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# **Advanced Crash Avoidance Technologies Program – Annual Report of the Volvo-Ford-UMTRI Project**

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16. Abstract  The Advanced Crash Avoidance Technologies program is a two-year cooperative research program in which Volvo Cars and its partners are one of four industry-led teams working on developing methodologies for estimating the effectiveness of advanced safety technologies intended to assist drivers in avoiding crashes. The program began in January 2007 and will continue through 2008. The aim of this Volvo-led project within the context of the ACAT program, is to develop the general principles of a safety impact methodology (SIM) tool that can be used for driving scenario-based benefit calculations over different phases of a lane departure crash sequence, and to evaluate the potential impact that emerging technologies may have on lane departures crash sequence by a single vehicle. Three new safety technologies from Volvo Cars designed to address lane departure crash sequences are considered for purposes of developing the SIM tool. This report describes the accomplishments and progress made during the first year of the project (January-December 2007). Activities in the first year focused on the development of the SIM tool, assessments of the safety areas and specifications for the candidate technologies, and definition of tests that would give the needed information about these technologies.					
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# EXECUTIVE SUMMARY

## *Project Summary*

This project is one of four projects within the National Highway Traffic Safety Administration's Advanced Crash Avoidance Technologies (ACAT) program. ACAT is a two-year program in which Volvo Cars, Ford Motor Company, and the University of Michigan Transportation Research Institute (UMTRI) comprise one of four teams working on complementary objectives. NHTSA's objective for the ACAT program is to develop a methodology for estimating the potential effectiveness of advanced safety technologies intended to assist drivers in avoiding crashes. NHTSA's prior experience indicates that the effectiveness of advanced safety technologies in reducing crashes is not well understood. ACAT is targeted at developing some of the tools needed for calculating the estimated benefit of these technologies in relation to the crashes they are intended to prevent.

The Volvo-Ford-UMTRI team project has two objectives:

- Develop the general principles of a safety impact methodology (SIM) tool that can be used for driving scenario-based benefit estimation over all phases in a crash sequence except the post-crash phase. This includes non-conflict (pre-conflict), potential conflict, imminent crash, and crash phases.
- Use the SIM tool to evaluate the potential impact that emerging technologies may have on crashes resulting from a vehicle drifting out of lane.

Three technologies from Volvo Cars, which may reduce lane departure crash sequences, are included in this study: driver alert control (DAC), lane departure warning (LDW) and emergency lane assist (ELA). These technologies are designed to detect degraded lane keeping performance and to provide appropriate information, warning or intervention.\*

This report summarizes the work performed during the first year of the ACAT program, and discusses the contributions by Volvo Cars and its partners, emphasizing the work done in developing a SIM tool and in developing objective tests that address the selected safety technologies. Overall, the first year of the ACAT project has been successful in the completion of several key research tasks required for successful completion of Tasks 1, 4, and 5 in the second year. In particular, significant progress has been made in the design and development of the SIM tool (Task 1); definition of the relevant safety areas via analysis of the crash data and synthesizing driving scenarios (Task 2); and in specification of a group of objective tests for evaluating the safety technologies under consideration (Task 3). Tasks that began in the first year and continue into the second year include the further development of the SIM tool (Task 1),

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\* It is important to note that these technologies are supplements to every driver's responsibility to keep attention to the roadway and driving task. In general, these technologies supplement characteristics within the driver's ability and control when driving in an alert state and responsive to changing road conditions.

completion of the tests of the safety technologies (Task 4) and estimation of the potential safety benefits of the DAC, LDW, and ELA systems through the SIM tool (Task 5).

### ***Summary of Accomplishments During 2007***

This ACAT project is partitioned into five main tasks. Research activities in the first year focused on aspects of Task 1 (development of the SIM tool), Task 2 (assessment of the targeted safety areas and specifications for the candidate technologies), and Task 3 (definition of tests to provide needed information about these technologies). Some testing for Task 4 (conducting tests) has been done; however the remainder of this task and Task 5 (assessing safety benefits) will be carried out in the second year of the project.

In Task 1, the overall architecture of the SIM tool was developed. The nature and form of the expected inputs and outputs were identified and the concept of a driving scenario was developed to capture information relating to the driving task and environment prior to a crash. A preliminary driver model was also developed that will utilize key driving scenario parameters as input.

In Task 2, crash data were analyzed to obtain relevant single-vehicle road departure crashes. Relevant summary data from these representative crashes were extracted from crash databases to obtain information about the conditions under which these crashes occurred. This information was cross-referenced with naturalistic driving data to obtain information on expected vehicle kinematics and dynamic states under similar conditions. This data is being synthesized into a set of driving scenarios within the SIM tool.

Recognizing that the human/machine interface (HMI) plays a role in the effectiveness of the proposed technologies, information about driver behavior and response that may have been relevant at the time of the crash was reviewed. This information is being used to refine the HMI aspects of these technologies.

In Task 3, the framework of the proposed objective testing was finalized. This two-pronged framework includes technical tests to characterize system performance and HMI tests to characterize driver response to the systems. Key qualitative and quantitative performance parameters for each of the technologies have been identified, and specific tests have been developed to assess the performance of each of these technologies and to characterize the driver response to them.

# 1.0 INTRODUCTION

## 1.1 *Background and Motivation*

This report documents the first-year activities and accomplishments of the Volvo-Ford-UMTRI team for this ACAT project. ACAT is a two-year safety research effort to develop methodologies for estimating the potential safety benefits of advanced safety technologies designed to reduce lane departures crash sequences by passenger vehicles.

This project has two objectives. The first is to develop the general principles of a safety impact methodology that can be used for driving scenario-based benefit estimation over all phases of the crash, except post-crash. The second objective is to use the SIM tool to evaluate the potential impact that emerging technologies may have on crashes resulting from vehicles drifting out of lane. Such lane departures can lead to crashes that encompass portions of the following crash types:

- Single-vehicle road departure crashes,
- Lane-change/merge crashes, and
- Head-on crashes.

The focus of this project, within this broad crash set, is on single-vehicle road departure crashes because of the number and severity of those types of crashes, as described in numerous reports by NHTSA and its contractors.<sup>1 2 3 4 5</sup> Lane-change/merge and head-on crashes are similar to road-departure crashes in that they also involve a lane-departure by the vehicle, but the lane departure is to an adjacent lane (with the line of travel either in the same or in the opposite direction) rather than off the road, as in the case of road-departure crashes. Pre-crash maneuvers for lane-change/merge and head-on crashes can involve a number of scenarios. The lane departure crash sequences likely include the same factors of fatigue and distraction as in road-way departure crashes, and thus are addressable by the same technologies that are applicable to road-departure crashes. The focus of the work proposed here will be on road-departure crashes, but it is important to note that the effect of the technologies will likely have a broader impact.

Studies from statistical analysis of accident data have identified factors such as drowsiness/sleepiness, distraction, inattention and adverse roadway conditions as increasing the risk of road-departure crashes.<sup>6 7 8</sup> In particular, fatigue and distraction appear to be significant contributors. General inattention has been found to be contributing in up to 24 percent of road-edge departures,<sup>9</sup> while Wang et al.<sup>10</sup> found that distraction factors were involved in 18.1 percent of single-vehicle crashes. For drift-out-of-lane crashes in the United States, fatigue has been found to be contributing in road-edge departures and in single-vehicle crashes in general.<sup>9 11</sup> Analyses by Najm et al.<sup>1</sup> indicate that almost 89 percent of road-departure crashes occur on surface roads, not on limited-access highways. The same report also indicated that road-departure crashes are more common in rural settings.

