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16. Abstract

The primary objective of the work described in this report was to determine the facility design characteristics for an advanced crash-avoidance technology test course including feasibility, estimated costs, and an implementation plan. In recent years, light- and heavy-vehicle manufacturers have introduced as OEM equipment technologies that can warn/mitigate/prevent crashes . These technologies have the potential to save lives, prevent injuries, and provide safety benefits to the public. Objective test procedures for these emerging technologies should be developed using test facilities, motion systems, and targets that can simulate a real-world environment and not interfere with vehicle sensing technologies. Effective evaluation of emerging technologies should be performed on facilities where researchers can safely and efficiently develop and conduct tests for light and heavy vehicles. These facilities would allow for research activities and unbiased assessment of advanced vehicle technologies. The content of this report was developed through a review of literature relating to vehicle crash statistics, existing and emerging test procedures for advanced crash-avoidance technology, and through a review of tests performed using existing facilities. The resulting test course includes prototypes for straight parallel lanes, intersecting lanes, and curved parallel lanes.

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List of Acronyms

ACAT	Advanced Crash Avoidance Technology
CICAS-V	Cooperative Intersection Collision Avoidance System for Violation
DRI	Dynamics Research Institute, Inc.
DSRC	dedicated short-range communication
FYL	functional years lost
GPS	global positioning system
GES	General Estimate System
IVBSS	Integrated Vehicle Based Safety System
IIHS VRC	Insurance Institute for Highway Safety Vehicle Research Center
LDW	lane departure warning
NASS-CDS	National Automotive Sampling System Crashworthiness Data System
NASS-GES	National Automotive Sampling System General Estimates System
SPaT	signal phase and timing
VDA	Vehicle Dynamics Area
VTTI	Virginia Tech Transportation Institute
V2V	vehicle-to-vehicle
V2I	vehicle-to-infrastructure

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Executive Summary

In recent years, light- and heavy-vehicle manufacturers have introduced technologies that can warn/mitigate/prevent crashes as original equipment (OE) on their vehicles. These technologies have the potential to save lives, prevent injuries, and provide safety benefits to the public. Objective test procedures for these emerging technologies should be developed using test facilities, motion systems, and targets that are able to simulate a real-world environment and not interfere with vehicle sensing technologies. Assessing advanced crash-avoidance technology (ACAT) addresses some fundamental research questions:

1. Does the technology provide the vehicle operator with adequate warning?
2. How do typical vehicle operators respond to such warnings?
3. Can vehicle systems intervene effectively if the vehicle operator fails to do so?

Vehicle road-test facilities have historically been designed for multiple purposes and simultaneous uses. Pre-crash scenario testing can use multiple vehicles orchestrated in staged events at a specific places on the facility with the timing and the position of each vehicle being critical to the success of the test. Consideration must be given for unexpected vehicle events to ensure the safety of test team members as well as test participants who may be recruited for naturalistic type studies. A cursory review of existing facilities revealed that some capability and current testing of ACAT exists, but the following problem statement emphasizes some potential future enhancements for the testing and evaluation of ACAT:

> *ACAT facilities need to allow researchers to* ***safely and efficiently develop and conduct tests*** *for light vehicles* ***and heavy vehicles,*** *which* ***support research activities*** *and* ***unbiased assessments*** *related to* ***advanced crash-avoidance technology****.*

The testing needs for the facilities are highlighted by the bolded passages in the problem statement and suggested corresponding facility characteristics are offered in Table 5.

A number of studies have been directed at classifying light-vehicle and heavy-vehicle accidents into pre-crash scenarios. Likewise, a body of work exists for the development of objective test procedures for off-road crashes, for intersection collision scenarios, and for situations where integrated vehicle-based safety systems (IVBSS) would likely be of help.

A review of the literature and inspections of existing test capabilities suggest that four distinct test course sections or event areas will accommodate a majority of the pre-crash scenarios in order to assess ACAT using objective test procedures. The test course sections consist of straight parallel lanes, curved parallel lanes (two different curve radii), and intersecting lanes (intersection). In order for the test course sections to be representative, the design of these sections should follow published guidelines for planning and constructing public roadways. The costs associated for building each section include some provisions for sub-base improvements, grading for roadways, the base course, and asphalt. The result is a proposed standardization of four event areas for testing a wide variety of ACAT.

1.0 INTRODUCTION

1.1. NHTSA STUDIES OF ADVANCED CRASH-AVOIDANCE TECHNOLOGY

NHTSA has been studying advanced technology for light- and heavy vehicles for several decades. In recent years, light- and heavy-vehicle manufacturers have introduced technologies that can warn/mitigate/prevent crashes as OE equipment on their vehicles. NHTSA recognizes that these technologies have the potential to save lives, prevent injuries, and provide safety benefit to the public. As the technologies become more mature and advanced, NHTSA may use test courses to develop objective test procedures for the emerging technologies, for the purpose of enhancing the understanding of these technologies.

In performing advanced crash-avoidance technology research, NHTSA uses a variety of test surfaces depending on the type of vehicle, test scenario, and test speed. A heavy vehicle generally needs to be tested on a different surface than a light vehicle. Forward crash-avoidance work is performed on multiple surfaces, sometimes depending on the use of surrogate vehicle targets or actual vehicles. Lane departure warning (LDW) research is often performed on yet another surface. As technology advances, intersections, pedestrian crosswalks, and other roadway configurations may be needed.

Advanced technologies will continue to become more typical and complex. Technologies such as vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications may create more varied crash-avoidance applications. A course or group of courses may be used to test these advanced technologies. Multiple lanes, communication with roadside furniture, and a facility that permits for a variety of test maneuvers at representative vehicle speeds will accommodate ACAT testing. The ability to control surrogate vehicle targets at roadway speeds will enhance the ability to create objective test procedures. Necessary targets may include representative automobiles, pedestrians, bicyclists, and motorcycles. Researchers will need to control the speed, acceleration, and position of these objects. The test facilities, motion systems, and targets should be able to simulate a real-world environment and not interfere with sensing technologies.

1.2. Crash-Imminent Scenarios

A number of studies have been directed at classifying light-vehicle and heavy-vehicle accidents into crash-imminent scenarios. Devising these typologies contributes to the development of technologies that warn, mitigate, or prevent crashes and helps in the development of objective test procedures and methods to evaluate such technologies. The study of pre-crash scenarios provides interested parties with information regarding vehicle dynamics, vehicle behaviors, and the critical events that precede the accident and also allows for benefit estimations that can help to prioritize scenarios. Information including vehicle types, road configuration, environmental factors, speed limits, actual or estimated vehicle speeds, crash frequency, functional years lost, and total economic costs all can be gleaned from these studies [1].

1.3. Facilities and Equipment used for Testing Crash-Imminent Scenarios

Vehicle road-test facilities have historically been designed for multiple purposes and simultaneous uses. The authors consider the potential shortcomings of these facilities to adequately evaluate the conditions of many pre-crash scenarios. These shortcomings typically relate to the complications of simultaneous and multiple uses, facility configuration, roadway load capacity, and speed ratings. Facilities used to test crash-imminent scenarios should subject sensing technologies to somewhat realistic roadway configurations and features.

Vehicle road tests have typically used sensors and data acquisition systems. In this regard, testing pre-crash scenarios is similar, but with a few additional needs. The staging of crash-imminent scenarios means that multiple vehicles must be orchestrated in maneuvers at a specific place on the facility with timing and the position of each vehicle being critical to the success of the test. GPS and data acquisition equipment with the ability to formulate and transmit information for vehicle speeds and positions are necessary. Surrogate vehicles are used in cases where safety must be observed, requiring specialized equipment to obtain surrogate speed and position for any given crash-imminent scenario.

1.4. Objectives

The objectives of this research were to:

1. Determine current and future facility characteristics needed to perform advanced crash-avoidance technology research.
2. Evaluate state of the art in facilities, test target systems, and apparatuses for performing crash-avoidance and mitigation research.
3. Determine the feasibility, estimated costs, and an implementation plan for executing the design basis developed from this analysis.

2.0 TESTING CONSIDERATIONS

2.1. Advanced Crash-Avoidance Technology

The seconds just prior to a vehicle crash represent an opportunity for advanced technologies to intervene by warning the driver and by possibly activating vehicle systems, both of which may lessen the crash severity or help to prevent the crash completely. Assessing this technology involves addressing some fundamental research questions:

1. Does the technology provide the vehicle operator with adequate warning?
2. How do typical vehicle operators respond to such warnings?
3. Can vehicle systems intervene effectively if the vehicle operator fails to do so?

