APPROACH FOR DERIVING SCENARIOS FOR SAFETY OF THE INTENDED FUNCTIONALITY

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ABSTRACT

Safety of the Intended Functionality (SOTIF) is a safety process in the automotive industry that addresses unintended system behaviors in the absence of electronic faults. Electronic system malfunctions are addressed through industry's functional safety process, ISO 26262. SOTIF on the other hand helps mitigate hazards that may arise when the driving conditions exceed the technology limitations of one or more system components or from certain human factor considerations, such as foreseeable system misuse or mode confusion.

The current approach applies a combination of analysis, simulation, test track, and on-road testing to identify unknown and potentially unsafe scenarios. This study supports the analytical part of this approach by developing a structured framework for deriving scenarios necessary for a SOTIF analysis. The scenarios derived through this framework could then be used to inform simulation and testing.

This paper provides a brief overview of the SOTIF process, describes the development of a framework for deriving scenarios, and presents preliminary results from applying this framework to a highly automated chauffeur system. The framework described in this paper could evolve over time as additional SOTIF-relevant parameters are identified.

INTRODUCTION

Driving automation systems and other advanced electronic and electrical (E/E) systems have the potential to transform the transportation landscape. Safety assurance of E/E systems introduced into the vehicle fleet is a primary consideration for industry and regulators. Recognizing the unique safety challenges presented by E/E systems, such as heavy reliance on software and complex system interactions, the International Organization for Standardization (ISO) published ISO 26262 (Functional Safety – Road Vehicles). ISO 26262 represents the current approach in the automotive industry with respect to the functional safety of E/E systems [1].

Functional safety deals primarily with electronic faults in E/E systems and is one component of the overall evaluation of system safety. In 2019, ISO published Publically Available Specification (PAS) 21448 (Safety of the Intended Functionality; SOTIF). SOTIF is a complementary process to functional safety that addresses the identification and mitigation of hazardous events that may occur in the absence of electronic faults. One aspect of the SOTIF approach focuses on identifying scenarios that may exceed the technology and performance limitations of the system, or increase the potential for system misuse by human operators. This paper describes a framework and approach for deriving scenarios that could be used in a SOTIF analysis.

SOTIF OVERVIEW

Figure 1 shows key steps in the SOTIF process as described in PAS 21448. This section describes relevant SOTIF concepts and the reader is referred to PAS 21448 [2] for a more detailed description of the overall SOTIF process.

The SOTIF risk identification and evaluation step determines if credible harm may result from hazardous events. PAS 21448 defines hazardous events as a combination of a potential system hazard and a particular operating situation [2]. Operating situations are defined in ISO 26262 as scenarios[1] that can occur during a vehicle's life [3]. PAS 21448 provides the following example of a hazardous event:

- Hazard: Unintended automatic emergency brake activation at x m/s^2 for y s;
- Operation situation: Operating on a highway [2].

After identifying hazardous events, the SOTIF process then focuses on identifying triggering events that may lead to unintended system behavior and ultimately one or more of the identified hazardous events. PAS 21448 defines triggering events, which include foreseeable misuse scenarios, as *driving scenarios with specific conditions that serves as an initiator for a subsequent system reaction* [2]. The analysis of triggering events attempts to identify system weaknesses as well as the related scenarios that could lead to an identified hazardous event [2].

Triggering events can be divided into two classifications.

- The first category contains events that exceed the performance limitations of the system and components. This paper defines triggering events in this category as SOTIF Type I events. This category includes both sensor limitations as well as limitations in algorithms, such as machine learning and neural net algorithms For example, a highly automated chauffeur system may be operating within its intended operating domain (e.g., highway, good weather) but then encounters a roadway configuration with glare conditions. The resulting lighting conditions may exceed the performance limitations of a front-facing camera.