The safety impact methodology being proposed will consider the crash data analyses when addressing safety benefits of the safety technologies under consideration. Three technologies from Volvo Cars designed to address lane departures will be included in this study: driver alert control, lane departure warning, and emergency lane assist. Each of these technologies operates in different phases of a crash sequence, ranging from non-conflict to imminent-crash, and they all have differing objectives in terms of how they interact with the driver and the vehicle.

## **1.2 Project Overview and Report Organization**

This project combines data and knowledge from various sources to develop a safety benefit estimation methodology for vehicle safety technologies that have been designed to reduce lane departure crash sequences. Several different disciplines and data sources are used for driving scenario definition and SIM tool development, such as national crash data bases, in-depth crash data, vehicle dynamics data, common and variable aspects of driver behavior, data from driving simulator, test track and naturalistic driving studies, algorithms and design information of safety technologies, engineering tests of the vehicle and its technologies, and highway information databases. Objective testing (comprised of both technical testing and HMI testing) provides objective data and response parameters for the SIM tool as well as refinements to the SIM tool. The SIM tool will estimate the effect of the technologies over all phases of the vehicle road departure crash phenomenon except the post-crash phase.

The remainder of this report is organized as follows:

- Section 2 describes the overall program management plan for the project.
- Section 3 discusses the technical activities for Tasks 1, 2, and 3. These tasks cover the development of the SIM tool, definition of the safety areas to be addressed and safety technology specification, and the definition of objective tests for the safety technologies.
- Section 4 summarizes the program milestones for the first year of the project and highlights the key activities for the second year.

## 2.0 PROGRAM MANAGEMENT

### 2.1 Overall Program Management Plan

The project team consists of experts from Volvo Car Corporation, Ford Motor Company, and University of Michigan Transportation Research Institute. The team is led by Volvo.

Volvo's main responsibilities are project management, identification of the safety areas to be addressed, description of the advanced technologies as well as developing and conducting the objective tests. The project director and key person at Volvo is Jan Ivarsson, serving as manager of Traffic Safety Strategy and Requirements within Volvo Cars Safety Centre in Gothenburg, Sweden.

Volvo is a wholly owned subsidiary of Ford Motor Company. Within the project, Ford contributes technical and administrative support in all tasks. Dr. Michael Shulman at Ford Active Safety Research and Advanced Engineering in Dearborn, Michigan, is leading the Ford team. UMTRI provides the knowledge and perspective of a leading automobile research organization combined with the independence and capabilities of a university. UMTRI's main responsibilities in the project are to develop the SIM and to develop safety benefits using the SIM. The UMTRI group is led by Professor Timothy Gordon, head of the Engineering Research Division of UMTRI in Ann Arbor, Michigan.

The project runs from early 2007 to late 2008, and comprises five tasks, with duration and interactions as illustrated in Figure 1.

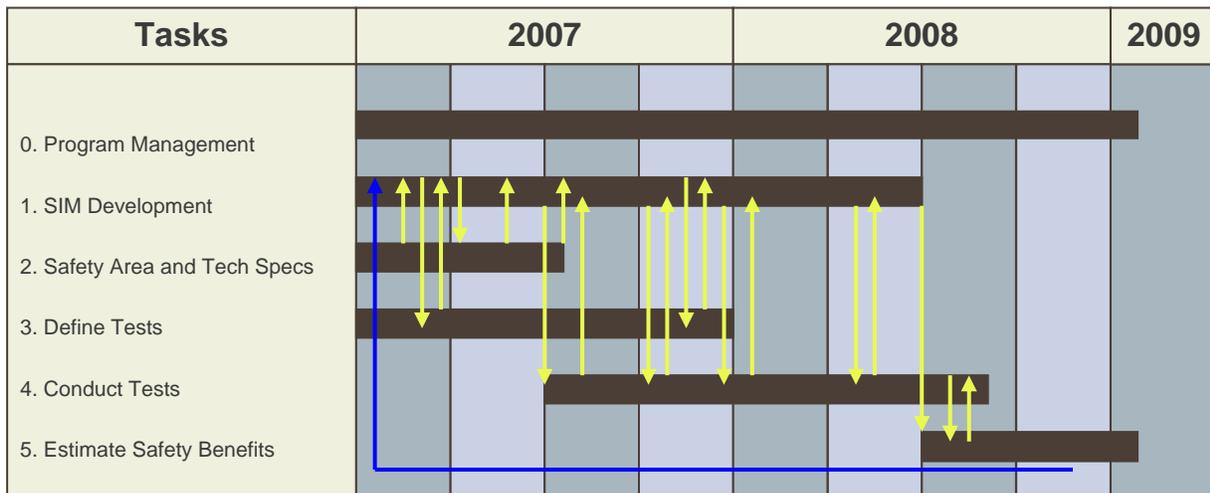


Figure 1. Project plan

## 3.0 TECHNICAL ACTIVITIES

The research activities over the first year of the project have focused on Tasks 1, 2 and 3. Task 1 emphasizes the development of the SIM. Task 2 focuses on characterization of the target safety area and technology specifications. Task 3 covers the definition of the various objective tests. This section discusses technical activities for the first year of this project within the program. Program activities for 2008 will focus on continuing development of the SIM tool and on Tasks 4 and 5. Task 4 refers to conducting the tests prescribed in Task 3; Task 5 focuses on estimating the potential safety benefits of the safety technologies using the SIM tool.

### 3.1 Task 1: The SIM Tool

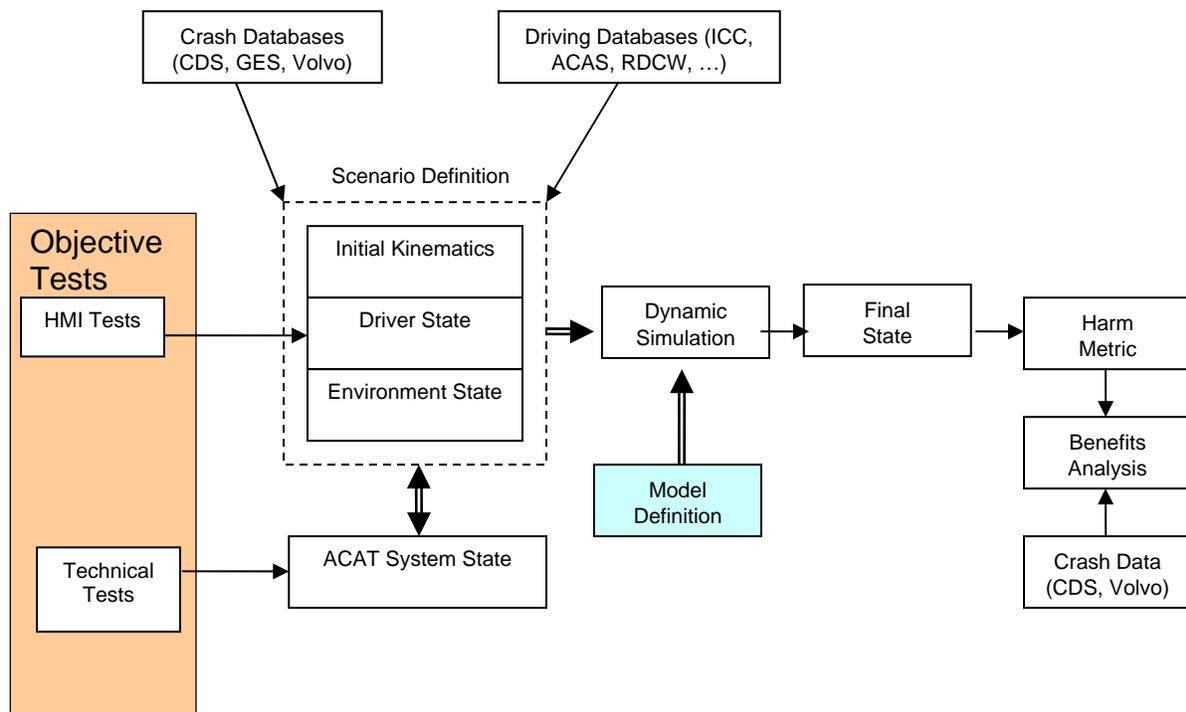
The SIM tool is intended as a computational device to predict the potential safety benefits of a particular safety technology. It represents the application of modeling, simulation and statistical analysis, based on a variety of data sources to evaluate the likely safety benefits of the proposed safety technologies for avoiding road departure crashes resulting from vehicles drifting out of lane. The safety technologies under consideration operate at three levels. Driver alert control advises a potentially drowsy driver to take a break, based on an evaluation of general lane-keeping performance based on evaluation of data from optical lane marker sensing. Lane departure warning provides a specific warning when the subject vehicle departs the lane without apparent driver intent to do so (i.e., through turn-signal use). Emergency lane assist provides directional control intervention by steering to avoid a lane departure when there appears to be an imminent risk of collision for the subject vehicle.

