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# SCENARIOS PRODUCED BY PROCEDURAL METHODS FOR DRIVING RESEARCH, ASSESSMENT AND TRAINING APPLICATIONS

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**ABSTRACT**

The objective of this paper is to discuss a procedural approach for designing and implementing driving scenarios including controlled hazard situations. Given a capable driving simulator, the development of appropriate driving scenarios is critical to applications in research, assessment and training. The scenario definition language (SDL) for implementing this procedural approach has been defined elsewhere. This paper describes examples of scenario elements, and overall integrated scenarios that have been prepared for specific applications involving research, assessment and training objectives. The SDL procedures can be subdivided into elements for control of roadway geometry, positioning of roadside elements, atmospheric conditions, as well as placement and control of traffic control devices, interactive traffic and pedestrians. SDL procedures are also used to select, control and position performance measurement opportunities and to control external hardware equipment. The visual elements controlled by the SDL can be used to set up a range of assessment and training options. Using the curvature and side slopes of roadway geometry combined with visibility conditions, limited site distance situations can be created to obscured traffic and pedestrians or upcoming intersections and traffic control devices. The placement and timing of signals and associated traffic and pedestrians can present situation awareness problems, which require detection, risk assessment and decision making on the part of the driver. More complex situations involving merging or speed variations of adjacent traffic also present situation awareness problems to the driver.

## INTRODUCTION

Procedural methods for designing scenarios and visual databases are critical for making driving simulators easily programmable and adaptable. Significant attention has been devoted to the development and application of procedural methods in recent years, e.g., (*1-7*). In designing driving scenarios, we wish to measure and train driver competence in tasks critical to safety. The driver must exert hierarchically structured skills in dealing with the complexity of the roadway environment. These skills, which include perceptual, psychomotor and cognitive functions required in vehicle navigation, guidance and control, must be applied competently to maintain system safety and performance.

As such, scenario development is important for defining a range of elements found in the driving environment including roadway geometry (e.g., horizontal and vertical curvature, intersections and traffic circles), TCD's (traffic control devices including signals, signs and markings), interactive traffic and pedestrians, and roadside objects (buildings and flora). Control of the timing of traffic, pedestrian and signals is also important in order to present critical hazards to drivers.

This paper describes the design of driving scenario elements and overall driving scenarios intended to train and/or evaluate driver behavior and skills using procedural methods. Scenario elements define the tasks required of the driver, including perceptual, psychomotor and cognitive behavior. Tasks are designed to elicit and test these behaviors, and performance measures are designed to quantify these behaviors. The driving scenarios control visual and auditory displays designed to train and/or assess driver behavior over the full range of critical hazards found in the driving environment. The combination of scenario elements and the desired performance measurement are emphasized in the scenario development process discussed herein.

## BACKGROUND

Databases for real-time simulation have traditionally been developed in graphics programs as composite 3D models. This approach requires extensive effort and experience with graphics modeling programs. The simplified method for scenario development considered here has been described previously (*5*). The so-called SDL (scenario definition language) described herein provides a simple procedural approach for scenario development. The events are defined by text statements in a simple syntax of the form:

**distance, event, attribute 1, attribute 2, …., attribute n**

where **distance** is defined along the path from the beginning of the run, the **event** refers to the procedure (e.g., road cross section, horizontal or vertical curvature, traffic, etc.) and **attributes** are specific to the type of event (e.g., curvature, location, speed, timing, etc.).

An example scenario text file is given in Table 1 which shows a short drive (5000 feet) with comments and various event specifications. The SDL text commands starts with roadway definitions and geometry. It then adds opposing traffic and activates a variety of roadside elements like speed limit signs, trees, and houses. At the end of the example, an intersection is created with a signal light and interactive cross traffic. SDL statements can be arbitrarily arranged since the program sorts all events according to distance during run initialization. This allows the user to group statements according to categories such as roadway definition, TCD's (signals, signs and markings), roadside objects, traffic, etc. or organize statements and events in a more linear fashion if preferred.

