advanced Safety Technologies

Six advanced safety technologies were examined for the potential of each to reduce the occurrence or to mitigate the consequences of the 15 crash categories previously described.

The six advanced safety technologies selected for this examination are:

- Collision Preparation, Automatic Brake Application
- Forward Collision Warning to Driver
- Side Alert/Lane Warning/Lane Keeping Assistance
- Emergency Brake Assistance to Driver

- Rear Automatic Brake Application
- Automatic Cruise Control

Electronic Stability Control (ESC), a recently legislated technology in the USA, was also included in the potential benefit assessment. ESC was included in order to put the relative benefits of the new technologies into perspective and to examine the hypothetical merits of ESC versus the six technologies.

The six advanced safety technologies were defined as described below:

Collision Preparation, Automatic Brake Application: Automatic brake application at the last "split second" before a frontal collision with an object occurs. The intent is to produce emergency vehicle deceleration just prior to impact thereby reducing kinetic energy and reducing impact velocity.

Forward Collision Warning to Driver: Driver warning system that informs and focuses the driver's attention to the high probability of an impending collision situation in front of the vehicle. This warning would inform the driver to act appropriately to avoid or mitigate the collision.

Side Alert / Lane Warning / Lane Keeping Assistance: Driver warning / assist system that helps keep the driver from wandering out of his lane and informs the driver that there are vehicles alongside in parallel lanes. The system can range from a warning system to a vehicle lane keeping assistance system.

Emergency Brake Assistance to Driver: Brake assist system that optimizes vehicle deceleration based upon recognition that a driver may be in a high stress situation requiring aggressive braking.

Rear Automatic Brake Application: Automatic brake application while in reverse if a collision is imminent.

Automatic Cruise Control: Cruise control that maintains spacing to the vehicle in front on a highway, adjusting speed up and down to keep appropriate distance. It requires the driver to activate it, does not apply brakes and does not work in stop and go traffic.

Electronic Stability Control: Current ESC technology, a brake actuated vehicle yaw stability control system which reacts to vehicle status and driver input. ESC adjusts vehicle yaw performance via four corner brake actuation to match the intended driver / vehicle path.

Since these six advanced technologies are emerging in the marketplace, minimal field data is available for study regarding their benefits in global applications. Field data will take a long time to acquire. It may also become difficult to draw conclusions from field data considering the minuscule data sets containing the specific technologies, the confounding effects of multiple factors and the noise levels throughout the data gathering and analysis process.

Focused field studies or advanced driving simulator studies of specific combinations of crash categories / scenarios and advanced safety technologies may provide significant value in the future. The studies can be designed to evaluate the benefit of a particular technology in a specific crash category / scenario in a quantifiable manner. This quantifiable data can then be weighed using frequency of occurrence, economic cost or functional years lost in a manner similar to the data presented in this study to produce an estimate of real world benefit.

Before large quantities of data are available, the existence of a POTENTIAL of benefit can be considered. A level of logic and judgment is required to do this assessment with the question being: Is it probable that a specific technology will be helpful in a particular crash category / situation? This will be referred to as the Potential Benefit in this paper.

The existence of a positive potential benefit, defined to be a factor of 1.0, was multiplied by the frequency of occurrence for a particular crash category to develop a frequency weighed potential benefit metric. The total potential benefit of a technology was determined by summing the frequency of crash categories where a particular technology was indicated to have a positive potential benefit. If the technology was not expected to provide a benefit in a crash category, the factor was defined as zero.

This does not result in a specific prediction of benefit, but it does provide a relative measure regarding the opportunity for different technologies to provide a safety benefit. The real world benefit of any technology will be based upon a multitude of environmental, technological and human factors. Complex assumptions, statistical analysis and research will be required to predict the real world benefit of emerging technologies.

Table 10 presents the Potential Benefit values for the technologies vs. crash categories in descending order of functional years lost and in descending order of potential benefit.