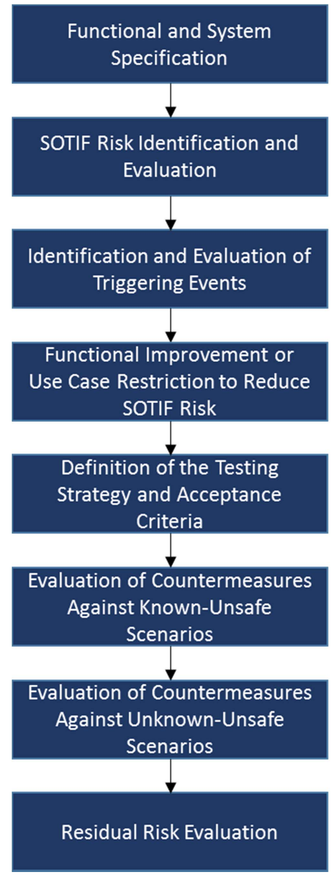

***Figure 1*. Key steps in the SOTIF process [2].**

- The second category contains human factor limitations, particularly in relation to the driver-vehicle interface. This paper defines triggering events in this category as SOTIF Type II events. This area broadly covers several human factors issues, such as the driver failing to keep their hands on the steering wheel; the driver's understanding of the system capabilities and limitations, and the driver's responsibilities; and the driver's ability to understand and respond to warnings and alerts. Under SOTIF, human factor limitations do not extend to intentional abuse of the system, such as intentionally ignoring driver takeover requests or purposely using products intended to override the system limitations.

The scenarios in which triggering events occur are defined in PAS 21448 as a sequence of scenes (i.e., snapshots of the environment) beginning with an initial scene and evolving through a series of events and actions (e.g., triggering events and system responses) [2]. A scene has several characteristics, including dynamic elements, scenery, and self-representations of actors and observers.

According to PAS 21448, scenarios may be classified as known-safe or known-unsafe depending on whether the mitigation strategies sufficiently reduce the SOTIF risk [2]. A third category, unknown-unsafe, represents those scenarios that are not known at the time of system design and are identified through long-term vehicle tests,

[1] Note that ISO 26262 does not define the term "scenario" as rigorously as PAS 21448.

simulations, random input testing, and other measures.[2] The approach in this study attempts to improve the initial identification of known-unsafe scenarios through use of a more comprehensive analysis.

APPROACH

Techniques for developing scenarios for SOTIF continues to be a challenge. Some guidance is provided in Annex F of PAS 21448. The approach described in this paper further develops an existing taxonomy to produce a hierarchical framework of variables that could be used to derive scenarios for SOTIF systematically. The intent is to enable a more comprehensive analysis and development of countermeasures by increasing the number of known-unsafe scenarios identified at the outset of the system design. Some elements of a scenario are not covered by the framework, such as system capabilities or programmed system goals and values [2]. The framework is intended to help identify the aspects of a scenario external to the vehicle.

Thorne et al. developed a top-level taxonomy for the operational design domain. The taxonomy identifies 6 top-level categories and 22 immediate subcategories, as shown in Table 1 [4].

Table 1.
Thorne et al. ODD Taxonomy Categories

Top-Level Category	Immediate Subcategory
Physical Infrastructure	Roadway Types
	Roadway Surface
	Roadway Edges
	Roadway Geometry
Operational Constraints	Speed Limit
	Traffic Conditions
Objects	Signage
	Roadway Users
	Non-Roadway User/Obstacles/Objects
Connectivity	Vehicles
	Traffic Density Information
	Remote Fleet Management System
	Infrastructure Sensors and Communications
Environmental Conditions	Weather
	Weather-Induced Roadway Conditions
	Particulate Matter
	Illumination
Zones	Geofencing
	Traffic Management Zones
	School/Construction Zones
	Regions/States
	Interference Zones

This study used the Thorne et al. taxonomy to categorize scenario factors presented in Annex F of PAS 21448 and relevant parameters from the Fatality Analysis Reporting System (FARS).[3] The FARS database provides coded variables based on decades of analyzing historical causes of fatal crashes. While FARS does not differentiate between human drivers and driving automation systems, the FARS variables still provide general insight into known challenging roadway conditions and behaviors that driving automation systems may need to navigate.

This study further expanded the Thorne et al. taxonomy as a list of 200 variables categorized into 41 detailed

[2] SOTIF is an iterative process and unknown-unsafe scenarios, once identified, become known-unsafe scenarios that can be mitigated through modifications of the system design.
[3] The FARS database contains information on all crashes on public roadways in the United States resulting in at least one fatality within 30 days of the crash [4].

subcategories, a feature of the SOTIF framework. For some variables and situations, analysts may need to consider the appropriate "negative case" when applying the framework. For example, one variable is "pedestrians, pedalcyclists, other non-motorist permitted in road." The corresponding "negative case" is that non-motorists are prohibited from using the roadway. Negative cases are not explicitly included in the framework.

Table 2 provides an example of the expanded framework using roadway type variables from FARS. Attachment A provides the full framework. The scenario variables in Attachment A also include some variables from the Thorne et al. study that were not included in the FARS database [4] and PAS 21448 Annex F [2].