These questions are multi-faceted and may be addressed through varying means of study, but objective test procedures are necessary to provide an even assessment across the many technologies intended to be viable active safety solutions. Impartial assessments of ACAT need to be performed on road surfaces that mimic real-world conditions to some degree, while offering repeatable and reproducible test results. ACAT can be grouped into three categories [2]:

1. Advanced Driver Assistance Systems,
2. Vehicle-to-X (V2X) Communication Systems, and
3. Autonomous Vehicle Systems.

With respect to ACAT, advanced driver assistance systems are self-directed countermeasures that use sensing technologies that reside on the vehicle to provide feedback to vehicle systems and to the driver. V2X systems use dedicated short-range communications at 5.9 GHz to transmit pertinent information between vehicles (V2V) and infrastructure (V2I) in proximity with each other. Autonomous Vehicle Systems are technologies that automate tasks typically performed by the driver. Examples may include self-highway driving, self-parking, platooning, and stop-and-go traffic assist. Since this report only considers ACAT, the basis of design for the test course sections do not consider many of the automated tasks that autonomous vehicle technologies may offer. The focus for the basis of design is limited to crash imminent situations and the respective driver/vehicle response to those crash imminent situations.

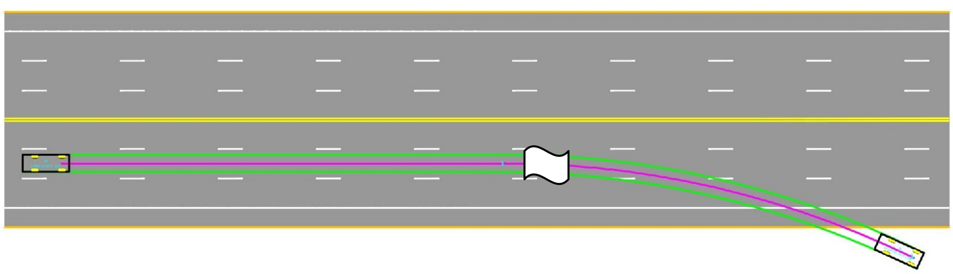
NHTSA along with the Research and Innovative Technology Administration published a V2V safety application research plan under the U.S. Department of Transportation Connected Vehicle Research Program [3]. The plan is specifically relevant in setting a direction toward the uses of V2V communications intended to address various crash scenarios. Test facilities could be capable of accommodating all three categories of ACAT.

2.2. Literature Review

2.2.1 Pre-Crash Scenario Typology for Crash-Avoidance Research

Najm, Smith, and Yanagisawa (2007) describe 37 crash-imminent scenarios drawn from the 2004 National Automotive Sampling System – General Estimate System [1]. The authors were able to describe 99.4 percent of all light vehicle crashes contained in the sample using 36 titles, and by including the remaining 0.6 percent in a category of "Other." The study did not examine accidents involving heavy vehicles. Societal costs were calculated from accident data and represented as functional years lost, total economic costs, and crash frequencies. The descriptions depict each scenario using circumstances contributing to the crash such as the first harmful event; the driving environment delineated by daylight, darkness, clear, or adverse conditions; and characterizations of the vehicle such as going straight. Figure 1 illustrates one such pre-crash scenario.

Figure 1 Control Loss Without Prior Vehicle Action



This particular scenario is described as follows:

> "*Vehicle is going straight in a rural area, in daylight, under adverse weather conditions, with a posted speed limit of 55 mph or more, and then loses control due to wet or slippery roads and runs off the road*."

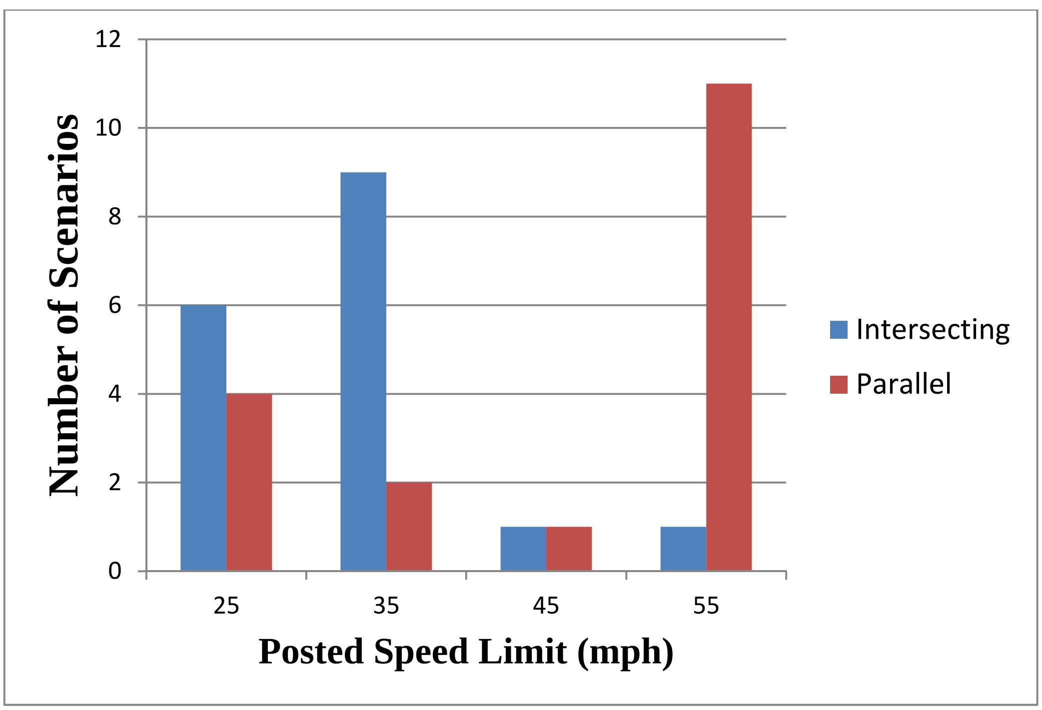
Vehicle action prior to the crash, environmental conditions, pavement conditions, and posted speed limits are given. The pre-crash scenario descriptors offer valuable insight that aids in the development of test procedures. The testing needs and facility characteristics for an ACAT Test Course might accommodate an array of test procedures derived from pre-crash scenarios. Parallel lanes and intersecting lanes account for 36 of the 37 pre-crash scenarios. Table 1 shows a fairly even distribution of the two facility configurations using functional years lost (FYL) for prioritization. FYL combines the years of life lost and the years of functional capacity lost [4]. All 37 pre-crash scenarios are listed in Appendix A.

Table 1 Functional Years Lost (FYL) Versus Facility Configurations

	Number of Facility Configurations	
FYL Rank	Parallel Lanes	Intersecting Lanes
1 – 12	6	6
1 – 24	12	12
1 – 36	19	17

The posted speed limits given in the 36 scenarios are illustrated in Figure 2 by facility configuration. As would be expected, the graph shows predominantly lower speeds for intersection situations than for parallel lane configurations.

Figure 2 Pre-Crash Scenario Posted Speeds by Facility Configuration



As previously stated, other studies have analyzed pre-crash scenarios. General Motors devised the 44-crashes typology using data from the 1991 General Estimates System crash database [4]. Likewise, U.S. DOT created a typology of crash scenarios using the National Accident Sampling System crash databases [5]. The 37 pre-crash scenarios used in the development of this study have been mapped previously to existing pre-crash typologies and have been shown both to overlap them as well as to identify deficiencies in the existing typologies [1]. Because the 37 pre-crash scenarios were devised from light vehicle accident data, the applicability to heavy vehicles for this report is assumed.

2.2.2 Crash Threats and Integrated Vehicle Based Safety Systems

Najm and Smith (2007) considered crash threats relative to integrated vehicle based safety systems (IVBSS) that warn motorists who are closing in on rear-end, lane change, run-off-road, and multiple-threat type crashes [6]. The research targeted crash-imminent scenarios from the 2003 NASS-GES data for light vehicles and heavy vehicles. The authors' purpose was to develop test scenarios for the various crash-imminent situations to aid in the examination of IVBSS. The work provides additional analysis of GES data incorporating heavy vehicles into the study. The authors delineated several individual test scenarios for each crash threat type using environmental factors, roadway configurations, and speed information from the databases. Their recommended test procedures use parallel lane configurations, one being straight and the other being curved, along with an intersecting lane configuration. Straight parallel and intersecting lanes are described as being level. The curved parallel lanes are characterized as sloped. Table 2 illustrates the test scenarios recommended as a result of the IVBSS study. The road configurations and speed ratings are consistent with the 36 pre-crash scenarios previously described for light vehicles.