The SIM tool uses a high level of modeling and simulation, since the safety technologies under consideration have not yet been widely deployed in any form. This modeling and simulation require objective data sources, and the most powerful predictor fuses data from available relevant sources. In brief these are:

- Detailed experimental tests of the vehicle and its safety systems, typically on the test track;
- Design information and algorithms associated with the safety technology;
- Basic scientific knowledge about vehicle dynamics and driving dynamics;
- Detailed analyses of crash investigations;
- Data from nationally representative crash databases;
- Databases of naturalistic driving (obtained from previous field operational tests); and
- Human factors testing where the driver is in the loop, typically on a test track or in a driving simulator.

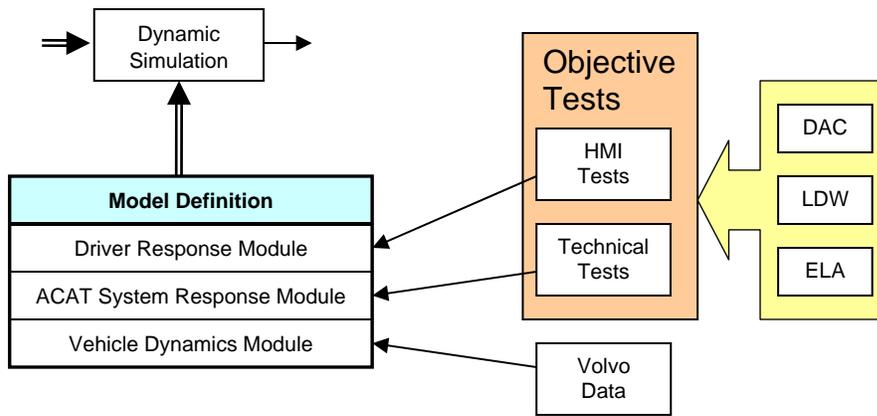
Figures 2(a) and 2(b) provide a conceptual picture of how the overall SIM tool is structured. The scenario definition includes what is known or assumed about the driving task and environment associated with a possible crash. Real-world crash mechanisms have been explored using an in-depth analysis of recorded crash events to understand contributory factors and associated pre-

crash event sequences, including the role of tiredness, distraction and judgment in actual crashes (Task 2). This information is generalized to develop a set of candidate driving scenarios that are likely to precede the types of crashes addressed by the safety technologies under consideration. It is important to recognize that crashes may or may not result from any given driving scenario as it develops over time, and this applies both in real driving and in simulations. Also, when crashes do result from a given driving scenario, they may not all follow the same crash sequence.



**Figure 2(a). SIM tool**

From a modeling perspective, crash mechanisms are represented using a computational model that time-steps from the parameterized driving scenarios. It includes random effects ( driver gaze control and reaction time) as well as fixed parameters (road curvature, surface friction, off-highway conditions). The computational model is refined and then validated based on detailed crash analysis, prior modeling work, published data, specific testing and also from existing naturalistic driving data. A preliminary driver model that will become part of the driver response module in Figure 2(b) has been developed. The objective tests have been defined for the safety technologies, and outputs from this testing will be used as inputs to the SIM tool. The human/machine interface (HMI) portion of the objective tests will be used to develop the inputs to the driver response module, while the results of technical performance tests will be mapped to the ACAT system response module which is comprised of models of the three safety technologies.