Table 2.
Example Expanded Taxonomy based on FARS and PAS 21448 Parameters

Top-Level Category	Immediate Subcategory	Detailed Subcategory	Scenario Variable
Physical Infrastructure	Roadway Type	Functional Class	Interstate
			Principal Arterial (Other Freeways/Expressways)
			Principal Arterial – Other
			Minor Arterial
			Major Collector
			Minor Collector
			Local
			Other
		Trafficway	Two-way, Divided, Unprotected
			Two-way, Divided, Positive Median Barrier
			Two-way, Not Divided
			Two-way, Not Divided, Continuous Left Turn Lane
			One-way Trafficway
			Non-trafficway or Driveway Access
…	…	…	…

In order to organize the variables from FARS and PAS 21448 further and into a structure amenable to scenario construction, this study categorized each variable as either permanent-regional, permanent-local, a compounding event or condition, or a potential threat.

- **Permanent-Regional** – These variables are characteristics of the ODD and form the backdrop of scenarios. Permanent-regional variables do not change over time or over significant spatial portions of the trip. Examples of permanent-regional variables include roadway functional class, lane type, and permitted types of non-vehicle uses. Permanent-regional variables may be most amenable to geocoding because of their persistent and pervasive nature. This study identified 31 scenario variables in the permanent-regional category.

- **Permanent-Local** – These variables persist over time, but are localized spatially. From a mobile frame of reference (e.g., a vehicle), permanent-local variables may only be encountered for brief portions of a trip.[4] A vehicle may encounter multiple permanent-local variables over the course of a trip. Each combination of permanent-local variables may represent different variations of the backdrop defined by permanent-regional variables. Examples of permanent-local variables include curves, hills, bridges, and intersections. Since permanent-local variables are temporally persistent, they could be geocoded—for instance, to inform vehicles of approaching intersections, tunnels, or other similar features. This study identified 44 scenario variables in the permanent-local category.

- **Compounding Event or Condition** – These variables are temporary events and conditions that may occur within the scenery defined by permanent-regional and permanent-local variables. For a fixed point in space,

[4] From a fixed frame of reference (e.g., vehicle-to-infrastructure sensors), permanent-local variables may not be appreciably distinct from permanent-regional variables.

compounding events or conditions are those aspects of the initial scene that can change. While a compounding event or condition may persist through an entire trip (e.g., rain), it is also possible for the same compounding event or condition to persist for only a portion of a trip (e.g., a short rain shower) or to change between trips (e.g., the weather may be clear one day and rainy the next). This study further defines compounding events or conditions as variables that are aspects of normal driving. This study identified 75 compounding event or condition variables.

- **Threats** – These variables are temporary events or conditions that relate to specific roadway threats to which the system may need to respond. Unlike compounding events/conditions, threats represent unexpected behaviors or deviations from normal driving situations—for example, other vehicles disobeying signs or traffic controls or pedestrians darting out into the roadway. Threats may be static (e.g., a stalled or disabled vehicle) or dynamic (e.g., an aggressive driver). This study identified 50 threat variables.

Together, the persistent regional, persistent local, compounding events or conditions, and threats define key aspects of the initial scene. Figure 2 shows the relationship of categories assigned to the FARS and PAS 21448 variables incorporated into the taxonomy.

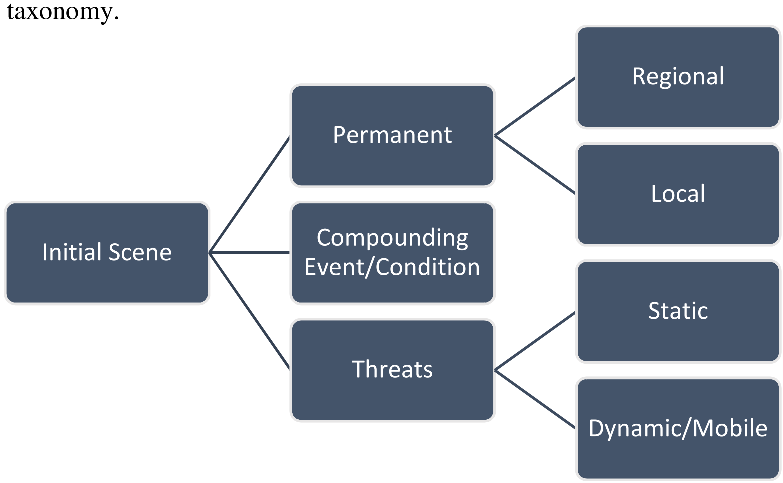

Figure 2. **Categorization schema for variables in the taxonomy.**

PAS 21448 does not differentiate between temporary and permanent elements of the scene. For instance, PAS 21448 includes "environment conditions" as part of the scenery element [2]. However, the framework presented in this study categorizes environmental conditions (e.g., weather, lighting) under compounding events or conditions that are more akin to other dynamic elements, such as traffic, objects, and pedestrians. Separating out the permanent variables can help identify elements of the scenario that a system could predict with greater confidence. This could be particularly important for systems that rely on transitioning control back to the driver. These variables may be more amenable to geocoding or mapping in order to transfer control to the driver with sufficient time for the driver to regain situational awareness.