**TABLE 1 Example SDL Syntax**

```
-1, Define roadway sections
-1,
 0,ROAD,12,2,1,3,.5,10,10,.333,.333,0
         ,-1,-1,0,6,0,6,-5,10,-5,10,0
 1000,ROAD,12,4,2,2,.5,10,10,.333,.33
    3,500,-1,-1,0,10,0,10,5,10,5,10,0
 3000,ROAD,12,4,2,2,.5,10,10,.333,.33
    3,500,-1,-1,0,10,0,10,5,10,5,10,0
-1,
-1, Add some vertical curvature
-1,
1000,VC,500,0.005
2000,VC,1000,-0.0025
3500,VC,250,-0.01
-1,
-1, Throw in some opposing traffic
-1,
100,A,65,1000,-6,*1~4
1075,A,65,1000,-6,6
2000,A,65,1000,-6,*1~4
3100,A,70,1000,-6,*1~8
4500,A,65,1000,-4,*1~4
-1,
-1, Activate various events
-1,
0,TREE,50,10,0,30,70
0,SOBJ,200,15,0,0,0,0,
        Data\Signs\sp35mph.3ds
-1,
-1, Curve the road to the left
-1,
150,SIGN,4,1000
800,C,500,0,500,0,-.0025
1450,SOBJ,1000,15,0,180,0,0,
         Data\Signs\Rcurve.3ds
-1, Curve the road to the right
-1,
2850,SIGN,5,1000
3500,C,500,0,500,0,.002
-1,
-1, Show houses on both sides of the
street and add traffic and trees
-1,
1160,BLDG,1000,40,5
1160,BLDG,1000,-40,2
1165,BLDG,1000,40,3
1165,BLDG,1000,-40,4
1170,V,0,1000,30,1,6
1255,TREE,0,10,1,40,100
1300,TREE,50,10,1,40,100
-1,
-1, Display the intersection, signal
light and the signal ahead sign
-1,
170,I,0,2200,1
1700,SIGN,8,1977
1700,SL,2227,10,5,15,0,10,3
-1,
-1, Add some cross traffic in the
intersection
-1,
1700,CT,2206,5,100,95,R,5,1
1905,CT,164,5,80,50,R,7,1
1905,CT,140,5,-100,40,L,8,1
-1, End the simulation run
-1,
5000,ES
```

The SDL statements can control auditory displays and evoke specific performance measures. Auditory display (e.g., messages) can be presented as commands to the driver (e.g., "Turn left at the next intersection."), or for feedback during training (e.g., "You have just been issued a traffic citation for speeding."). Performance measures (e.g., steering and speed control, time-to-collision, and events such as accidents, speeding, road edge excursions, etc) can be evoked in conjunction with critical events to quantify behavior.

Depending on the research, evaluation or training objectives, e.g., (*8-11*), the desired drive exposure to the subject is flexible. Scenarios of various lengths (e.g., 10 minute exposures for training novice drivers or scenarios exceeding one hour for assessing fatigue and drowsiness) can be set up with the SDL (5) to require speed and steering control, situation awareness, hazard detection and risk assessment, decision making and action as discussed below.

## SCENARIO DESIGN AND DEVELOPMENT

Given a procedural method for defining scenarios, scenario design and development can proceed through a number of well defined steps. These steps are dependent on the SDL capabilities and the desired scenario, and will clearly vary from simulators employing visual databases. For example, scenarios for fatigue, drowsiness and inattention studies will probably be relatively long (one or more hours in length) and boring and may include occasional critical hazard encounters. High workload study scenarios might be short to medium length (less than a half hour) with a significant amount of critical hazards (traffic, pedestrians, limited sight distance). The steps that might be followed in scenario development can be summarized as follows:

**Scenario Definition** – Defining a scenario starts with a clear objective of the behavior desired of the driver, the performance measures of interest, the pace of the events and the overall length of the scenario. The scenario definition step is the equivalent of story-boarding a visual database or movie. Provided below is a process to begin the definition and development of a prototypical scenario.