The technology offering the highest potential benefit opportunity was:

- Collision Preparation, Automatic Brake Application

The technologies following Collision Preparation in descending order of total potential benefit opportunity were:

- Forward Collision Warning to Driver / Emergency Brake Assistance to Driver (tie)
- Automatic Cruise Control
- ESC: Electronic Stability Control
- Side Alert/Lane Warning/Lane Keeping Assistance
- Rear Auto Brake Application

Collision Preparation, Auto Brake Application shows potential to be beneficial in all 6 of the highest contributors to economic cost and functional years lost and in 11 of the 15 crash categories. Collision Preparation cannot be considered a factor in reducing frequency because it is a crash velocity mitigation technology. It should not be expected to eliminate crashes events.

Forward Collision Warning and Emergency Brake Assist were tied in value and show opportunities to be effective in 2 of the top 5 categories for frequency of occurrence, in 3 of the top 6 categories for economic cost and 4 of the top 6 categories for functional years lost. Both are potentially beneficial in 8 of the 15 crash categories.

Automatic Cruise Control shows potential benefit in 1 of the top 6 categories and in 2 of the 15 crash categories.

ESC shows potential benefit in 2 categories of the top 6 from a functional years lost viewpoint and in 4 of the 15 crash categories. ESC is indicated to be beneficial in the "Other" crash category because that category includes on-road rollover incidents per the DOT report.

Side Alert and Rear Auto Brake Application show potential benefit in 2 and 1 of the fifteen crash categories respectfully, none of which is in the top six.

Table 10.
Potential Benefit of Technology

POTENTIAL BENEFIT OF TECHNOLOGY			benefit						
SORTED BY FUNC. YEARS LOST									
CATEGORY	CATEGORY DESCRIPTION		Auto Brake Interven.	Forward Coll. Warning	Panic Brake Assist	Auto Cruise	ESC	Side Alert, Lane Warning	Rear Auto Brake
11	CRASH AT INTERSECTION		1144000	1144000	1144000				
2	LOSS OF CONTROL		632000				632000		
10	REAR END COLLISION		1632000	1632000	1632000	1632000			
4	ROAD EDGE DEPARTURE		402000				402000		
9	TRAVELING IN OPPOSITE DIRECTIONS		139000	139000	139000				
6	PEDESTRIAN, PEDALCYCLIST CRASH		98000	98000	98000				
8	TRAVELING AND TURNING TOGETHER					791000		791000	
3	RUNNING RED LIGHTS and STOP SIGNS		302000	302000	302000				
12	EVASIVE ACTION		69000	69000	69000		69000	69000	
5	ANIMAL CRASH		328000	328000	328000				
1	VEHICLE FAILURE		42000						
14	RUNNING INTO OBJECT		85000	85000	85000				
15	OTHER						36000		
7	BACKING UP								197000
13	NON-COLLISION								
		Total	4,873,000	3,797,000	3,797,000	2,423,000	1,139,000	860,000	197,000

DESCENDING ORDER of POTENTIAL BENEFIT

Discussion of ESC and Advanced Safety Technologies

It is interesting to note that ESC ends up ranking fifth of the seven technologies examined. Considering the recognized benefit of ESC in the real world [2] a question needs to be posed: Are the new advanced technologies of potentially greater benefit than ESC or are there other factors to consider? Granted, this study only examines the potential benefit of these technologies and develops a relative ranking, but it is surprising that ESC comes out relatively low in total potential benefit opportunity. Could it be that other technologies will prove to be more beneficial, will their real benefit be less than ESC, does ESC provide additional benefits that have not been recognized, or is it a combination of all these and other factors? A significant amount of work will need to go into the research regarding the relative benefits of technologies before answers rise to the top.

The author would like to offer the hypothesis that ESC may be providing benefits that are an extension of ESC's original intent. The author offers the observation that ESC continues to function after an impact under certain conditions. Given that the brakes, tires and electrical system are still operational after an impact, ESC will continue to attempt to match vehicle trajectory to the driver's steering wheel motions while the vehicle is out of control and proceeding upon a post impact trajectory. Since ESC operates by applying the brakes, deceleration occurs while it is adjusting the vehicle yaw characteristics. The more severe the deviation between vehicle behavior and steering wheel motion, the more aggressively ESC will apply the brakes. This would be especially true in a traumatic sequence of events such as immediately after an on-road impact when the vehicle trajectory and driver steering motions are no longer related to each other. If the vehicle is relatively intact electrically and mechanically (the brakes and tires still function), then ESC will be reducing the vehicle's velocity prior to subsequent impacts.