This study derived triggering events through analysis of the physical limitations of sensors and probabilistic nature of algorithms (Type I SOTIF events). Analysis techniques such as Systems Theoretic Process Analysis (STPA) were used to derive potential driver misuse scenarios (Type II SOTIF events). For each triggering event, initial scenes were constructed that linked the triggering event to a potential hazardous event to create a SOTIF scenario.

EXAMPLE SCENARIO DERIVATION

This study uses hazardous events and triggering events to constrain the development of scenarios. Note that other approaches to develop scenarios exist and this paper presents only one possible way through which scenarios could be derived. To illustrate this process used in this study, this paper presents examples related to the lane centering maneuver of highly automated chauffeur system. This maneuver attempts to keep the vehicle centered in the travel lane. A prior study by Brewer, et al., identified hazards for a generic lane centering system [5]. A relevant hazard identified in that prior study is "lane/roadway departure while the system is engaged."[5]

This study begins developing scenarios by identifying hazardous events. This corresponds to the second step in the SOTIF process shown in Figure 1. The study applied the permanent-regional variables to develop the operating situation for the hazardous event. One example hazardous event derived through this process is:

- Hazard: Lane/roadway departure while the highly automated chauffeur system is engaged
- Operating situation: Operating in a shoulder lane on a two-way divided interstate or freeway/expressway (i.e., restricted access)
- Potential crash type: Sideswipe (same direction of travel)

Permanent-regional variables are the most consistent with the examples of operating scenarios provided in PAS 21448. Permanent-regional variables define the general context of a trip and may be the only variables that persist throughout the segment of the trip in which the system is engaged. Worst-case assumptions can be made about other conditions when assessing the hazardous event at this level.

In developing operating situations, some variable categories may not be relevant to the particular situation. For instance, in the example above, the shoulder type (paved/gravel versus dirt) does not matter. The omission of a variable means that all relevant cases considered are included as subsets of the stated operating situation.

Triggering events were developed independent of the hazardous events, based on system limitations and potential driver misuse. This corresponds to the third step in the SOTIF process shown in Figure 1. Note that in this paper only SOTIF Type I triggering events are considered. Example triggering events developed for highly automated chauffeur system include:

- The lane model algorithm[6] incorrectly establishes the lane lines.
- The road model algorithm[7] incorrectly establishes the road model in the absence of clear lane markings.
- The camera fails to detect landmarks because of inadequate contrast between the landmarks and the environment.

At this point in the SOTIF process, system designers may consider functional improvements to mitigate triggering events (Step 4 in Figure 1) and establish testing and acceptance criteria (Step 5 in Figure 1). The next step in the SOTIF process relevant to scenario development is to identify known-unsafe scenarios (Step 6 in Figure 1).

The operating situation used for this hazardous event imposes restrictions on the types of variables to consider in constructing the scenario. For example, since the operating situation is specific to interstate or freeway/expressway (i.e., restricted access) roadways, only certain intersection types need to be considered during development of the initial scene—tollbooth/tollgate and entrance/exit ramp.[8]

The triggering events may also impose restrictions on the types of variables to consider in constructing the scenario. For example, to develop scenarios related to the first triggering event listed above, this study only considers variables and combinations of variables that could affect detection of the lane markings. Similarly, to develop scenarios for the third triggering event, this study considered variables that affect the contrast of lane markings and pavement.

This paper provides three examples of scenarios developed within the constraints of the example hazardous event

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[5] Brewer et al. considered two variations of this hazard based on whether a system fault resulted in excessive or insufficient steering [5]. However, SOTIF presumes that the underlying system is free from faults and therefore this study did not identify a need to differentiate between the two variations of the hazard.

[6] The lane model algorithm is responsible for identifying the lane boundaries and road edge.

[7] The road model algorithm establishes a lane for the vehicle based on landmarks in the absence of lane markings or a lead vehicle to follow.

[8] According to the Federal Highway Administration Highway Functional Classification Concepts [8], some freeways/expressways could have a limited number of at-grade intersections. However, this study assumes that freeways/expressways roadways are more akin to interstates and have restricted access; a possible SOTIF mitigation measure may be to restrict use of the system on freeways/expressways with at-grade intersections.

and triggering events, using the variables presented in the framework.