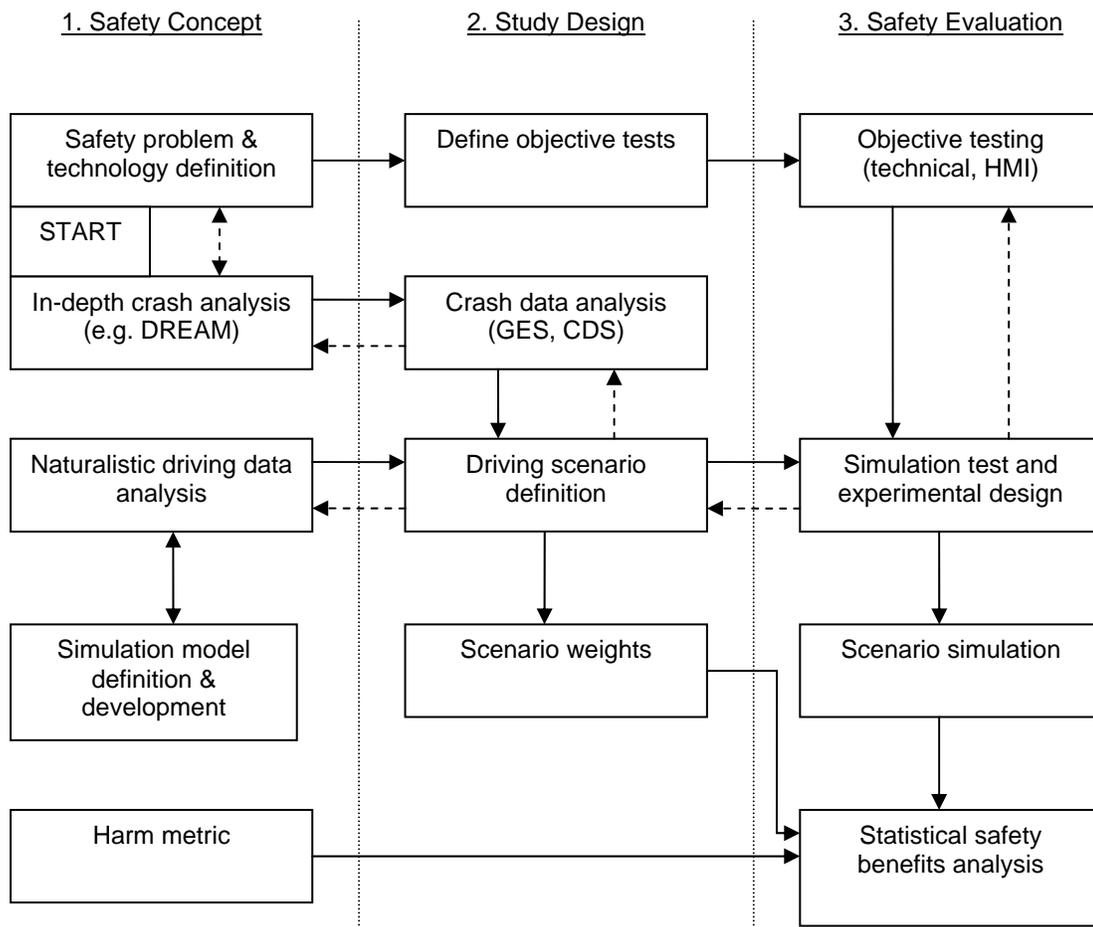


**Figure 2(b). SIM tool components**

The second phase, completed in 2008, conducted a large-scale simulation study to estimate crash numbers and outcome distributions within each scenario, both for the null case when the safety technologies are not operational, and for the case when the safety technologies are operational. While the absolute frequency of each driving scenario could be determined from naturalistic driving data, this is not necessarily the best approach as there is substantial uncertainty over the effects of geographic region on weather, highway conditions, and driver behavior that all interact and influence exposure.

The emphasis of the SIM tool will be on developing detailed and statistically valid predictions of vehicle kinematics at the end point of relevant conflicts, whether or not those conflicts result in crashes. Comparing such predictions with and without the presence of the DAC, LDW, and ELA technologies provides the basis for estimating a wide range of measures of benefit, either in terms of crash numbers or in the form of an estimated harm metric. This information could then be used in a benefits analysis that is part of Task 5.

Finally, the possibility of including an analysis of negative unintended consequences will be reviewed, though not quantitatively analyzed. The overall process can be summarized in terms of the flow chart shown in Figure 3. This has three phases, *safety concept*, *study design*, and *safety evaluation*, which are all part of the current project.



**Figure 3. Overall SIM tool process: information flow (solid arrows); validation (dashed arrows)**

### **3.2 Task 2: Safety Area to Be Addressed and Advanced Technology**

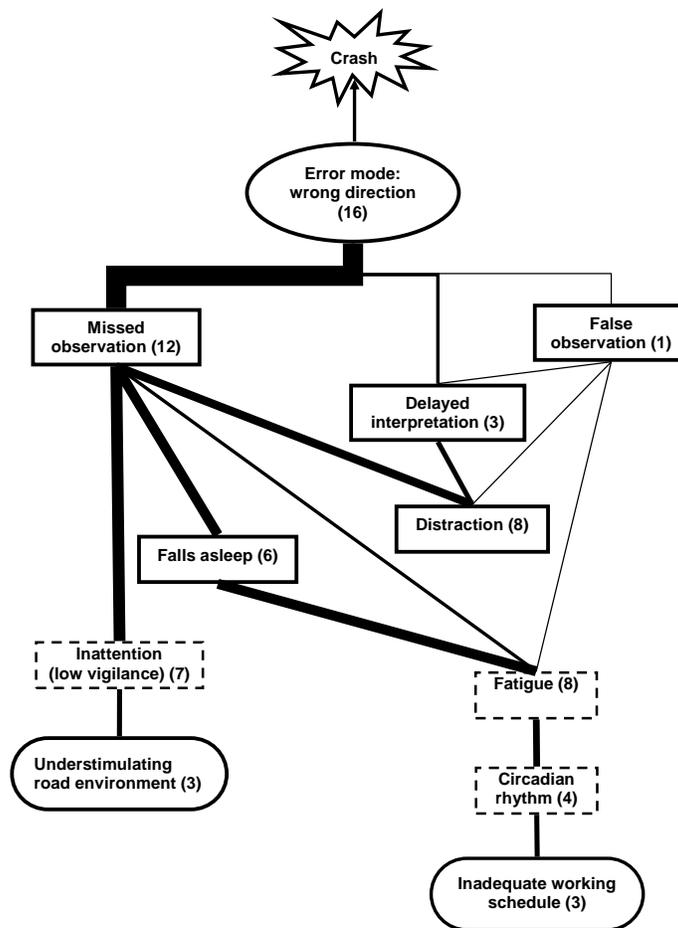
Task 2 identifies and characterizes a group of priority safety areas associated with lane departures. It also provides an overview of the safety technologies under consideration in this project that potentially address these safety areas for estimation of safety benefits.

#### **3.2.1 Crash Scenario Definition Using In-Depth Studies**

To gain insight into factors influencing causation, in-depth crash studies were conducted. The cases were analyzed using the Driver Reliability and Error Analysis Method (DREAM).<sup>12</sup> This approach allows the results of the individual case analysis to be aggregated to help identify causation patterns among different groupings of crashes. This is accomplished through an

overlaying of the causal links from the classification scheme. This is a useful tool when looking for patterns in accident causation. A Swedish database of in-depth crash investigations was used for this analysis, and the details of the database and analysis methods can be found in Sandin & Ljung.<sup>13</sup> To define relevant scenarios for the present project, aggregate analysis has been performed on the 38 single-vehicle cases available in the database. The aggregation showed that the accidents could be clustered into four typical scenarios, which are:

- Scenario 1: Vehicle drifts slowly out of lane ( tired and/or distracted driver);
- Scenario 2: Control loss on curved roadways with locally reduced road friction;
- Scenario 3: Excessive speed on curved roadway; and
- Scenario 4: Startled driver over-reacts.

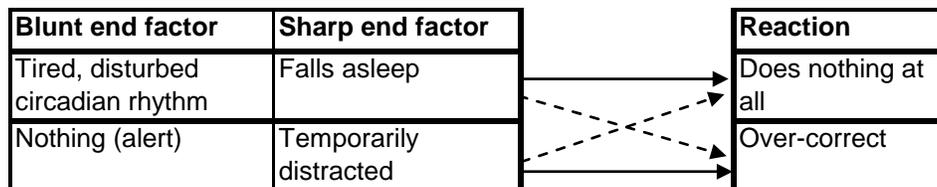


**Figure 4. Scenario 1: Vehicle drifts slowly out of lane**

The case analysis showed that the 16 cases in scenario 1 are relevant to the scope of this project. Figure 4 shows the contributing factors and “error modes” just prior to the crashes for scenario 1. The number of cases in which each contributing factor is present is shown in the brackets, and the frequency of the interaction links is represented by the line thickness. Because multiple

contributing factors are typically recorded, summations of contributing factors may exceed the case count.

The 16 cases can be further subdivided into two characteristic categories based on the drivers' reactions. Tired drivers who become involved in lane departure crashes will sometimes do nothing at all (they remain asleep) and other times they will over-correct. Distracted drivers involved in lane-departure crashes also sometimes do nothing and other times over-correct, as illustrated in Figure 5.



**Figure 5. Contributing factors and typical reactions for the 16 single-vehicle lane departure crashes of scenario 1**

The factors identified in this analysis were also analyzed for crash data from the General Estimates System (GES) database, a component of the National Automotive Sampling System (NASS) that provides a nationally-representative sample of police-reported crashes in the United States.

### 3.2.2 Crash Scenario Definition Using GES Data

The scenarios described in Section 3.2.1 depict several different conditions under which lane departures that result in crashes occur. Scenario 1 was found to be applicable for quantifying lane departures using comparable crash data from GES. The scenario described tired and distracted crash-involved drivers who either did nothing or over-corrected in response to the lane departure.