A further scenario to consider would be the events just prior to an impact. If a driver recognizes that a crash is imminent and attempts an avoidance maneuver, ESC will tend to engage and decelerate the vehicle. ESC would therefore tend to reduce impact velocity to some degree if it functions prior to the impact. Impact velocity reduction has been shown to be a significant factor in fatality risk reduction.

The probability that ESC can introduce deceleration prior to initial impact and throughout the crash trajectory could be the reason that ESC provides an overall beneficial reduction in more crashes than the potential benefit expected from the Loss of Control and Road Edge Departure categories that it was specifically designed to address.

Hans C. Joksch, in the research “Velocity Change and Fatality Risk in a Crash – a Rule of Thumb” and in “Final Report Light Weight Car Safety Analysis, Phase II Part II: Occupant Fatality and Injury Risk in Relation to Car Weight” [3] discusses impact velocity as being a strong indicator of fatality potential. Joksch's research establishes that fatality risk is related to impact velocity to the forth power. Being so, small impact velocity reductions provide significant benefit in the reduction of fatality risk. For example, if an impact velocity of 50kph (31.1 MPH) is reduced by 2kph (1.24 MPH) to 48kph (29.8 MPH) the fatality risk is reduced by 15% based upon the velocity to the forth power. If the velocity is reduced 4 kph (2.48 MPH) the fatality risk is reduced by 29% and if reduced 6 kph (3.73 MPH) the fatality risk is reduced by 40%.

Collision Preparation, Automatic Brake Application technology which applies the vehicle brakes automatically without any driver action upon sensing an imminent collision can be expected to have a positive reduction in vehicle speed before impact and therefore a reduction in fatalities and injuries. The benefit of fatality risk reduction can be expected to be similar to H. C. Joksch's curve. Exactly how much benefit this technology could deliver is yet to be established. This technology probably would not prevent incidents from occurring but it could significantly reduce the severity of the incidents by reducing impact velocities.

Forward Collision Warning to Driver technology can be beneficial in reducing the frequency of occurrence and also in reducing impact velocity. However, an attention focusing and warning technology that activates at a point before a situation becomes critical runs the risk of being too intrusive during normal driving if conservatively programmed. This technology relies upon the driver to “do the right thing, promptly” as the situation is becoming critical.

Both considerations pose risks; intrusive alarms will frustrate drivers and may ultimately be turned off or ignored. On the other hand, a warning given at the "last instant" while the driver is in a developing unfamiliar high stress situation (where the correct actions are critical) the driver may not act appropriately to avoid the accident. The driver may react too slowly, may get confused by the unfamiliar alarm or may just do the wrong thing such as apply the brakes improperly or steer improperly for the particular situation.

The Emergency Brake Assistance to Driver technology is not a warning technology, but a technology that assists the driver in generating high braking deceleration in a situation when the driver seems to need to decelerate aggressively. This technology runs the risk of being either intrusive or rarely engaging depending upon the programming. It also relies upon the driver to "do the right thing, promptly" to be fully beneficial in avoiding incidents.

Given that maximizing deceleration before impact is beneficial, the Forward Collision Warning and Emergency Brake Assist technologies may provide more benefit in reducing the severity of impact than in reducing the the frequency of occurrence.

Side Alert/Lane Warning/Lane Keeping Assistance is a technology that assists the driver during the normal course of events that are familiar to the customer. This technology would tend to give a warning earlier than technologies such as Forward Collision Warning. The closing velocities between vehicles in traveling and turning together scenarios would tend to be lower than perpendicular, oblique and head on velocities so there would be more time for warning and driver reaction with less urgency than associated with forward collision scenarios. This technology could be considered an "advisement" technology where it advises the driver of a developing situation before it becomes critical. A benefit of an "advisement" technology could be the continual "training" of the driver to operate the vehicle in a safe manner.