Table 3.
First Example SOTIF Scenario

Operating Situation	Operating in a shoulder lane on a two-way divided interstate or freeway/expressway (i.e., restricted access)	
Triggering Event	The lane model algorithm incorrectly establishes the lane lines, and the vehicle drifts into the adjacent lane.	
Permanent-Local Variables	*Physical Infrastructure → Roadway/Lane Edges → Lane Characteristic*	Narrow lanes
Compounding Event or Condition	*Operational Constraint → Traffic Conditions → Standard Traffic*	Traffic backup due to regular congestion
Threat	*Objects → Local Traffic Control Missing*	Inadequate warning of exits, narrowing lanes, traffic controls, etc.
Scenario	In heavy traffic, certain roads allow travel on the shoulder lane. However, the shoulder lane might narrow without adequate advance warning that would allow the system to merge out of the shoulder lane. If the vehicle enters a narrower shoulder lane, the lane model algorithm may not be able to determine the appropriate lane width. The system could cross over into the adjacent lane.	

Table 4.
Second Example SOTIF Scenario

Operating Situation	Operating in a shoulder lane on a two-way divided interstate or freeway/expressway (i.e., restricted access)	
Triggering Event	The road model algorithm incorrectly establishes the road model and causes the vehicle to drift into the adjacent lane in the absence of clear lane markings.	
Permanent-Local Variables	*Physical Infrastructure → Roadway/Lane Edges → Road Edge Type/Quality*	Guard rails
Compounding Event or Condition	*Environmental Condition → Weather → Precipitation*	Snow
Threat	*Physical Infrastructure → Roadway/Lane Edges → Lane Marking Type/Quality*	No markings or obscured lane markings
Scenario	Snow may cover the lane markings, making it difficult for the lane model algorithm to track the lane boundaries. Heavy snow may also stick to radars, preventing detection of other landmarks to support the road model algorithm, such as guardrails. Without an appropriate road model, the vehicle may drift out of the shoulder and into the adjacent lane.	

Table 5.
Third Example SOTIF Scenario

Operating Situation	Operating in a shoulder lane on a two-way divided interstate or freeway/expressway (i.e., restricted access)	
Triggering Event	The camera fails to detect landmarks because of inadequate contrast between the landmarks and the environment.	
Permanent-Local Variables	*Physical Infrastructure → Roadway Geometry → Alignment*	Curve Right
Compounding Event or Condition	*Environmental Condition → Light Conditions → Ambient Light*	Dark (unlighted)
Threat	*Physical Infrastructure → Roadway/Lane Edges → Lane Marking Type/Quality*	No markings or obscured lane markings
Scenario	The vehicle is operating on the shoulder at night on an unlit road, and encounters a region without lane markings. A roadway curving to the right may reduce illumination of roadside features by the vehicle's headlights, which may result in inadequate contrast between the landmarks and the environment. The vehicle may drift out of the shoulder lane and into an adjacent lane.	

APPLICATION BEYOND SOTIF

The framework presented in this study could extend beyond SOTIF to provide a general classification of challenging scenarios for driving automation systems. In particular, by separating permanent-regional and permanent-local variables depending on the frame of reference, this framework in this study could help characterize scenarios for vehicle to infrastructure (V2I) and improved GPS mapping (e.g., for geofencing).

Use of a common framework for defining scenarios both in the development of driving automation systems as well as supporting infrastructure could provide consistency between analyses (e.g., types of situations where vehicle-based systems may rely more heavily on V2I). For example, SOTIF scenarios developed using the framework could translate into scenarios where V2I may improve vehicle operation.

CONCLUSIONS

This study established a framework to help develop SOTIF scenarios. The framework combines variables derived from three sources (Thorne et al., PAS 21448, and FARS) into a common typology proposed by Thorne et al. This paper also presents a categorization schema for the variables in the framework to facilitate development of SOTIF scenarios. Certain variables were classified as permanent, with permanence depending on the frame-of-reference (i.e., regional or local features). Non-permanent variables were classified as either compounding events/conditions or threats, based on whether the variable could be anticipated as part of normal driving.

The permanent-regional and permanent-local variables tend not to change over long periods, and can be geocoded with reasonable confidence. If the SOTIF mitigation strategy includes restricting the ODD to avoid certain hazardous events related to permanent-regional or permanent-local variables (e.g., branching or merging lanes), it may be possible to begin alerting the driver with sufficient lead-time through use of detailed maps and GPS. This could increase the probability that the driver will safely resume control of the vehicle. Compounding events or conditions and threats are less predictable and therefore less amenable to geocoding. For instance, a compounding event or condition, or threat may emerge suddenly, necessitating a quick transfer of control to the driver.