Table 2 IVBSS Test Scenario Road Configurations, Vehicle Speeds, and Environmental Conditions

Scenario	Roadway Configuration	Vehicle Max Speed (mph)		Environmental Conditions
		Light Vehicle	Heavy Vehicle	
Rear-End (4 Test Scenarios)	Straight & Level	60	55	Daylight & Clear Weather
Lane Change (3 Test Scenarios)	Straight & Level	60	55	Daylight & Clear Weather
Lane Change (1 Test Scenarios)	Intersection & Level	40	35	Daylight & Clear Weather

Run-Off-Road (2 Test Scenarios)	Straight & Level	60	55	Daylight or Darkness & Clear Weather
Run-Off-Road (2 Test Scenarios)	Curve & Sloped	60	55	Daylight or Darkness & Clear or Adverse Weather
Run-Off-Road (1 Test Scenarios)	Intersection & Level	45	40	Daylight & Clear Weather

2.2.3 Off-Roadway Scenarios

Najm, Koopmann, Boyle, and Smith (2002) discuss off-roadway crash scenarios based on data from 1988 to NASS-GES and from 1993 NASS-CDS [7]. These crashes were cataloged as rear-end, off-roadway, lane change, crossing paths, driver impairment, reduced visibility, and vehicle instability crashes. Using the physical setting, vehicle speed, and environmental conditions, the authors described eight crash-imminent hazard scenarios for off-roadway crashes.

This research provides a wealth of information for a design basis of an ACAT test course. Physical setting is characterized by roadway type (freeway/non-freeway), land use (urban/rural), and the relation to a junction along with posted speed and number of travel lanes. Vehicle speed and environmental conditions were examined and identified as contributing factors for some of the off-roadway crashes. The authors were able to determine if vehicle speed was a contributing factor using the Speed Related variable in the 1988 GES. Environmental conditions were grouped between day/dark, clear/dry, and adverse/slippery. Table 3 lists some of the pertinent information that may contribute to a design basis for an ACAT test course.

Table 3 Off-Roadway Crash Scenarios – Physical Setting

Scenario	Roadway Type	Relation to Junction	Posted Speed (mph)	Number of Travel Lanes
Going straight and departed road edge	Undivided/Non-Freeway	Non-Junction	25 – 65	2
Going straight and lost control	Undivided/Non-Freeway	Non-Junction	25 – 65	2
Negotiating a curve and lost control	Undivided/Non-Freeway	Non-Junction	35 – 65	2

Negotiating a curve and departed road edge	Undivided/Non-Freeway	Non-Junction	35 - 65	2
Going straight and lost control	Freeway	Non-Junction	55 - 65	2
Going straight and departed road edge	Freeway	Non-Junction	55 - 65	2
Turning and departed road edge	Undivided/Non-Freeway	Intersection	25 - 35	2
Turning and lost control	Undivided/Non-Freeway	Intersection	25 - 35	2

2.2.4 Cooperative Intersection Collision Avoidance System for Violations

Brewer, Koopmann, and Najm (2011) conducted objective testing of Cooperative Intersection Collision Avoidance Systems for Violations [8]. CICAS-V enables communication between instrumented vehicles and intersection traffic control devices equipped with Signal Phase and Timing equipment, or instrumented roadside hardware such as stop signs. The study offers several objective test scenarios detailing vehicle speeds and corresponding minimum and maximum warning distances needed to allow the driver of the vehicle to bring it safely to a stop. Table 4 provides the scenario types, vehicle speeds, and the maximum nominal warning distances from the study.

Table 4 CICAS-V Objective Test Parameters

Scenario	**Nominal Speed (mph)**	**Max Nominal Warning Distance (m)**
Red Light Approaches at Various Speeds	25, 35, 55	102.9
Stop Sign Approaches at Various Speeds	25, 35, 55	113.6
Edge of Approach Test (Warning)*	35	38.8
Edge of Approach Test (Nuisance)		
Late Lane Shift Test (Warning)**		

Late Lane Shift Test (Nuisance)		
Multiple Intersections - 300 m Radius (Warning)[***]	35	40.2
Multiple Intersections - 300 m Radius (Nuisance)[***]		
Dynamic Signal Change to Yellow (Too Late to Warn)	35	38.8
Dynamic Signal Change to Red (Sufficient to Warn)		
Dynamic Signal Change to Green (No Warning)		
SPaT Reflection and Reception	35	41.7

[*] Edge of approach is where the vehicle is near the approach lane
[**] Late lane shift is where the vehicle shifts dramatically for one lane to another
[***] Partner intersections may be simulated with signal phase and timing equipment

2.3 Existing Facilities

A review of existing facilities was conducted to assess current capability for ACAT testing. The authors of this study visited the Virginia Smart Road located in Blacksburg, Virginia, and discussed its capabilities with staff from the Virginia Tech Transportation Institute. A visit was also made to the Vehicle Research Center of the Insurance Institute for Highway Safety. Staff at the VRC shared their own design concepts for a course to test ACAT. The authors' first-hand knowledge of the facilities at the Transportation Research Center, Inc., and Dynamics Research, Inc., was also used in assessing current capabilities to test ACAT.

While all these facilities have capability and are currently testing ACAT, the following are some common themes emerging from the inspections:

- Testing capabilities can be constrained by safety needs.
- Testing efficiency can be confined to multipurpose test facilities.
- Testing of heavy vehicles can be limited due to the size and load bearing capacity of the test facilities.
- Conducting research and developing repeatable objective test procedures can be challenging where variations from test surface to test surface exist.

- Testing of real-world crash scenarios can be limited by all of the above.

2.3.2 Safe and Efficient Conduct of Testing

The host vehicle in ACAT testing generally refers to the vehicle equipped with the safety system being examined. A remote vehicle serves as a "target" for the host vehicle to detect in many of the scenarios. Sometimes the remote vehicle is represented by a surrogate vehicle designed specifically for safety should an impact occur. These surrogate vehicles are generally lightweight. Some are designed to be impacted with little consequence, and others attempt to either lessen the severity of or avoid contact altogether with the host vehicle. While problems still exist in surrogate vehicle solutions, they remain an important consideration for use in testing ACAT. The safety in the delivery of surrogate vehicle systems can be confounded by mixed testing occurring simultaneously and in proximity on a test facility. The most common resolution is either procurement of exclusive time on the facility or an altering of the test procedures to accommodate companion traffic.

Consideration must be given for unexpected vehicle events to ensure the safety of test team members as well as test participants who may be recruited for naturalistic-type studies. An ACAT test course should include safety features such as escape lanes, run-off areas, and vehicle-friendly roadside hardware. Vehicle road test beds have historically been designed for multipurpose testing and simultaneous uses. For example, the Vehicle Dynamics Area managed by TRC, is a multipurpose facility for dynamic testing, durability testing, brake testing, performance testing, product demonstrations, and driver training.

The ability to install fixtures and equipment can be problematic in an environment designed to accommodate simultaneous testing of various types. Lane markings suitable for testing a lane departure warning system may complicate other types of tests, which would mean repeated installation and removal of the striping. Installation of traffic lights or signs can also be a nuisance to other modes of testing and may be complicated by lack of power to the facility, prohibitions on facility modifications, or safety considerations.

2.3.3 Heavy Vehicle Accommodations

A common problem with existing test course availability is the inability to accommodate heavy vehicles. Heavy vehicles use more robust construction for surface loading and need more room to accelerate and to achieve steady test speeds. Vehicle weight should be taken into consideration in the design needs of a test course. The length needed for acceleration runs, stabilization, and recovery zones that accommodate heavy vehicle testing well exceed those of light vehicles, but were not considerations in the design of some existing testing facilities. In cases where facilities are designed for heavy vehicle testing, other shortcomings may complicate ACAT testing like facility configuration, speed ratings, and mixed use. A test course designed for heavy vehicles will accommodate light vehicles.

2.3.4 Research Activities and Unbiased Assessments of Advanced Crash-Avoidance Technology

Real-world accident data propels research activities and the design of objective test procedures in ACAT performance assessments. The facilities and test procedures need to provide for unbiased assessments of the technology, vehicle systems, and vehicle operators. Currently, ACAT test procedures are adapted to suit the facilities available for testing. This can limit a researcher's ability to fully evaluate the technology as it would perform in real-world crash-imminent situations.