To estimate the number of relevant crashes, GES data for passenger cars from 2002-2006 was analyzed. The selected crash data for this study represented about 284,000 crashes on an annual basis. The functionality of DAC, LDW, and ELA restrict the crash types and scenarios which they can reasonably target in the following ways:

- The safety technologies are relevant for crashes in which the subject vehicle departs the lane/road to initiate the crash sequence. Excluded are crashes which are initiated by another vehicle or vehicles, and the reference vehicle is involved as a consequence of that earlier event, e.g., two vehicles may collide and one might be forced into the lane of the reference vehicle.
- The safety technologies are relevant for crashes in which the subject vehicle was not maneuvering prior to the initiation of the crash sequence, i.e., where the lane/road departure was unintentional. The technologies are not activated if it can be assumed that the driver is actively maneuvering the vehicle. Active maneuvering covers actions such as

vehicle braking, accelerating, rapid steering, or activation of the turn signal during a lane change maneuver. Crashes where the driver was determined to be maneuvering the vehicle actively (based on the available information in GES) were excluded.

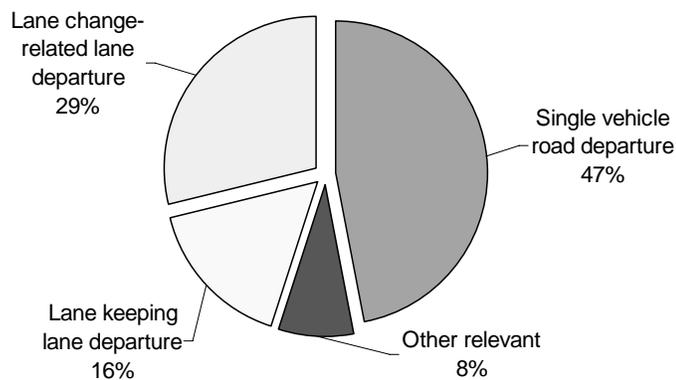
The GES database includes a variable that codes the “critical event,” which is the event that is judged to have precipitated the crash. This critical event variable in GES includes codes that apparently identify crashes that were initiated by lane/road departures. The coded values capture the direction of the vehicle movement (left or right) and whether it was a lane or road departure. There are four code values in GES that identify crashes relevant to the safety technologies under consideration:

1. Vehicle traveling over the left lane line;
2. Vehicle traveling over the right lane line;
3. Vehicle off the edge of the road on the left side; and
4. Vehicle off the edge of the road on the right side.

Based on these criteria, an algorithm was developed to identify the characteristics of crashes that most closely represent the crash types of interest for this project (based on the available data elements). The results can be summarized as follows:

- Crashes in which the vehicle initiated the crash by departing lane/road;
- Crashes in which the vehicle was not maneuvering prior to initiation of crash sequence;
- Crashes in which the lane/road departure was gradual and with no signal (unintentional); and
- Travel speed 40+ mph.

Figure 6 shows the team’s classification of the target crash types based on the available information in GES. Each category label describes the status of the reference vehicle at the time of the crash, as recorded in GES. Nearly half of the crashes involve single-vehicle road departure, and 16 percent of the crashes occurred when the driver was essentially keeping to the lane and the vehicle had a lane departure.



**Figure 6. Crashes of interest from GES (including speed criteria)**

In the crash data analysis process, a number of factors and conditions were examined for association with the relevant crashes shown earlier. Factors assessed included driver age, driver sex, driver distraction, driver fatigue, driver alcohol/drug use and speed limits. Crash conditions assessed included items such as road class, road type, weather and light conditions, road surface condition, roadway curvature, and roadside conditions. The aggregated distributions of the crash conditions are used as inputs to the SIM tool as shown in Figure 2(a). This data, along with other vehicle data extracted from naturalistic driving data, are key elements for developing driving scenarios within the SIM tool.

### 3.2.3 Countermeasure Technologies

The three advanced safety technologies identified for this project address different parts of the driving pre-crash, and crash sequence. DAC monitors the driver's level of alertness by comparing driver steering inputs and the vehicle lateral motion pattern with respect to travel lane markings. LDW senses the location of the lane markers and vehicle lateral position to indicate line crossings. ELA autonomously steers a vehicle drifting out of lane back into the original travel lane under certain conditions. It does this if the system senses (via radar and optical image processing) that there is an in-path obstacle detected in the adjacent lane (e.g., a parked car on the berm) and there is no sensed obstacle present in the original travel lane. Figure 7 gives an overview of how the three technologies function in the various phases of a crash sequence.

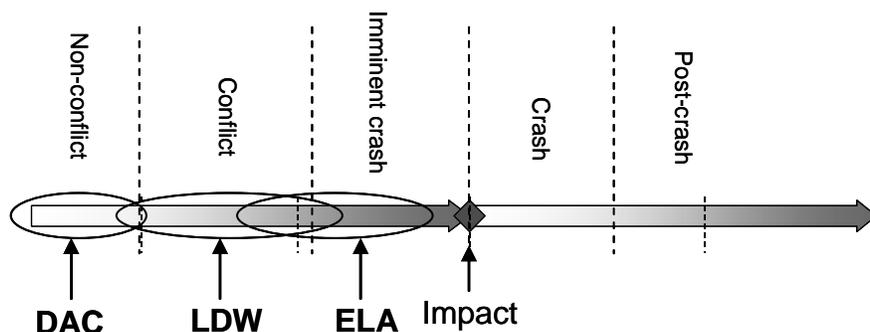


Figure 7. Countermeasure technologies in crash sequences

#### 3.2.3.1 Driver Alert Control

DAC monitors the movements of the vehicles and assesses whether the vehicle is being driven in a normal or deteriorating fashion. Nominally, the DAC is intended to detect driver fatigue or drowsy driving. Functionally, DAC does not monitor fatigue directly but instead infers fatigue or decreased concentration based on degraded lane keeping performance. DAC is intended to alert or warn the driver to take a rest break. A key aspect of DAC is that it is a driver support system only, and does not take any responsibility for driving away from the driver.

The DAC hardware consists of a camera, a number of sensors, and a control unit. The camera, which is installed between the windscreen and the interior rear-view mirror, continuously

measures the distance between the vehicle and the road lane markings as long as those lane markings are of sufficient quality. The sensors register the vehicle's movements. The control unit stores the information and calculates whether the pattern of lane keeping is sufficiently degraded to indicate a significant risk of a lane or road departure. If the risk is assessed as high, the driver is alerted via an audible signal and a visual text message that appears in the car's information display to alert the driver to take a rest break, as shown in Figure 8(a). The driver can also check how the DAC algorithm assesses his/her current driving behavior. Figure 8(b) shows the DAC indicator in the instrument cluster. The starting point is 5 bars. The less consistent the driving, the fewer bars remain.