The variables presented in this expanded framework can be combined to develop scenarios to support the SOTIF analysis. Three such examples are presented in this paper. Considering a more expanded set of variables and scenarios during the analysis at the outset of the SOTIF process could help reduce the amount of on-road testing and simulation required to identify unknown-unsafe scenarios.

It is important to note that the framework in Attachment A is not intended to be a complete set of *all* relevant variables. Rather, it represents an extension of the taxonomy in Thorne et al. as an effort to progress the state-of-the-art in SOTIF scenario development. The framework presented in this paper could be enhanced by adding additional factors, such as those observed during real world road tests of driving automation systems. A more complete framework would improve the overall comprehensiveness of the SOTIF analysis.

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APPENDIX A: SOTIF SCENARIO FRAMEWORK

Table 6.
Permanent-Regional Variables

Top-Level Category	Immediate Subcategory	Detailed Subcategory	Scenario Variable
Physical Infrastructure	Roadway Type	Functional Class	Interstate
			Principal Arterial (Other Freeways/Expressways)
			Principal Arterial – Other
			Minor Arterial
			Major Collector
			Minor Collector
			Local
			Other
		Trafficway	Two-way, Divided, Unprotected
			Two-way, Divided, Positive Median Barrier
			Two-way, Not Divided
			Two-way, Not Divided, Continuous Left Turn Lane
			One-way Trafficway
			Non-trafficway or Driveway Access
	Roadway Surface and Features	Lane Type	Single Lane
			Multi-lane
			Reversible Lane
			Shoulder Lane
			Managed Lane (HOV, etc.)
		Surface Type	Concrete
			Blacktop, Bituminous, or Asphalt
			Brick or Block (Including Cobblestone/Belgian Brick)
			Slag, Gravel, or Stone
			Dirt
	Roadway/Lane Edges	Shoulder Type	Paved/Gravel
			Unpaved
Objects	Roadway Users	Other Non-Vehicle Users Permitted on Roadway	Pedestrian, Pedal-cyclist, Other Non-motorist Permitted in Road (e.g., Restricted versus Unrestricted)
	Non-Roadway Users	Pedestrian Crosswalks/ Intersections	Crosswalks/Intersections Present in Roadway Type (e.g., Restricted versus Unrestricted)
		Other Users on Side of Roadway	Non-motorists Permitted Along Roadway
Zones	Regions/States	Regional Traffic Laws	Special Regional Traffic Laws and Norms
		State Traffic Laws	Special State Traffic Laws and Norms

Table 7.
Permanent-Local Variables

Top-Level Category	Immediate Subcategory	Detailed Subcategory	Scenario Variable
Physical Infrastructure	Roadway Surface and Features	Intersection	Median Crossover Road
			Tollbooth/Tollgate
			Entrance/Exit Ramp
			Four-way Intersection
			T-intersection
			Y-intersection
			Traffic Circle
			Roundabout
			Five-point or More
			L-intersection
		Surface Type	Local Change in Surface (e.g., Concrete Bridge)
			Step Difference/Uneven
		Roadway Condition	Manhole Cover
	Roadway/Lane Edges	Lane Marking Type/Quality	Bott's Dots or Cat's Eye
			Other Non-Traditional Markings
		Lane Type	Narrow Lane
			Wide Lane
			Merging
			Branching
		Road Edge Type/Quality	Median
			Curb
			Concrete Barrier
			Guardrails
			Grating
			Telephone Poles
	Roadway Geometry	Alignment	Straight
			Curve Right
			Curve Left
		Grade	Level
			Grade, Unknown Slope
			Hillcrest
			Sag (Bottom)
			Uphill
			Downhill
			Banked
Operational Constrain	Speed Limit	Speed Limit Signage	Posted Speed Limit
Zones	Traffic Management Zone	Variable Speed Zone	Variable Speed Zone
		Loading/Unloading Zone	Loading/Unloading Zone
	School/ Construction Zone	School Zone	Within Designated School Zone
	Interference Zones	Structures	Tunnels
			Bridges (Double-deck, Covered, Viaduct, etc.)
			Tall Buildings (e.g., Urban Canyon)
			Parking Garage
		Natural Conditions	Geologic Formations (e.g., Canyons, Overhang)