Rear Automatic Brake Application technology could be useful in preventing impacts due to backing up, however it needs to be insensitive enough to allow the driver full maneuvering room in tight quarters. Some level of warning prior to the automatic brake application may be appropriate. The question is how much intrusiveness is appropriate without the technology being a hindrance to mobility and how to minimize driver irritation. This technology might be able to reduce the frequency of drivers backing up over pedestrians.

Automatic Cruise Control technology could assist drivers in keeping an adequate distance between vehicles in traffic patterns that have a relatively constant traffic velocity. A technology that tends to increase the distance between vehicles may serve to give the driver more reaction opportunity when a high stress situation is developing. This technology may also overlap with Forward Collision Warning by being able to warn the driver of an unexpected speed change in front. It is possible however, that some drivers could be lulled into a sense of security and inattention because of the automated speed control and end up in unexpected situations that lead to accidents.

Conclusions

All the advanced safety technologies considered in this work have the potential to reduce fatalities, injuries or accidents. The overall benefit of the technologies discussed can only be established in the future as real data becomes available. The actual benefit of each technology will be difficult to predict and analyze with accuracy because of the complexity of the challenge. There are multitudes of ways that drivers and vehicles become involved in accidents. There are also multitudes of ways that drivers act behind the wheel. The question regarding exactly when would a technology be beneficial and to what degree that technology would be beneficial is a problem that deserves intense study and research.

The Pareto principle methodology of crash prioritization in this paper could be applied as fresher data becomes available and as on-road transportation evolves. It can also be applied to the study of driver behavior and other crash factors. The Pareto principle can be used to sort information such as pre-crash scenarios and accident categories into perspectives that may assist in prioritizing research and development activity toward the most socially beneficial challenges.

The crash categories presented here seem to summarize the various vehicle accident situations that can occur in a broad, global perspective. There is no

single perfect perspective. Other arrangements of crash data also yield useful insights into vehicle safety. Different perspectives, used together, can improve understanding and accelerate progress. The details regarding why crash situations happen may evolve but drivers and vehicles will still tend to crash while traveling together, when meeting at intersections, when traveling in opposite directions as well as in all the other crash categories presented here.

Electronic stability control, ESC, has proven to be a life saving technology but not all has been understood regarding why it is such a benefit throughout the world. Is it because it is preemptive, is it because drivers maintain control of vehicles easier, is it because vehicles tend to stay on the road, is it because it decelerates vehicles in critical developing situations or is it for all these reasons and other reasons not yet conceived, researched or understood? Continued research regarding ESC is needed. The knowledge gained in understanding why ESC is beneficial may shed light upon how to examine other technologies, driver behavior and to further advance vehicle safety.

The six advanced safety technologies discussed in this paper are only some of the new technologies that are being developed for the vehicle transportation market. The benefit of any technology will progress from a conjecture of the potential benefit in the beginning to some level of understanding regarding the actual contribution in improving safety. This understanding will never be perfect. Methodologies will need to be continuously developed to process the data streams and evolve knowledge regarding the safety effectiveness of the transportation system. The methodology and viewpoints presented in this paper may be helpful in considering new technologies. The matrix of crash categories vs. technologies and the factoring/weighing method presented in this paper may be of use in planning research and experiments to determine the effectiveness of new technology for improving automobile safety.

REFERENCES

[1] Juran, J. M., Juran Institiute, Quality Minutes – Pareto Principle

[2] USA Federal Register 49 CFR Parts 571 and 585
Aga M, Okada A. (2003) Analysis of Vehicle Stability Control (VSC)'s Effectiveness from Accident Data, 18th International Technical Conference on the Enhanced Safety of Vehicles (ESV), Nagoya.

Dang, J. (2004) Preliminary Results Analyzing Effectiveness of Electronic Stability Control (ESC) Systems, Report No. DOT HS 809 790. U.S. Dept. of Transportation, Washington, DC.