**Figure 8(a). DAC alert message in vehicle instrumentation cluster**



**Figure 8(b). DAC alertness indicator in vehicle instrumentation cluster**

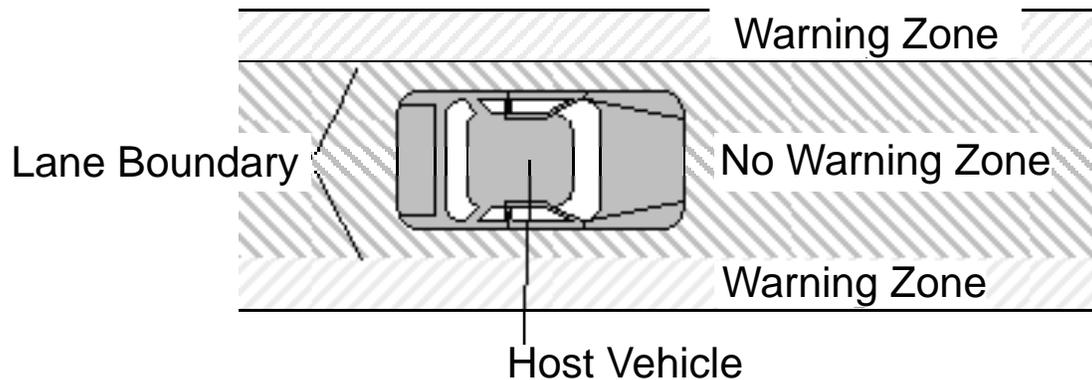
The functionality of the DAC technology depends on the presence and quality of the lane markings. The lane markings must be clearly visible to the camera. Poor light, fog, snow and extreme weather conditions will affect the availability of the DAC. Some other general limitations inherent to the current DAC technology include:

- A driver can be drowsy or inattentive without any apparent impact on the lane keeping behavior.
- The DAC function will not warn when the system senses that the driver is actively maneuvering.
- DAC warnings have a lower priority than collision warnings and lane departure warnings.
- The DAC feature can be deactivated by a driver.

### **3.2.3.2 Lane Departure Warning**

LDW alerts the driver with an audible warning sound if the car crosses a lane marking without an obvious reason, such as the use of the turn indicator. LDW will not take any automatic action to prevent a possible lane departure. Responsibility for the safe operation of the vehicle remains with the driver.

LDW uses a camera mounted between the windscreen and the rear-view mirror to monitor the vehicle's position between the road lane markings; this is the same camera that is used for DAC. Figure 9 shows a schematic of the system functionality.



**Figure 9. LDW functionality**

Lane tracking performance is highly dependent on the quality of the lane markings, the lighting conditions, as well as environmental aspects such as rain, snow, and fog that reduce visibility. On roads with low-quality lane markings, there is a trade-off between system availability and driver annoyance with frequent changes in LDW status in the instrument cluster. LDW functionality follows the general principles that:

- The warning should operate under a lower priority than, for instance, forward collision warning (FCW) and adaptive cruise control (ACC);
- The function should not warn when the driver appears to be actively maneuvering;
- The function should be able to be deactivated by the driver; and
- Repeated warnings should be avoided to reduce driver annoyance, which may reduce driver confidence in the system and lead the driver to ignore or disable the system.

### **3.2.3.3 Emergency Lane Assist**

ELA is designed to help prevent a frontal collision by using both a camera and radar to monitor the position of the car and obstacles in the adjacent lane toward which the subject vehicle is drifting. If the subject vehicle is drifting into the adjacent lane, and ELA estimates that the subject vehicle is on a collision course with an obstacle in that lane, the car is automatically steered back into the original travel lane of the subject vehicle under certain conditions (e.g., a clear path in the original travel lane).

The vehicle position is evaluated through the use of a camera mounted between the windscreen and the rear-view mirror. Potential obstacles in the adjacent lane are monitored by radar mounted in the subject vehicle's radiator grill along with the camera image processing. Both sources of sensor data are needed since this is an active steering intervention and there is a need for a high

The vehicle position is evaluated through the use of a camera mounted between the windscreen and the rear-view mirror. Potential obstacles in the adjacent lane are monitored by radar mounted in the subject vehicle's radiator grill along with the camera image processing. Both sources of sensor data are needed since this is an active steering intervention and there is a need for a high level of confidence before initiating an active steering intervention to prevent loss of consumer confidence in the system. Volvo experts are still assessing which degrees of steering wheel intervention are relevant and the exact speed range within which it can operate. Responsibility for the safe operation of the vehicle remains with the driver; however, the vehicle may take action without driver input.

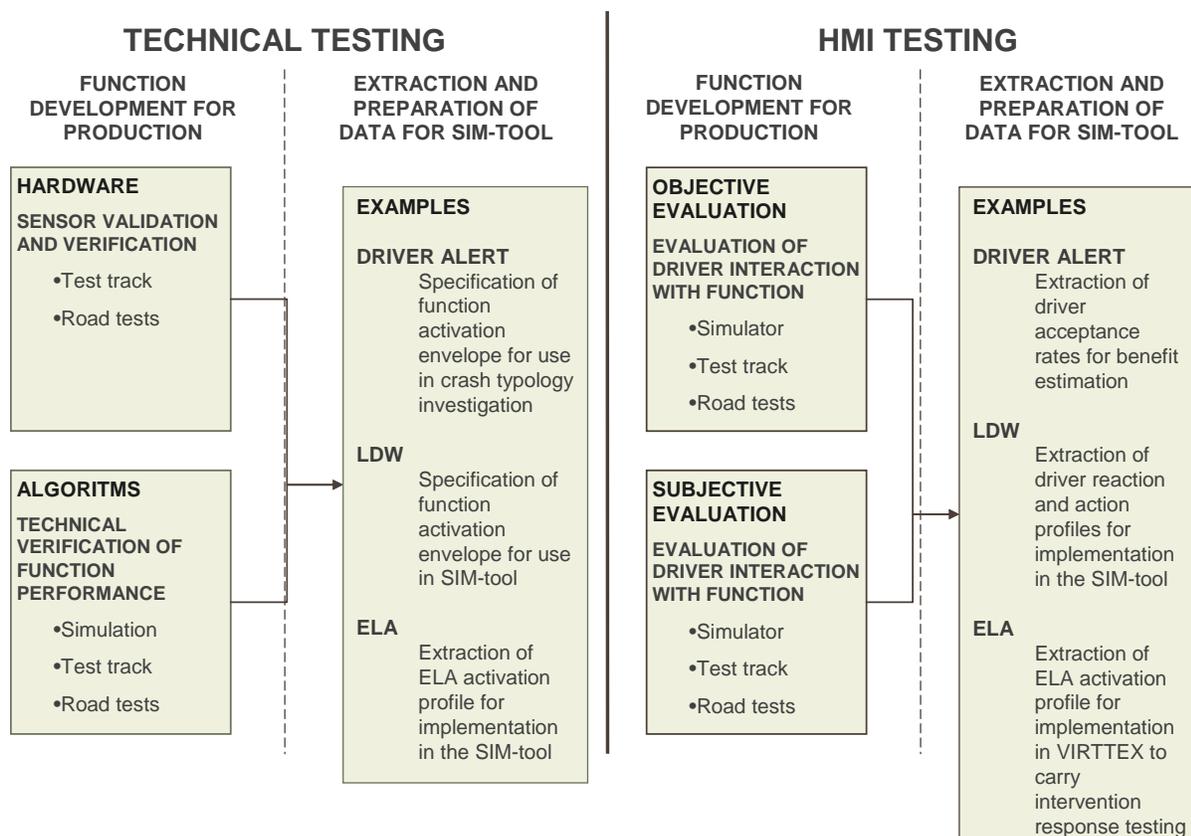
As in the case of the DAC and LDW technologies, ELA functionality depends on the visibility and quality of the road markings. ELA also depends on the quality of the radar returns. These technologies supplement but do not replace the driver's responsibility to keep attention to the roadway and driving task.