Table 8.
Compounding Event or Condition Variables

Top-Level Category	Immediate Subcategory	Detailed Subcategory	Scenario Variable
Physical Infrastructure	Roadway Surface and Features	Roadway Condition	Ruts, Holes, Bumps in Road
			Other Maintenance or Construction-Related Condition
			Shoulder Related (Design or Condition)
			Inadequate Construction or Poor Design of Roadway, Bridge, etc.
	Roadway/Lane Edges	Road Edge Type/Quality	Cones
Operational Constraints	Speed Limit	Operating Speed	Posted Maximum Limit Below Minimum System Operating Speed
			Posted Minimum Limit Above Maximum System Operating Speed
			Relative Speed Above Surrounding Traffic
			Relative Speed Below Surrounding Traffic
			Speed Inappropriate for Conditions (e.g., Surface, Geometry)
		Speed Limit Signage	None (Inferred Speed Limit)
	Traffic Conditions	Standard Traffic	Light or No Traffic
			Backup Due to Prior Non-Recurring Incident
			Backup Due to Prior Crash
			Backup Due to Regular Congestion
		Altered Traffic Flow	Tollbooth/Plaza Related
Objects	Signals and Signage	Local Traffic Control Type	No Control or Uncontrolled
			Flashing Traffic Control Signal
			Traffic Signal with or without Pedestrian Crossing Signal
			Regulatory Sign
			Warning/Information/Temporary Sign
			Railroad Crossing Device/Gate
			Traffic Officer/Flag Person/Hand Signs
	Roadway Users	Standard Vehicles	Standard Vehicles in Roadway
		Non-Standard Vehicles	Special Cargo Body Type (e.g., Garbage, Gravel, Flatbed, Auto Transporter)
			Large Vehicle Configuration (e.g., Bus, Tractor-Trailer, Single Unit Truck, Etc.)
			Towed Vehicle (Fixed or Non-Fixed Linkage)
			Multiple Trailing Units
			Wide-Load Vehicle
		Other Non-Vehicle Users Permitted on Roadway	Pedestrian, Bicyclist, Other Cyclist or Person on Personal Conveyances in Travel Lane
			Pedestrian, Bicyclist, Other Cyclist or Person on Personal Conveyances on Paved Shoulder/Bicycle Lane/Parking Lane
			Pedestrian Jogging/Running in Roadway

Top-Level Category	Immediate Subcategory	Detailed Subcategory	Scenario Variable
Objects (cont.)	Non-Roadway Users	Pedestrians	Pedestrian, Bicyclist, Other Cyclist, or Person on Personal Conveyances in Intersection Area
			Pedestrian, Bicyclist, Other Cyclist, or Person on Personal Conveyances in Crosswalk Area
			Pedestrian, Bicyclist, Other Cyclist, or Person on Personal Conveyances in Median/Crossing Island
			Pedestrian, Bicyclist, Other Cyclist, or Person on Personal Conveyances Waiting to Cross Roadway
		Other Users on Side of Roadway	Pedestrian, Bicyclist, Other Cyclist, or Person on Personal Conveyances on Sidewalk/Shared-Use Path/Driveway Access
			Pedestrian, Bicyclist, Other Cyclist, or Person on Personal Conveyances in Unpaved Right-of-Way
			Pedestrian, Bicyclist, Other Cyclist, or Person on Personal Conveyances in Non-trafficway (Driveway)
			Pedestrian, Bicyclist, Other Cyclist, or Person on Personal Conveyances in Non-trafficway (Parking Lot/Other)
			Pedestrian, Bicyclist, Other Cyclist, or Person on Personal Conveyances Adjacent to Roadway (e.g., Shoulder, Median)
			Pedestrian Jogging/Running Adjacent to Roadway
Environmental Conditions	Weather	Wind	Severe Crosswind
			Wind from Passing Truck
		Precipitation	Clear/Cloudy
			Rain
			Sleet/Hail
			Snow
			Blowing Snow
			Freezing Rain or Drizzle
		Particulate Matter	Fog, Smog, Smoke
			Blowing Sand, Soil, Dirt
	Weather-Induced Roadway Condition	Roadway Obscured	Surface Under Water
			Splash or Spray from Another Vehicle
		Surface Condition (Including Low-μ)	Wet
			Snow
			Ice/Frost
			Sand
			Water (Standing or Moving)
			Mud, Dirt, Gravel
			Slush
			Surface Washed Out (e.g., Cave-in, Road Slippage)
			Loose or Slippery Surface (Mud, Gravel, Sand, Wet Leaves)
	Light Conditions	Ambient Light	Daylight
			Dark (Lighted)
			Dark (Unlighted)
			Dawn
			Dusk
		External Lighting	Reflected Glare, Bright Sunlight, Headlights