1. Define the desired data that will be collected. This will determine the 'critical events' and driving sequences that will be incorporated into the scenario. During this step make sure that the simulator is capable of recording the desired data. For example, it may be desired to test a driver's perception to a critical roadway situation. As part of this test, it is desired to look at driver reaction time and the driver's behavior (decision action) during the task.
2. Design the critical events so that they will elicit the type of data desired. For example a merge event will require either a blocked or dropped lane and traffic in an adjacent lane that the driver must merge with. The exact timing can be determined later during scenario refinement.
3. Layout the roadway that will be used. Pay particular attention to the location of intersections, curves and hills. It is important to do this early on because the critical events and overall performance measures should be at roadway locations that are conducive to the event and where the roadway geometry is or is not a factor.
4. Add the critical events to the roadway and iterate between the roadway design and the events so that everything fits and the event spacing is sufficient. Positioning of the various elements is crucial because different events should not interact with one another (for example, dynamic vehicles carrying over into the next event).
5. Add the infrastructure. This consists of the static objects such as buildings, parked cars, trees, road signs, etc. that will make the scenario more interesting to the driver and may be important in terms of sight distance.
6. Add benign events. The final step in the storyboarding process is to add any desired benign events that will look like the critical events, but not cause the driver to react. This can be as simple as ambient traffic that is driving along the road, or more complex such as the exact same setup as a critical event but without the event actually occurring.

**Prepare Models -** A range of standard models of TCD's, buildings, flora, vehicles and pedestrians are available for selection by the SDL. However, special models may be required because of the locale of the simulation scenario (e.g., US, Europe, Middle East) that require a specific appearance of the scenario elements. New models can be prepared using standard graphical modeling tools, e.g., (*12-14*). Models can be prepared for the standard SDL events (buildings, flora, vehicles, pedestrians, signs), and for more complicated features such as specific intersections with special marking patterns and signal systems.

**Prepare Scenarios –** From an experimental design point of view, the scenario should be designed in convenient sub-elements that can be randomized or counterbalanced to avoid sequence patterns that may influence the results. Furthermore, if subjects will experience multiple drives, event sequence patterns that the subjects may learn, must be avoided. While one may develop highly detailed and individual scenarios to address these issues, the development hours required can often be unpractical.

The SDL affords several programming tools and shortcuts. The text files for the actual SDL can be assembled in any convenient text editor. Text editor macros can be developed to simplify programming, and several GUI's (graphical user's interface) have been developed to allow SDL programming on a point and click basis.

The SDL also allows the user to define grouped events referred to as previously defined events (PDEs) that are a combination of procedure statements that give a desired composite effect (e.g., buildings grouped around an intersection with traffic and pedestrians, traffic patterns associated with lane drop or merge situations, etc.). Parameters can be passed to a PDE each time it is called so that it will appear different (e.g., object component model, location, timing, etc.) for each presentation.

With PDEs using the same syntax as the overall scenario files (*5*), scenario development can be greatly simplified. The drive can be segmented and defined as PDEs, developed independently, and then assembled (in a counterbalanced manner if desired) into an overall scenario file.

**Run and Refine Scenario** – Scenario development is an iterative process, and many characteristics require adjustment as PDEs and scenarios are reviewed. Colors, locations, and timing of critical events need to be refined based on driving the events. The visual appearance may suggest more or less visual complexity depending on subjective assessment and the objectives of the application. Examples of scenario elements that are designed to train and/or assess given driver behaviors are given below.

## SCENARIO ELEMENTS

### Roadway Geometry

Roadway geometry includes horizontal and vertical curvature, the cross section profile (slope) of the roadway, shoulders and side slopes, and intersections. This SDL capability has been described previously (*5*). Several examples of typical roadway geometries are illustrated in Figure 1.