### ***3.3 Task 3: Develop Objective Tests for Predicting Potential Safety Benefits***

Objective testing consists of engineering testing of the vehicle and its safety technologies (technical testing), as well as controlled tests involving driver interaction (HMI testing) with or without the safety technologies active. The data from objective tests is not used directly in the safety benefits calculation, but is used to establish parameter values in a simulation model. The technical tests are used to set model parameters and model vehicle system performance. HMI tests are used to establish parameter values in the simulation model of driver performance. In the HMI tests, there is a great deal of variability in performance, so the model will attempt to capture the range of driving behaviors observed in HMI testing rather than just specific values in single recorded events. There are two parallel processes continually ongoing for the technical and HMI testing. One is the testing being performed within the function development, and the other is the extraction and/or preparation of data for use in the SIM tool. This is illustrated in Figure 10.

Testing covers both vehicle tests (on road and track) as well as simulator tests. Each is necessary to provide input data to the SIM tool. Objective tests have been developed to validate the performance of the suite of vehicle technologies being used in the SIM tool. The tests were structured to assess the potential impact of these technologies individually to characterize driver interactions with the technologies and to establish parameter ranges for the driver responses in the SIM tool.

## OBJECTIVE TESTING



**Figure 10. Objective testing of safety technologies**

Figures 2(a) and 2(b) show conceptually how the objective test data will be used in the development of the SIM tool. Figure 2(b) suggests that an “all-inclusive” set of tests is fundamentally not possible given the wide range of crash circumstances and vehicle and driver characteristics. What is feasible is assessment of a set of probabilistic scenarios that can be used to describe the range of likely responses from drivers and vehicles. The intent is to fix the parametric ranges and to validate the operation of the model, qualitatively and quantitatively. Qualitatively, the expectation is that the model would output plausible driver behaviors for a set of scenarios. From a quantitative standpoint, the expectation is that the model would accurately predict the vehicle states after an attempted driver correction, if the correction and the initial states are adequately characterized.

As indicated earlier, driver response to a DAC warning will be influenced by a number of factors whose effects are not well understood. Driver clinics conducted to date indicate a high level of driver acceptance and consumer demand for DAC. Participants in these clinics indicate that they would like a warning when in danger of falling asleep at the wheel. However, this data only provides a preliminary estimate of the required objective evaluation, and the real-world

performance and driver acceptance over time remains to be determined in future studies that are beyond the scope of the current ACAT program.

The LDW and the ELA technologies have a more direct and immediate impact on the likelihood of a lane or road departure crash in that they directly warn or intercede in the case of lane departure crash sequences. Testing for LDW will focus on whether or not the driver makes a corrective steering/braking input to the vehicle and the responses are generally more quantifiable than for DAC. ELA is an active-intervention type system and responses are quantifiable in terms of whether (a) the intervention was warranted, and (b) whether the vehicle orientation after the ELA intervention resulted in the vehicle staying in its lane. It is essential that all three technologies be “accurate” in their capability to assess the conflict situation since false alerts tend to reduce driver confidence in systems, and may cause drivers to ignore or disable the systems.

### 3.3.1 Driver Alert Control Testing

DAC is intended to help the driver in the pre-conflict phase of a crash sequence. The results of the technical tests are used to directly develop an estimate of the DAC benefit.. The resulting benefit estimate is used by the SIM tool to address the pre-conflict phase. As Figure 11 indicates, there are several DAC technical performance factors that influence the outcome of a benefit estimate.

- True positive performance (i.e., the system predicts drowsiness when the driver is, in fact, drowsy) and false negative performance (i.e., the system does not predict drowsiness when the driver is drowsy) is suitable to test on a test track. The result has a direct link to the benefit of the system.
- The estimate of system availability has to be based on a representative sample of road and environmental conditions. System availability has a direct impact on the DAC benefit estimate.
- False positive performance (i.e., the system predicts drowsiness when the driver is, in fact, not drowsy) is suitable to test on different public roads during different environment conditions. The result should be used as an input to discussion on driver acceptance and compliance.

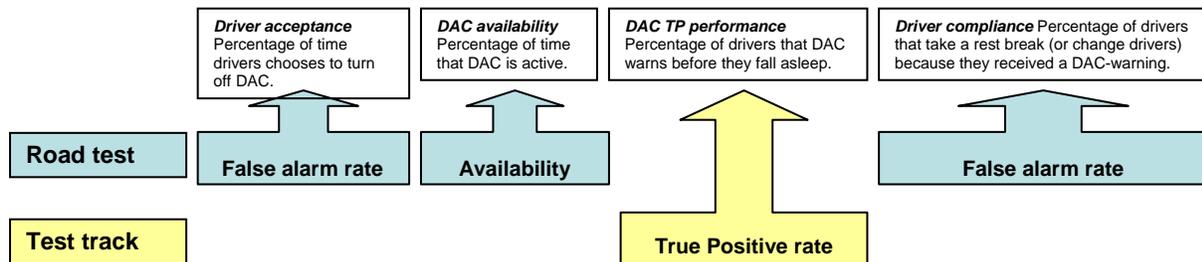


Figure 11. Factors that affect DAC effectiveness

### 3.3.2 Lane Departure Warning Testing

LDW potential benefits will be realized in the conflict phase in the crash sequence. In this phase the SIM tool uses the system performance of the actual LDW system to estimate the preliminary safety benefit. There are several technical performance factors for LDW that will be used in conducting the benefit analysis as illustrated in Figure 12.

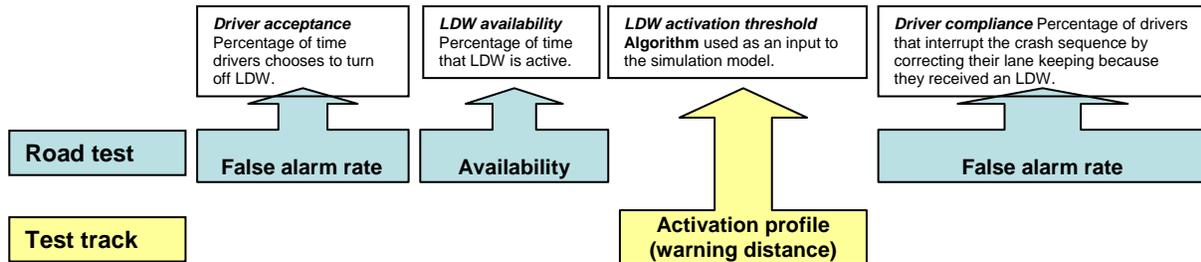


Figure 12. Factors that affect LDW effectiveness

In general:

- True positive and false negative system performance is suitable to test on a test track. The result is used as an input to the simulation model.
- LDW availability (percentage of driving time where the system is able to recognize the lane markings and actively function) has to be tested on different roads during different environment conditions. This result has a direct impact on the estimated benefit of the system.
- False positive performance also has to be tested on different roads during different environment conditions. The result should be used as an input in evaluating the impact of driver acceptance and the nature of driver compliance with the system warning.

### 3.3.3 Emergency Lane Assist Testing

ELA works in the conflict and imminent-crash phases of the crash sequence. In these phases the SIM tool uses the system performance of the ELA feature to estimate the preliminary safety benefit. There are several technical performance factors for ELA that will be used in conducting the benefit analysis as shown in Figure 13.