Top-Level Category	Immediate Subcategory	Detailed Subcategory	Scenario Variable
Zones	Special Zone	Special Zone	Special Zone
	School/ Construction Zone	School Zone	Pedestrian, Bicyclist, Other Cyclist, or Person on Personal Conveyances Going To or From School (K-12)
		Construction Zone	Construction
			Utility Work
			Maintenance
	Interference Zone	Natural Conditions	Dense Foliage

Table 9.
Threat Variables

Top-Level Category	Immediate Subcategory	Detailed Subcategory	Scenario Variable
Physical Infrastructure	Roadway/Lane Edges	Lane Marking Type/Quality	No Markings or Obscured Lane Markings
Operational Constraints	Traffic Conditions	Altered Traffic Flow	Recent Previous Crash Scene Nearby
			Police Pursuit
			Stalled/Disabled Vehicle or Vehicle Fire
Objects	Signals and Signage	Local Traffic Control Missing	Inadequate Warning of Exits, Narrowing Lanes, Traffic Controls, Etc.
			Traffic Controls Not Functioning Properly
	Roadway Users	Standard Vehicles	[Other Vehicle] Aggressive Behavior by Non-Contact Vehicle Owner
			[Other Vehicle] Overloading or Improper Loading of Vehicle with Passengers or Cargo
			[Other Vehicle] Following Improperly
			[Other Vehicle] Travelling on Prohibited Trafficways
			[Other Vehicle] Passing Through or Around Barrier
			[Other Vehicle] Failure to Observe Warnings or Instructions on Vehicles Displaying them
			[Other Vehicle] Failure to Signal Intentions
			[Other Vehicle] Driving Wrong Way or On Wrong Side
			[Other Vehicle] Other Bad Driving
			[Other Vehicle] Disobeying Signs or Traffic Controls
			[Other Vehicle] Other Driving in the Wrong Place (e.g., Bike Lane)
			[Other Vehicle] Other Misbehavior – Moving (e.g., Not Dimming Headlights)
			[Other Vehicle] Other Misbehavior – Fixed (e.g., Open Door into Trafficway)
			Jackknife of Articulated Vehicle
			Nearby Trailer (Swerving, Swaying, or Fishtailing)
			[Vision Obscured by] In-Transport Motor Vehicle (including load)
		Other Non-Vehicle Users Permitted on Roadway	Non-Occupant Struck Vehicle
			Non-Motorist Inattentive, Careless, Distracted
			Non-Motorist Failure to Yield Right-of-Way
Objects (cont.)	Roadway	Other Non-Vehicle	Non-Motorist Failure to Obey Traffic Signs, Signals, or

Top-Level Category	Immediate Subcategory	Detailed Subcategory	Scenario Variable
	Users (cont.)	Users Permitted on Roadway (cont.)	Officer
			Non-Motorist Improper or Erratic Lane Changing
			Non-Motorist Failure to Keep in Proper Lane or Running Off Road
			Non-Motorist Passing with Insufficient Distance or Inadequate Visibility, or Failing to Yield to Overtaking Vehicle
			Non-Motorist Making Improper Entry To or Exit From Trafficway
			Non-Motorist Making Improper Turn or Merge
			Non-Motorist Improper Passing
			Non-Motorist Not Visible (Dark Clothing, No Lighting, etc.) or Failing to Have Lights On When Required
			Non-Motorist Operating without Required Equipment
			Non-Motorist in Roadway Improperly (Standing, Lying, Working, Playing)
			Non-Motorist Wrong-way Riding or Walking
			Non-Motorist Working in Roadway (Incident Response)
			Non-Motorist Entering/Exiting Parked or Stopped Vehicle
			Disabled Vehicle Related (Working On, Pushing, Leaving/Approaching)
	Non-Roadway Users	Stationary Object	Debris or Objects in Road
			[Vision Obscured by] Curve, Hill, or Other Roadway Design Features
			[Vision Obscured by] Building, Billboard, etc.
			[Vision Obscured by] Trees, Crops, Vegetation
			[Vision Obscured by] Not-in-Transport Motor Vehicle (Parked, Working)
		Dynamic Object	Struck by Falling Cargo or Something that was Set in Motion by Vehicle
			Non-Occupant Struck by Cargo/Debris
			Animal in Road
		Pedestrian	Pedestrian, Bicyclist, Other Cyclist, or Person on Personal Conveyances Dart-out
			Pedestrian, Bicyclist, Other Cyclist, or Person on Personal Conveyances Improper Crossing of Roadway or Intersection (Jaywalking)
			Pedestrian, Bicyclist, Other Cyclist, or Person on Personal Conveyances Crossing Expressway