Environmental conditions are often described in pre-crash scenarios using adjectives like daylight, dark, clear, dry, and adverse. Unfortunately, little to no consensus exists regarding quantitative definitions of these terms. The VTTI Smart Road has advanced capabilities to simulate adverse weather in terms of rain, snow, and fog. The facility also boasts a variable lighting test bed for the examination of highway lighting practices. Research in this area is important since environmental conditions may influence the performance of ACAT. An ACAT test course design may be augmented as consensus develops regarding quantifiable environmental conditions. Environmental and lighting conditions were not considered in the design basis of the ACAT test course in this report, because of the lack of agreement regarding standardization of the conditions.

Facilities used in testing ACAT should subject sensing technologies to somewhat realistic crash-imminent scenarios. Facilities should be representative of public roadways and test results should be repeatable and reproducible. To this end, the authors consider facility characteristics based on common roadway design standards. This report advocates an outdoor test facility because most roadways are not constructed with an overhead cover. The influences a shelter over an ACAT test course might have are not well known, so the authors leave this issue for future consideration.

2.4 Summary

Review of literature and inspection of existing test capabilities suggest that four distinct test course sections or event areas are necessary to capture the majority of the pre-crash scenarios and test procedures previously cited. The proposed ACAT test course sections consist of straight parallel lanes, curved parallel lanes (two different curve radii), and intersecting lanes (intersection). The nature of the testing that will be performed in the suggested event areas might employ restrictions on simultaneous use of the sections or necessitate the pairing of compatible testing.

The following problem statement assists in developing the facility characteristics for the ACAT test course:

> *ACAT facilities need to allow researchers to* ***safely and efficiently develop and conduct tests*** *for light vehicles* ***and heavy vehicles,*** *which* ***support research activities*** *and* ***unbiased assessments*** *related to* ***advanced crash-avoidance technology****.*

The testing needs for the facilities are highlighted by the bolded passages in the problem statement and corresponding facility attributes are offered in Table 5.

Table 5 Testing Needs and Facility Characteristics

TESTING NEEDS	FACILITY ATTRIBUTES
Safe and Efficient Testing	• Escape lanes, run-off areas, recovery space • Installation of vehicle friendly roadside hardware/props • Lane markings
Heavy Vehicle Capability	• Load ratings • Acceleration and return routes
Support Research Activities and Unbiased Assessments of Advanced Crash-Avoidance Technology	• Representative roadway configurations • Speed ratings • Compatible with the use of surrogates vehicles and pedestrians • Single to multiple vehicle traffic patterns • Staging of pre-crash scenarios • Compatible with the use of global positioning systems and wireless communications

3 BASIS OF DESIGN

3.2 Facility Characteristics

3.2.2 Safe and Efficient Testing

The four test course sections are planned for six lanes of travel to provide paths of escape for test drivers performing pre-crash maneuvers. Each section can be configured with a combination of lane widths of 3.7 or 4.3 meters. The roadway cross-slope for the straight and intersecting sections is 2 percent maximum. The curved-section roadway cross-slope is specified to be 4 percent maximum. The paved shoulder width is 2.4 meters with unpaved extensions of 6.7 meters. The paved shoulders and extended clear zones have a maximum cross-slope of 4 percent for the straight and intersection sections. The curved sections have maximum high side and low side cross-slopes of 3 percent and 4 percent, respectively.

For each test course section, with the exception of the intersection, it is recommended that one-half of the test area roadway include only the outside edge of pavement striping to allow for temporary striping configurations. The intersection section prototype (Figure 6) is shown with crosswalks, directional markings, and simple lane markings all for reference only in order to highlight that almost any combination of representative patterns can be used based on testing needs.

3.2.3 Heavy Vehicle Accommodations

ACAT in heavy vehicles have the potential for a timely positive influence on traffic safety due to the compatibility of aftermarket technology with current heavy vehicle systems. In order for the ACAT test course to accommodate heavy vehicles, the course must facilitate acceleration of the vehicle to test speed, provide room for stabilization of speed, and provide an area for the test event. As previously noted, post-event recovery room is also needed. An ACAT test course sized for heavy vehicles would easily accommodate light vehicles. The course sections specified in this report represent the event areas for ACAT testing. Acceleration, stabilization, and recovery are briefly addressed later in the discussion of the test course layout in section 3.2.4. A suggested load rating for each ACAT section and the respective approaches is 97,000 lbs.

3.2.4 Characteristics of Research Activities and Unbiased Assessments for Advanced Crash-Avoidance Technology

In order to conduct research and to perform objective testing, the course sections need to be representative of actual roadway configurations. While it is impossible to simulate every roadway condition, using standards for roadway construction assists in creating representative test course sections. Design speeds, cross-slopes, grades, and superelevations should meet highway design guidelines. Surface characteristics should support the use of surrogate vehicles and surrogate pedestrians by not having significant imperfections or transitions. The course should be large enough to allow several vehicles equipped with advanced technology to operate in close proximity.

In staging of pre-crash scenarios, the area where the test course sections are located should be compatible with the use of GPS and wireless communications. While technologies should be able to continue operating effectively when signals are momentarily lost, this condition can be simulated for evaluation purposes. The availability of global positioning and wireless signals should be present at all locations of testing.

3.3 ACAT Test Course

3.3.2 Straight Parallel Lanes

Table 6 shows the highest priority related pre-crash scenarios using the FYL rank for the standing.

Table 6 Pre-Crash Scenarios Requiring Straight Parallel Lanes

Pre-Crash Scenario	FYL Rank	Posted Speed (mph)
Control Loss Without Prior Vehicle Action	1	55
Road Edge Departure Without Prior Vehicle Maneuver	2	55
Vehicle(s) Not Making a Maneuver – Opposite Direction	4	55
Pedestrian Crash Without Prior Vehicle Maneuver	6	55
Lead Vehicle Decelerating	11	55
Vehicle(s) Changing Lanes – Same Direction	13	55
Vehicle(s) Drifting – Same Direction	17	55
Evasive Action Without Prior Vehicle Maneuver	18	35
Vehicle(s) Making a Maneuver – Opposite Direction	20	55
Vehicle Failure	22	ND
Animal Crash Without Prior Vehicle Maneuver	24	55

These crash-imminent scenarios use straight parallel lanes for the research and testing of ACAT countermeasures. Likewise, nine of the objective test procedures for the IVBSS targeted scenarios discussed in Section 2 recommend straight and level roads for conducting assessments [6]. Specifically, four rear-end, three lane-change, and two run-off-road test scenarios are depicted as being on straight and level roads. Table 7 shows the specific scenarios along with speeds for light- and heavy vehicles.

Table 7 IVBSS Straight Road Scenario Configurations and Vehicle Speeds

Scenario	Roadway Configuration	Vehicle Max Speed mph (m/s)	
		Light Vehicle	Heavy Vehicle
Rear-End (4 Test Scenarios)	Straight & Level	60 (27)	55 (25)
Lane Change (3 Test Scenarios)	Straight & Level	60	55
Run-Off-Road (2 Test Scenarios)	Straight & Level	60	55

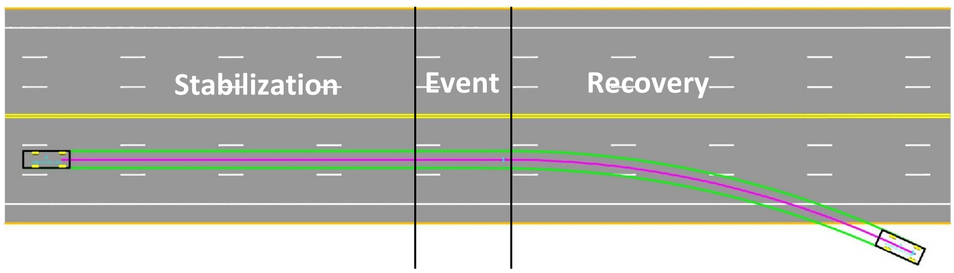
The off-road scenarios referred to in Section 2 describe a number of the scenarios being staged on undivided (non-freeway) or freeway-type roads at non-junction locations all occurring on parallel lanes of travel [7]. Table 8 lists these scenarios and the associated minimum and maximum posted speeds.