Farmer, C. (2004) Effect of Electronic Stability Control on Automobile Crash Risk, Traffic Injury Prevention Vol. 5:317–325.

Kreiss J-P, *et al.* (2005) The Effectiveness of Primary Safety Features in Passenger Cars in Germany. 19th International Technical Conference on the Enhanced Safety of Vehicles (ESV), Washington, DC.

Lie A., *et al.* (2005) The Effectiveness of ESC (Electronic Stability Control) in Reducing Real Life Crashes and Injuries. 19th International Technical Conference on the Enhanced Safety of Vehicles (ESV), Washington, DC.

[3] Joksch H. C., (1993) Velocity Change and Fatality Risk in a Crash – A Rule of Thumb. Accident Analysis and Prevention. Volume 25, No. 1

Joksch H. C., (1982) Light-Weight Car Safety Analysis, Phase II Part II: Occupant Fatality and Injury Risk in Relation to Car Weight

March 2009

APPENDIX

Table 3.
37 Crash Scenarios Sorted into 15 Crash Categories

CRASH CATEGORIES	
	Pre-Crash Scenarios
1. VEHICLE FAILURE	
	1. Vehicle Failure
2. LOSS OF CONTROL	
	2. Control Loss With Prior Vehicle Action
	3. Control Loss Without Prior Vehicle Action
3. RUNNING RED LIGHTS AND STOP SIGNS	
	4. Running Red Light
	5. Running Stop Sign
4. ROAD EDGE DEPARTURE	
	6. Road Edge Departure With Prior Vehicle Maneuver
	7. Road Edge Departure Without Prior Vehicle Maneuver
5. ANIMAL CRASH	
	9. Animal Crash With Prior Vehicle Maneuver
	10. Animal Crash Without Prior Vehicle Maneuver
6. PEDESTRIAN AND PEDALCYCLIST CRASH	
	11. Pedestrian Crash With Prior Vehicle Maneuver
	12. Pedestrian Crash Without Prior Vehicle Maneuver
	13. Pedalcyclist Crash With Prior Vehicle Maneuver
	14. Pedalcyclist Crash Without Prior Vehicle Maneuver
7. BACKING UP	
	8. Road Edge Departure While Backing Up moved from ROAD EDGE DEPARTURE
	15. Backing Up Into Another Vehicle
8. TRAVELING AND TURNING TOGETHER	
	16. Vehicle(s) Turning – Same Direction
	17. Vehicle(s) Parking – Same Direction
	18. Vehicle(s) Changing Lanes – Same Direction
	19. Vehicle(s) Drifting – Same Direction
	22. Following Vehicle Making a Maneuver moved from REAR END COLLISION
9. TRAVELING IN OPPOSITE DIRECTIONS	
	20. Vehicle(s) Making a Maneuver – Opposite Direction
	21. Vehicle(s) Not Making a Maneuver – Opposite Direction
10. REAR END COLLISION	
	23. Lead Vehicle Accelerating
	24. Lead Vehicle Moving at Lower Constant Speed
	25. Lead Vehicle Decelerating
	26. Lead Vehicle Stopped
11. CRASH AT INTERSECTION	
	27. Left Turn Across Path From Opposite Directions at Signalized Junctions
	28. Vehicle Turning Right at Signalized Junctions
	29. Left Turn Across Path From Opposite Directions at Non-Signalized Junctions
	30. Straight Crossing Paths at Non-Signalized Junctions
	31. Vehicle(s) Turning at Non-Signalized Junctions
12. EVASIVE MANEUVER	
	32. Evasive Action With Prior Vehicle Maneuver
	33. Evasive Action Without Prior Vehicle Maneuver
13. NON COLLISION INCIDENT	
	34. Non-Collision Incident
14. RUNNING INTO OBJECT	
	35. Object Crash With Prior Vehicle Maneuver
	36. Object Crash Without Prior Vehicle Maneuver
15. OTHER	
	37. Other