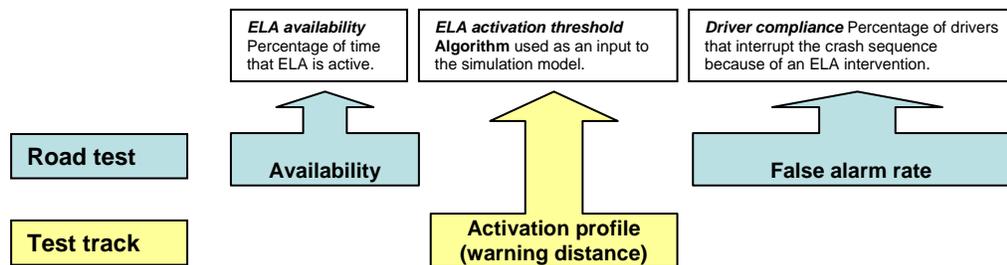


Figure 13. Factors that affect ELA effectiveness

In general:

- True positive performance is suitable to test on a test track. The result is used as an input to the simulation model.
- The availability of the system has to be tested on a representative sample of roads during a variety of environmental conditions. This result has a direct impact on the benefit of the system.
- False positive performance also has to be tested on a representative sample of roads during a variety of environmental conditions. The result should be used as an input in evaluating the impact of driver acceptance and the nature of driver compliance with the system warning.

## **4.0 SUMMARY OF FIRST YEAR MILESTONES AND KEY FUTURE ACTIVITIES**

The first year of this ACAT project was both challenging and rewarding. The project has been largely successful in completing several key elements that are critical to the development of the SIM tool and the completion of this research activity. The activities in the first year will provide a solid foundation to support the remaining research tasks relating to SIM tool development, testing and benefits estimation.

The inputs to the SIM tool were defined, the specifications of the technologies were completed and the technical tests were selected. Crash databases were reviewed and relevant crashes were selected. These crashes were then analyzed to extract detailed information that is being used to develop driving scenarios for the SIM tool. A detailed assessment of relevant crash cases from the priority safety areas was used for enhanced understanding in relation to the candidate safety technologies from Volvo. These technologies are the DAC, LDW, and the ELA.

The estimation of safety benefits for active safety technologies is a challenging problem, especially when there is only a very limited deployment of those technologies in the field, and where no large-scale field operational test has been conducted. The potential benefits for such a benefits estimation methodology are very large – to be able to evaluate system operational performance in the absence of field data, and without having to wait for crash statistics to accumulate over several years. While it is too much to expect that highly accurate predictions of crash or injury reductions can be made given the current state of knowledge about drivers and the driving task (especially when there are inattentive, distracted, or drowsy drivers), the progress made to date in this work suggests that the basic technical problems can be overcome, and trend comparisons of the performance of different safety technologies can be made.

Even with a sound basic analysis method, large databases, and a representative SIM tool, questions remain regarding driver compliance to the system alerts and the warnings offered by the technologies. The long term effects involving driver behavior adaptation with the new technologies are also unknown, including changed driver behavior resulting from unintended driver reliance on the system. As these technologies are supplements not intended to supplant

driver responsibility, alertness, and judgment, over-reliance may have a potential negative effect. This means that the current project will not answer all questions related to safety benefit analysis, but will define an approach capable of making an initial estimate of the benefit, subject to the limitations described above.

#### **4.1 *First-Year Milestones***

The key milestones for the first year of the Volvo-Ford-UMTRI project are as follows:

- The underlying architecture of the SIM tool was formulated and reviewed with the team and with NHTSA during the regular quarterly briefings.
- A preliminary driver model was formulated in terms of a sequence of time-dependent processes associated with both driving and non-driving activities.
- Sources of data were identified for inputs to the SIM tool and for developing driving scenarios.
- In-depth analysis of crash data from NASS was carried out and detailed information regarding the crash conditions was extracted for developing the driving scenarios.
- The priority safety areas were identified and mapped to the countermeasure technologies.
- Outstanding requirements of the computational model were reviewed.
- Test procedures for objective testing (technical and HMI) were defined addressing the DAC, LDW, and ELA technologies.

#### **4.2 *Key Activities for 2008***

Section 3.1 contains detail on activities pertaining to the SIM tool development (Task 1). In addition, the focus of the Volvo-Ford-UMTRI team will be on completing the remaining Task 4 objective tests as specified in Task 3. The SIM tool developed under Task 1 will be exercised, updated and refined to reflect the additional data from Tasks 2 and 4. Based on this updated SIM tool, the benefits estimates for each of the safety technologies will be developed as part of Task 5.

## 5.0 REFERENCES

1. Najm, W., Koopman, J., Boyle, L., & Smith D. (2002). *Development of Test Scenarios for Off-road Crash Countermeasures Based on Crash Statistics*, Report No. DOT HS 809 505. Washington, DC: National Highway Traffic Safety Administration.
2. Najm, W., Sen, B., Smith, J. D., and Campbell, B. N. (2003). *Analysis of Light Vehicle Crashes and Pre-Crash Scenarios Based on the 2000 General Estimates System. Contract No. DOT-VNTSC-NHTSA-02-04*. Report No. HS 809 573. Washington, DC: National Highway Traffic Safety Administration.
3. Barr, L., Najm, W., & Smith J., (1999). *Crash Problem Definition for the Intelligent Vehicle Initiative*. Project Memorandum DOT-VNTSC-HW00Q-PM-00-01. Washington, DC: National Highway Traffic Safety Administration.
4. Pomerleau, D., Jochem, T., Thorpe, C., Batavia, P., Pape, D., Hadden, J. et al. (1999). *Run-Off-Road Collision Avoidance Using IVHS Countermeasures* Report No. DOT HS 809 170. Washington, DC: National Highway Traffic Safety Administration.
5. LeBlanc, D., Sayer, J., Winkler, C., Bogard, S., Devonshire, J., Mefford, M., Hagan, M., Bareket, Z., Goodsell, R., & Gordon, T. (2006). *Road Departure Crash Warning System (RDCW) Field Operational Test Final report*, UMTRI report 2006-9-1. Ann Arbor, MI: University of Michigan.
6. Horne, J. A., & Reyner, L. A. (1995). *Sleep Related Vehicle Accidents*, British Medical Journal, Vol. 310, No. 6979, pp.565-567.
7. Najm, W., Mironer, M., Koziol, J., Wang, J. S., & Knipling, R. R. (1995). *Synthesis Report: Examination of Target Vehicular Crashes and Potential ITS Countermeasures*, Report No. DOT HS 808 263. Washington, DC: National Highway Traffic Safety Administration.
8. Larsson, J., & Anund, A. (2002). *Fatigue in traffic*, VTI Notat 34-2002. Swedish National Road and Transport Research Institute. (In Swedish.) Linköping, Sweden: Linköping University.
9. Campbell, B. N., Smith, J. D., & Najm, W. G. (2003). *Examination of Crash Contributing Factors using Crash Databases*. Report No. DOT HS 809 664 Washington, DC: National Highway Traffic Safety Administration.
10. Wang, J. S., Knipling, R. R., & Goodman, M. J. (1996). *The Role of Driver Inattention in Crashes; New Statistics From the 1995 Crashworthiness Data System*, 40<sup>th</sup> Annual Proceedings of the Association for the Advancement of Automotive Medicine, Vancouver, B.C.
11. Knipling, R. R., & Wang, J. S. (1995). *Revised Estimates of the U.S. Drowsy Driver Crash Problem Size Based on General Estimates System Case Review*, 49<sup>th</sup> Annual Proceedings of the Association for the Advancement of Automotive Medicine, Chicago, Illinois.

12. Ljung, M. (2002). *DREAM – Driving Reliability and Error Analysis Method*, Master of Science Thesis. Linköping, Sweden: Linköping University.
13. Sandin, J., & Ljung, M. (2007). *Understanding the causation of single-vehicle crashes: a methodology for in-depth on-scene multidisciplinary case studies*, International Journal of Vehicle Safety 2007 - Vol. 2, No.3 pp. 316 – 333.



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