Table 8 Off-Roadway Crash Scenarios – Physical Setting

Scenario	Roadway Type	Posted Speed mph	Posted Speed m/s
Going straight and departed road edge	Undivided/Non-Freeway	25 - 65	11 – 29
Going straight and lost control	Undivided/Non-Freeway	25 - 65	11 – 29
Going straight and lost control	Freeway	55 - 65	25 - 29
Going straight and departed road edge	Freeway	55 - 65	25 - 29

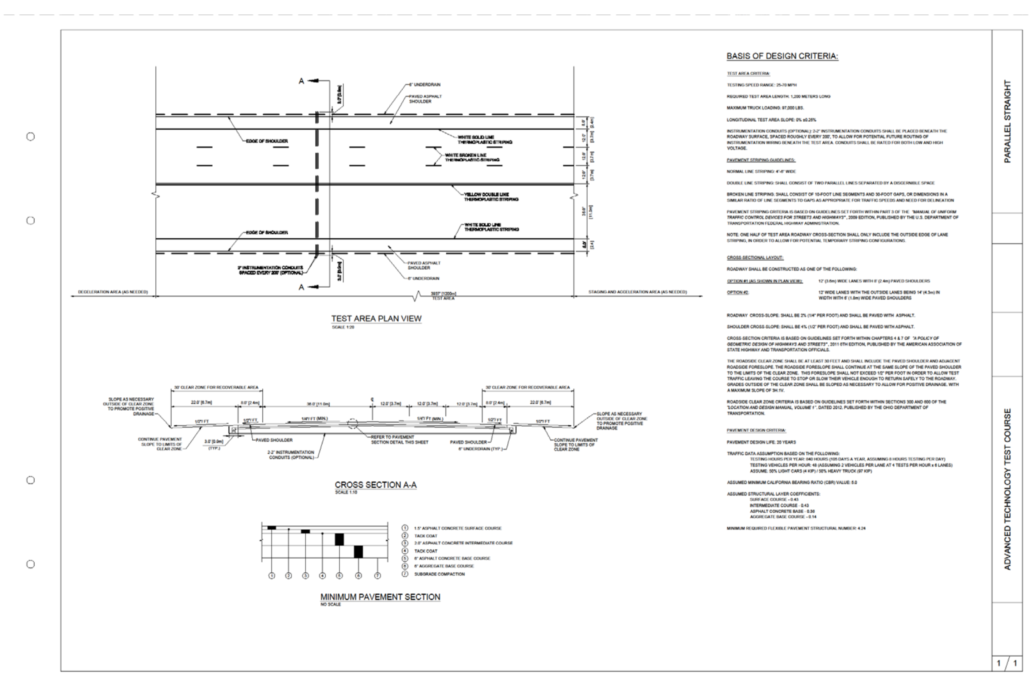
These studies suggest that straight parallel lane test course sections should be capable of accommodating light-vehicle or heavy-vehicle test speeds up to 65 mph (29 m/s). At a maximum speed of 65 mph (29 m/s), a 1,200 meter long section would support about 41 seconds of time to be split among the stabilization, event, and recovery phases of the test shown in Figure 3.

Figure 3 Straight Parallel Lanes



The drawing block for the straight parallel lane is shown in Figure 4. The 1,200 meter length provides adequate room for vehicle speed stabilization, the execution of a maneuver, and room to recover control of the vehicle. The roadway can be configured to simulate many roadway types, both freeway and non-freeway.

Figure 4 Drawing Block - Straight Parallel Lanes



Double click figure to zoom

3.3.3 Curved Parallel Lanes

While the majority of pre-crash scenarios discussed in Section 2 do not specifically address vehicles negotiating a curve; it stands to reason that technologies assisting vehicles traveling straight may also assist vehicles navigating curves. Systems such as lane keeping assist, forward collision warning, and blind spot detection should be functional on both curved and straight roadways. Two situations for the IVBSS targeted scenarios used curved roads for conducting assessments [6]. Table 9 shows the two scenarios, road configuration, and speeds for light and heavy vehicles.

Table 9 IVBSS Curved Road Scenario Configurations and Vehicle Speeds

Scenario	Roadway Configuration	Vehicle Max Speed mph (m/s)	
		Light Vehicle	Heavy Vehicle
Run-Off-Road (2 Test Scenarios)	Curve & Sloped	60 (27)	55 (25)

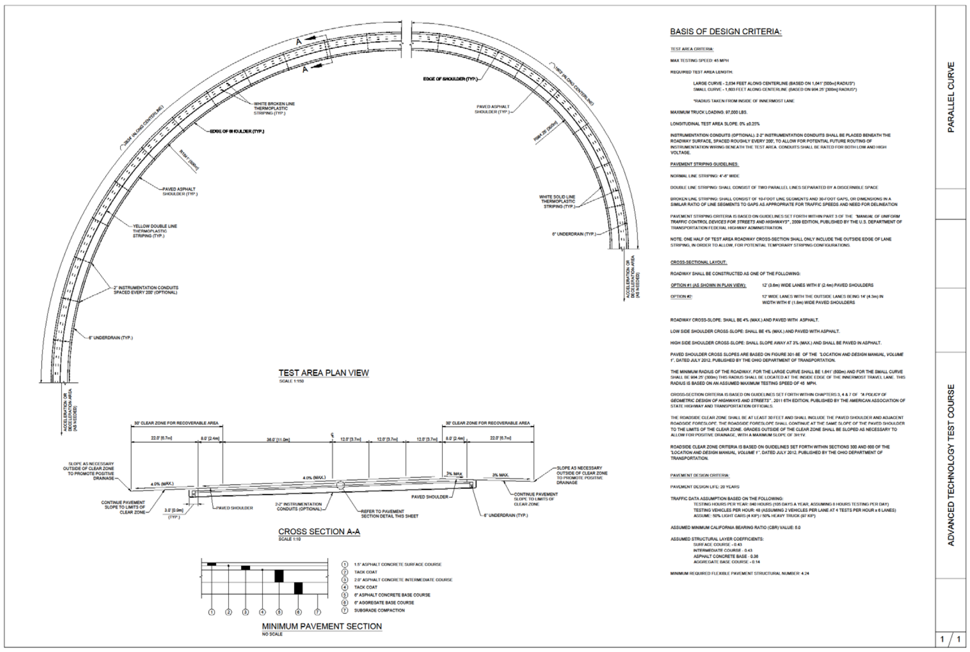
The off-road scenarios referred to in Section 2 include a scenario being staged on a curved road with a cross slope. Table 10 provides the physical setting for the off-roadway scenarios.

Table 10 Curved Road Off-Roadway Scenarios – Physical Setting

Scenario	Roadway Type	Relation to Junction	Posted Speed mph	Posted Speed m/s
Negotiating a curve and lost control	Undivided/Non-Freeway	Non-Junction	35 - 65	16 - 29
Negotiating a curve and departed road edge	Undivided/Non-Freeway	Non-Junction	35 - 65	16 - 29

These studies suggest that a curved parallel lane test course section be capable of accommodating a light-vehicle or heavy-vehicle speed range of 35 to 65 mph (16 – 29 m/s). Based on experience with emerging test procedures, the authors of this report recommend two different curve sections with radii of 300 and 500 meters, each with a design speed of 45 mph (20 m/s). This design is the result of trade-offs between test speed and curve geometry. The drawing block for the curved parallel lane are shown in Figure 5.

Figure 5 Drawing Block - Curved Parallel Lanes



Double click figure to open zoom

3.3.4 Intersecting Lanes

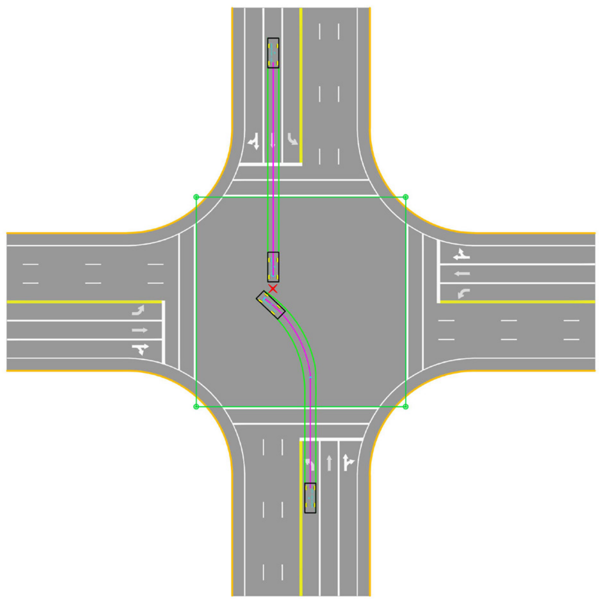
Table 11 shows the highest priority intersection related pre-crash scenarios using the FYL rank for the standing [1].

Table 11 Intersection Related Pre-Crash Scenarios (Perpendicular) Lanes

Pre-Crash Scenario	FYL Rank	Speed (mph)
Lead Vehicle Stopped	3	35
Straight Crossing Paths at Non-Signalized Junctions	5	25
Vehicle(s) Turning at Non-Signalized Junctions	7	35
Running Red Light	8	35
Left Turn Across Path From Opposite Directions at Signalized Junctions	9	35
Left Turn Across Path From Opposite Directions at Non-Signalized Junctions	10	55
Lead Vehicle Moving at Lower Constant Speed	12	45

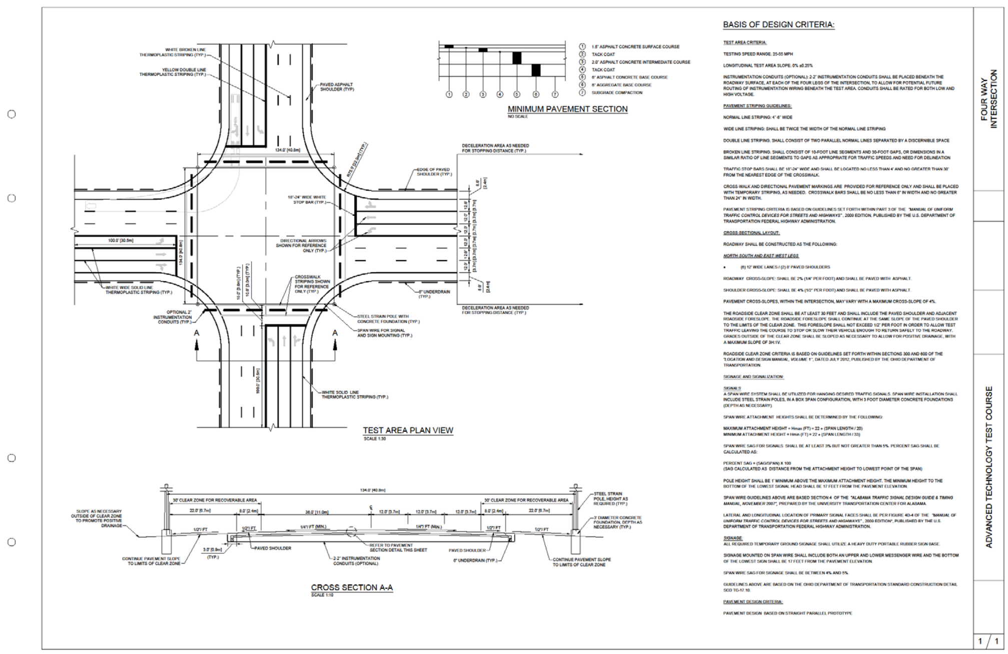
Likewise, the CICAS-V objective tests referenced in Section 2 use an intersection with features (crosswalks, etc.). These scenarios have the test vehicle approaching the intersection at various speeds up to 55 mph (25 m/s). Figure 6 is an illustration of the intersecting lanes with features (not to scale).

Figure 6 Intersecting (Perpendicular) Lanes With Features



The design speed for the intersection is based on test speeds between 25 and 55 mph (11 and 25 m/s). The intersection can be configured with or without a signal as needed for any given test. The signal system conceived uses span wire and steel strain poles for traffic lights and overhead signs. The span wire concept allows the lights and/or signs to be installed or removed depending on the conditions of the testing scenario. It also distances the steel span poles from the test section for the safety of test participants. The drawing block for the intersecting lanes with features is provided as Figure 7.

Figure 7 Drawing Block – Intersecting Lanes with Features



Double click figure to open zoom

3.3.5 Layout of ACAT Test Course

ACAT testing uses routes for accelerating the vehicle to test speed, an area for stabilization of the vehicle's speed, an event area to perform the test, room to recover the vehicle, and for efficiency reasons, routes to allow the vehicle to continue the test pattern. The test course sections previously described allow for the performance of the test maneuver and for the straight parallel lanes, stabilization and recovery of the vehicle is present in the design. Delivering the test vehicles to the test areas involves additional facilities for acceleration, recovery, and continuation of testing. There are a number of ways the test course sections could be integrated to provide a complete solution. Resources such as available real estate, funding, and testing priorities could dictate the test course layout used at any single site.

3.3.6 Construction Estimates

Because different locations will have different needs for preparation of a sub-base it is not within the scope of this report to fully specify or estimate the costs of preparing a sub-base. The estimates for construction of the ACAT test course provides for some sub-base improvements, grading for roadways, the base course, and asphalt. Table 12 shows the construction estimates for each section and Appendix B provides the detail for the estimates.

Table 12 Cost Estimates for ACAT Test Course

ACAT Test Course Section	Cost Estimate*
Straight Parallel Lanes	$ 4.2M
Curved Parallel Lanes (300 & 500 meter radii)	$ 4.5M
Intersecting Lanes	$ 1.0M
Grand Total	**$ 9.7M**

* Does not include costs for land acquisition

Some of the costs for construction may be reduced by eliminating optional items such as conduits placed every 200 feet. Most communications systems are wireless, rendering communication cables unnecessary. Power to the event areas is a relevant consideration, but not necessarily to the extent specified in these course sections. Likewise the number of lanes could be reduced to three in order to reduce the cost of each section. Six lanes provide optimal safety in conducting tests with multiple vehicles, and gives more flexibility with lane striping. The basis of design in this report represents ideal course sections, but obviously other factors may be considered in the contemplation of such facilities. Test section components may be evaluated for a specific needs and priorities.

4 CONCLUSIONS

To effectively test ACAT, test surfaces are used to develop and conduct tests for light vehicles and heavy vehicles. Information from the tests allows for research activities and unbiased assessments of ACAT. The construction of an ACAT test course should incorporate safety and efficiency in the design and accommodate heavy vehicles. The human driver interface systems used in ACAT are far more complex than safety systems of the generations past and will add a degree of complexity to maintaining safety during road course testing where non-experienced test participants are involved. Likewise, the difficulty of staging test scenarios has become greater than performing single vehicle maneuvers. The sections should be consistent with highway construction standards and allow for representative testing of applicable pre-crash scenarios capable of involving multiple vehicles.

Addressing the variety of potential roadside fixtures that may be needed for testing and research is beyond the scope of this report. However, the installation of roadside fixtures should consider the safety of test drivers and test participants. The intersection with features is specified with the placement of the steel strain poles outside the clear zone for a cable span signalization system. Temporary ground signage may use a heavy-duty rubberized sign base as another of many examples. The use of surrogate vehicle systems is safer for some ACAT testing. While this report initially set out to include an analysis of systems currently available, the rapidly changing surrogate vehicle design concepts and stages of readiness prohibit a meaningful analysis. GPS, DSRC, and other radio communication signals need to be available at all places on an ACAT test course, and that the course needs to be level and reasonably free of significant surface imperfections in the event areas.

The ACAT test course offered in this report is based on pre-crash scenarios as opposed to the rapidly changing technologies of ACAT. The authors believe that the application of the prototype sections into an ACAT course could provide the ability to make objective assessments and allow for enhanced research of emerging technologies.

5 REFERENCES

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[8] Brewer, J., Koopmann, J., & Najm, W. G. (2011, July). *System capability sssessment of cooperative intersection violations collision avoidance system for violations (CICAS-V)*. (Report No. DOT HS 809 505). Washington, DC: National Highway Traffic Safety Administration.

6 APPENDICES

Appendix A, 37 Pre-Crash Scenarios With Functional Years Lost Prioritization

Total Economic Cost (TEC), Functional Years Lost (FYL), Crash Frequency (Freq.)

Najm, Smith, and Yanagisawa (2007), 37 Pre-Crash Scenarios				
Pre-Crash Scenario	**Description**	**TEC Rank**	**FYL Rank**	**Freq. Rank**
Control Loss Without Prior Vehicle Action	Vehicle is going straight in a rural area, in daylight, under adverse weather conditions, with a posted speed limit of 55 mph or more, and then loses control due to wet or slippery roads and runs off the road.	1	1	2
Road Edge Departure Without Prior Vehicle Maneuver	Vehicle is going straight in a rural area at night, under clear weather conditions, with a posted speed limit of 55 mph or more, and departs the edge of the road at a non-junction area.	3	2	5
Lead Vehicle Stopped	Vehicle is going straight in an urban area, in daylight, under clear weather conditions, at an intersection-related location with a posted speed limit of 35 mph; and closes in on a stopped lead vehicle.	2	3	1
Vehicle Not Making a Maneuver – Opposite Direction	Vehicle is going straight in a rural area, in daylight, under clear weather conditions, at a non-junction with a posted speed limit of 55 mph or more; and drifts and encroaches into another vehicle traveling in the opposite direction.	7	4	15

Najm, Smith, and Yanagisawa (2007), 37 Pre-Crash Scenarios				
Pre-Crash Scenario	**Description**	**TEC Rank**	**FYL Rank**	**Freq. Rank**
Straight Crossing Paths at Non-Signalized Junctions	Vehicle stops at a stop sign in an urban area, in daylight, under clear weather conditions, at an intersection with a posted speed limit of 25 mph; and then proceeds against lateral crossing traffic.	5	5	8
Pedestrian Crash Without Prior Vehicle Maneuver	Vehicle is going straight in an urban area, in daylight, under clear weather conditions, with a posted speed limit of 25 mph; and then encounters a pedestrian at a non-junction location.	12	6	27
Vehicle Turning at Non-Signalized Junctions	Vehicle stops at a stop sign in a rural area, in daylight, under clear weather conditions, at an intersection with a posted speed limit of 35 mph; and proceeds to turn left against lateral crossing traffic.	4	7	3
Running Red Light	Vehicle is going straight in an urban area, in daylight, under clear weather conditions, with a posted speed limit of 35 mph; vehicle then runs a red light, crossing an intersection and colliding with another vehicle crossing the intersection from a lateral direction.	6	8	9
Left Turn Across Path From Opposite Directions at Signalized Junctions	Vehicle is turning left in an urban area, in daylight, under clear weather conditions, at a signalized intersection with a posted speed limit of 35 mph; and cuts across the path of another vehicle straight crossing from an opposite direction.	9	9	11

Najm, Smith, and Yanagisawa (2007), 37 Pre-Crash Scenarios				
Pre-Crash Scenario	**Description**	**TEC Rank**	**FYL Rank**	**Freq. Rank**
Left Turn Across Path From Opposite Directions at Non-Signalized Junctions	Vehicle is turning left, in daylight, under clear weather conditions, at an intersection without traffic controls, with a posted speed limit of 35 mph; and then cuts across the path of another vehicle traveling from the opposite direction.	10	10	13
Lead Vehicle Decelerating	Vehicle is going straight and following another lead vehicle in a rural area, in daylight, under clear weather conditions, at a non-junction with a posted speed limit of 55 mph or more; and the lead vehicle suddenly decelerates.	8	11	4
Lead Vehicle Moving at Lower Constant Speed	Vehicle is going straight in an urban area, in daylight, under clear weather conditions, at a non-junction with a posted speed limit of 55 mph or more; and closes in on a lead vehicle moving at lower constant speed.	13	12	12
Vehicle(s) Changing Lanes – Same Direction	Vehicle is changing lanes in an urban area, in daylight, under clear weather conditions, at a non-junction with a posted speed limit of 55 mph or more; and then encroaches into another vehicle traveling in the same direction.	11	13	6
Control Loss With Prior Vehicle Action	Vehicle is turning left or right at an intersection-related area, in daylight, under clear weather conditions, with a posted speed limit of 45 mph or less, and then loses control due to wet or slippery roads and runs off the road	15	14	16

Najm, Smith, and Yanagisawa (2007), 37 Pre-Crash Scenarios				
Pre-Crash Scenario	**Description**	**TEC Rank**	**FYL Rank**	**Freq. Rank**
Vehicle Turning – Same Direction	Vehicle is turning left at an intersection in an urban area, in daylight, under clear weather conditions, with a posted speed limit of 35 mph; and then cuts across the path of another vehicle initially traveling in the same direction.	14	15	10
Pedalcyclist Crash Without Prior Vehicle Maneuver	Vehicle is going straight in an urban area, in daylight, under clear weather conditions, with a posted speed limit of 25 mph; and encounters a pedalcyclist at an intersection.	20	16	30
Vehicle Drifting – Same Direction	Vehicle is going straight in an urban area, in daylight, under clear weather conditions, at a non-junction with a posted speed limit of 55 mph or more; and then drifts into an adjacent vehicle traveling in the same direction.	17	17	17
Evasive Action Without Prior Vehicle Maneuver	Vehicle is going straight in an urban area, in daylight, under clear weather conditions, at a non-junction location with a posted speed limit of 35 mph; and takes an evasive action to avoid an obstacle.	18	18	22
Road Edge Departure With Prior Vehicle Maneuver	Vehicle is turning left/right at an intersection-related location, in a rural area at night, under clear weather conditions, with a posted speed of 25 mph; and then departs the edge of the road.	22	19	19

Najm, Smith and Yanagisawa (2007), 37 Pre-Crash Scenarios				
Pre-Crash Scenario	**Description**	**TEC Rank**	**FYL Rank**	**Freq. Rank**
Vehicle Making a Maneuver – Opposite Direction	Vehicle is passing another vehicle in a rural area, in daylight, under clear weather conditions, at a non-junction with a posted speed limit of 55 mph or more; and encroaches into another vehicle traveling in the opposite direction	25	20	35
Running Stop Sign	Vehicle is going straight in a rural area, in daylight, under clear weather conditions, with a posted speed limit of 35 mph or less; and runs a stop sign at an intersection.	19	21	24
Vehicle Failure	Vehicle is going straight in a rural area, in daylight, and then loses control due to catastrophic failure of tires, brakes, powertrain, steering system, and wheels	23	22	26
Pedestrian Crash With Prior Vehicle Maneuver	Vehicle is turning left in an urban area, in daylight, under clear weather conditions with a posted speed limit of 35 mph; and encounters a pedestrian in the crosswalk at a signaled intersection.	26	23	33
Animal Crash Without Prior Vehicle Maneuver	Vehicle is going straight in a rural area at night, under clear weather conditions, with a posted speed limit of 55 mph or more; and encounters an animal at a non-junction location.	16	24	7
Object Crash Without Prior Vehicle Maneuver	Vehicle is going straight in a rural area at night, under clear weather conditions, at a non-junction location with a posted speed limit of 55 mph or more; and collides with an object on the road.	27	25	21

Najm, Smith and Yanagisawa (2007), 37 Pre-Crash Scenarios				
Pre-Crash Scenario	**Description**	**TEC Rank**	**FYL Rank**	**Freq. Rank**
Following Vehicle Making a Maneuver	Vehicle is changing lanes or passing in an urban area, in daylight, under clear weather conditions, at a non-junction with a posted speed limit of 55 mph; and closes in on a lead vehicle.	21	26	18
Non-Collision Incident	Vehicle is going straight in a rural area, in daylight, under clear weather conditions, at a non-junction location with a posted speed limit of over 55 mph; and then fire starts.	29	27	25
Vehicle Parking – Same Direction	Vehicle is leaving a parked position an urban area, in daylight, under clear weather conditions, with a posted speed limit of 25 mph; and encounters another vehicle traveling in the same direction at a non-junction area.	28	28	23
Pedalcyclist Crash With Prior Vehicle Maneuver	Vehicle is turning right in an urban area, in daylight, under clear weather conditions, with a posted speed limit of 25 mph; and encounters a pedalcyclist at an intersection.	30	29	32
Backing Up Into Another Vehicle	Vehicle is backing up in an urban area, in daylight, under clear weather conditions, at a driveway or alley location, with a posted speed limit of 25 mph; and collides with another vehicle.	24	30	14
Road Edge Departure While Backing Up	Vehicle is backing up in an urban area, in daylight, under clear weather conditions, with a posted speed limit of 25 mph; and then departs the road edge on the shoulder/parking lane in a driveway/alley location.	32	31	20

Najm, Smith, and Yanagisawa (2007), 37 Pre-Crash Scenarios				
Pre-Crash Scenario	**Description**	**TEC Rank**	**FYL Rank**	**Freq. Rank**
Lead Vehicle Accelerating	Vehicle is going straight in an urban area, in daylight, under clear weather conditions, at an intersection-related location with a posted speed limit of 45 mph; and closes in on an accelerating lead vehicle.	33	32	34
Vehicle Turning Right at Signalized Junctions	Vehicle is turning right in an urban area, in daylight, under clear weather conditions, at a signalized intersection with a posted speed limit of 35 mph; and turns into the same direction of another vehicle crossing straight initially from a lateral direction.	31	33	28
Evasive Action With Prior Vehicle Maneuver	Vehicle is turning left at an intersection-related location, in an urban area, in daylight, under clear weather conditions, with a posted speed limit of 35 mph; and takes an evasive action to avoid an obstacle.	34	34	36
Object Crash With Prior Vehicle Maneuver	Vehicle is leaving a parked position at night, in an urban area, under clear weather conditions, at a non-junction location with a posted speed limit of 25 mph; and collides with an object on road shoulder or parking lane.	35	35	29
Animal Crash With Prior Vehicle Maneuver	Vehicle is leaving a parked position in a rural area at night, under clear weather conditions; and encounters an animal at a non-junction area.	36	36	31
Other	Other scenarios include on-road rollover, no driver present, hit-and-run, and crash types without any details or specifics.	37	37	37

Appendix B, Test Course Cost Estimates

ADVANCED TECHNOLOGY TEST COURSE - STRAIGHT CONFIGURATION

DATE:2013	WORK ACTIVITY	QUANTITY	UNIT	UNIT PRICE		TOTAL
	EARTHWORK					
	Clearing and grubbing	12.00	**ac**	$6,500.00	**$/ac**	$78,000.00
	Topsoil stripping (6", 500' haul)	9,700	**cy**	$9.55	**$/cy**	$92,635.00
	Cut/Fill	48,200	**cy**	$10.00	**$/cy**	$482,000.00
	Haul excess/spoils	63,700	**lcy**	$6.40	**$/lcy**	$407,680.00
	SUBTOTAL					$1,060,315.00
	PAVEMENT					
	1.5" Asphalt Wearing Course	38,500	**sy**	$7.35	**$/sy**	$282,975.00
	2.0" Asphalt Intermediate Course	38,500	**sy**	$8.65	**$/sy**	$333,025.00
	6.0" Asphalt Base Course	38,500	**sy**	$24.50	**$/sy**	$943,250.00
	6.0" Aggregate Base	39,400	**sy**	$8.05	**$/sy**	$317,170.00
	Tack Coat	77,000	**sy**	$0.80	**$/sy**	$61,600.00
	Soil Stabilization/Compaction	39,400	**sy**	$15.10	**$/sy**	$594,940.00
	SUBTOTAL					$2,532,960.00
	MISCELLANEOUS					
	Lane Striping (Thermoplastic - 6")	23,700	**lf**	$0.69	**$/lf**	$16,353.00
	6" Perforated Underdrain	7,900	**lf**	$14.10	**$/lf**	$111,390.00
	6" Underdrain Tee	40	**ea**	$25.50	**$/ea**	$1,020.00
	6" PVC Storm Outlet Pipe	800	**lf**	$7.95	**$/lf**	$6,360.00
	Engineering Fabric (for Underdrain)	5,500	**sy**	$2.16	**$/sy**	$11,880.00
	Drainage Stone (for Underdrain)	400	**cy**	$34.50	**$/cy**	$13,800.00
OPTIONAL	2" Instrumentation Conduit	4,000	**lf**	$11.60	**$/lf**	$46,400.00
OPTIONAL	2" Instrumentation Elbow	80	**ea**	$45.00	**$/ea**	$3,600.00
	SUBTOTAL					$210,803.00
					TOT	**$3,804,078.00**
				10% CONTINGENCY		$380,407.80
				GRAND TOTAL		**$4,184,485.80**

NOTE: UNIT PRICES BASED ON NATIONAL AVERAGE INSTALLED COST (MATERIALS AND LABOR) PROVIDED WITHIN "RS MEANS SITE WORK & LANDSCAPE COST DATA", DATED 2012.

ADVANCED TECHNOLOGY TEST COURSE - CURVE CONFIGURATION

DATE:2013	WORK ACTIVITY	QUANTITY	UNIT	UNIT PRICE		TOTAL
	EARTHWORK					
	Clearing and grubbing	13.00	ac	$6,500.00	$/ac	$84,500.00
	Topsoil stripping (6", 500' haul)	10,400	cy	$9.55	$/cy	$99,320.00
	Cut/Fill	51,800	cy	$10.00	$/cy	$518,000.00
	Haul excess/spoils	68,400	lcy	$6.40	$/lcy	$437,760.00
	SUBTOTAL					$1,139,580.00
	PAVEMENT					
	1.5" Asphalt Wearing Course	41,500	sy	$7.35	$/sy	$305,025.00
	2.0" Asphalt Intermediate Course	41,500	sy	$8.65	$/sy	$358,975.00
	6.0" Asphalt Base Course	41,500	sy	$24.50	$/sy	$1,016,750.00
	6.0" Aggregate Base	42,400	sy	$8.05	$/sy	$341,320.00
	Tack Coat	82,900	sy	$0.80	$/sy	$66,320.00
	Soil Stabilization/Compaction	42,400	sy	$15.10	$/sy	$640,240.00
	SUBTOTAL					$2,728,630.00
	MISCELLANEOUS					
	Lane Striping (Thermoplastic - 6")	25,500	lf	$0.69	$/lf	$17,595.00
	6" Perforated Underdrain	8,500	lf	$14.10	$/lf	$119,850.00
	6" Underdrain Tee	45	ea	$25.50	$/ea	$1,147.50
	6" PVC Storm Outlet Pipe	850	lf	$7.95	$/lf	$6,757.50
	Engineering Fabric (for Underdrain)	5,900	sy	$2.16	$/sy	$12,744.00
	Drainage Stone (for Underdrain)	450	cy	$34.50	$/cy	$15,525.00
OPTIONAL	2" Instrumentation Conduit	4,200	lf	$11.60	$/lf	$48,720.00
OPTIONAL	2" Instrumentation Elbow	84	ea	$45.00	$/ea	$3,780.00
	SUBTOTAL					$226,119.00
				10% CONTINGENCY		$409,432.90
				GRAND TOTAL		**$4,503,761.90**

NOTE: UNIT PRICES BASED ON NATIONAL AVERAGE INSTALLED COST (MATERIALS AND LABOR) PROVIDED WITHIN "RS MEANS SITE WORK & LANDSCAPE COST DATA", DATED 2012.

ADVANCED TECHNOLOGY TEST COURSE - FOUR-WAY INTERSECTION

DATE: 2012	WORK ACTIVITY	QUANTITY	UNIT	UNIT PRICE		TOTAL
	EARTHWORK					
	Clearing and grubbing	2.00	ac	$6,500.00	$/ac	$13,000.00
	Topsoil stripping (6", 500' haul)	1,650	cy	$9.55	$/cy	$15,757.50
	Cut/Fill	7,750	cy	$10.00	$/cy	$77,500.00
	Haul excess/spoils	10,400	lcy	$6.40	$/lcy	$66,560.00
	SUBTOTAL					$172,817.50
	PAVEMENT					
	1.5" Asphalt Wearing Course	7,000	sy	$7.35	$/sy	$51,450.00
	2.0" Asphalt Intermediate Course	7,000	sy	$8.65	$/sy	$60,550.00
	6.0" Asphalt Base Course	7,000	sy	$24.50	$/sy	$171,500.00
	6.0" Aggregate Base	7,100	sy	$8.05	$/sy	$57,155.00
	Tack Coat	14,000	sy	$0.80	$/sy	$11,200.00
	Soil Stabilization/Compaction	7,100	sy	$15.10	$/sy	$107,210.00
	SUBTOTAL					$459,065.00
	MISCELLANEOUS					
	Lane Striping (Thermoplastic - 6")	2,700	lf	$0.69	$/lf	$1,863.00
	Lane Striping (Thermoplastic - 12")	1,200	lf	$1.51	$/lf	$1,812.00
	6" Perforated Underdrain	650	lf	$14.10	$/lf	$9,165.00
	6" Underdrain Tee	8	ea	$25.50	$/ea	$204.00
	6" PVC Storm Outlet Pipe	160	lf	$7.95	$/lf	$1,272.00
	Engineering Fabric (for Underdrain)	450	sy	$2.16	$/sy	$972.00
	Drainage Stone (for Underdrain)	35	cy	$34.50	$/cy	$1,207.50
OPTIONAL	2" Instrumentation Conduit	1,100	lf	$11.60	$/lf	$12,760.00
OPTIONAL	2" Instrumentation Elbow	16	ea	$45.00	$/ea	$720.00
	Traffic Signal System (Intersection)	1	lump	$282,000.00	$/lump	$282,000.00
	SUBTOTAL					$311,975.50
					TOTAL	**$943,858.00**
					10% CONTINGENCY	$94,385.80
					GRAND TOTAL	**$1,038,243.80**

NOTE: UNIT PRICES BASED ON NATIONAL AVERAGE INSTALLED COST (MATERIALS AND LABOR) PROVIDED WITHIN "RS MEANS SITE WORK & LANDSCAPE COST DATA", DATED 2012.

ADVANCED TECHNOLOGY TEST COURSE - SUMMARY

DATE: 2012

PROTOTYPE	TOTAL
PARALLEL STRAIGHT	$4,184,485.80
PARALLEL CURVE	$4,503,761.90
FOUR WAY INTERSECTION	$1,038,243.80
	$9,726,491.50

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