**FIGURE 1 Roadway Geometry Examples**

Horizontal curvature can be used to require road geometry perception and speed control of the driver in order to safely negotiate a curve. Figure 2 shows a typical curve with definitions of radius of curvature and length. Curvature determines the safe speed at which a curve can be negotiated. The speed is influenced by the lateral or centripetal acceleration ($a_c$) encountered by the vehicle. Centripetal acceleration is function of the vehicle forward speed ($U$) and radius of curvature of the curve, and radius of a curvature ($R$) is also the inverse of curvature ($C$):

$$a_c = U^2 / R = CU^2$$

The tires on a car usually limit its cornering capability to about 0.8 g's (25.7 feet/sec$^2$, 7.83m/sec$^2$), and drivers will typically limit their cornering acceleration to less than 0.5 (16.1 feet/sec$^2$, 4.90m/sec$^2$) except under emergency maneuvering conditions. Furthermore, the advisory speeds posted on curve warning signs are set to give a lateral acceleration of about 0.22 g's = 7.1 feet/sec$^2$/(2.16m/sec$^2$). The length of a curve determines how much of an angle the driver will turn through, where the angle ($\varphi_c$) and length ($L$) are related to the radius ($R$):

$$\varphi_c \text{ (radians)} = L/R$$

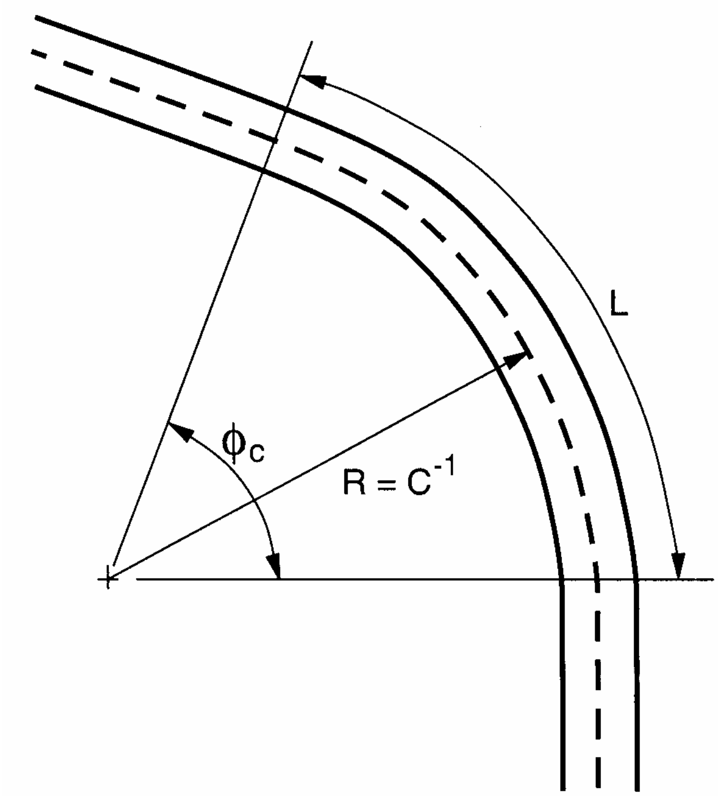


**FIGURE 2 Horizontal Geometry Definitions**

Some examples of curvature, advisory speeds and lengths are given in Table 2.

**TABLE 2 Examples of Curvature and Typical Speeds**

| Curvature, feet$^{-1}$ (meters$^{-1}$) | Radius, feet (meters) | Advisory Speed, mph (kph) | Curve Length for 30° Turn, feet, (meters) | Curve Length for 45° Turn, feet, (meters) | Curve Length for 90° Turn, feet, (meters) |
|---|---|---|---|---|---|
| .001 (.00328) | 1000 (304.8) | 57.3 (92.2) | 523.6 (159.6) | 785.3 (239.4) | 1,570.7 (478.7) |
| .003 (.00985) | 333 (101.5) | 33.0 (53.2) | 174.4 (53.1) | 261.5 (79.7) | 523.0 (159.4) |
| .01 (.0328) | 100 (30.5) | 18.1 (29.1) | 52.4 (16.0) | 78.5 (23.9) | 157.1 (47.9) |
| .03 (.0985) | 33.3 (10.2) | 11.4 (16.8) | 17.4 (5.3) | 26.2 (8.0) | 52.3 (15.9) |

The largest curvature (smallest radius) in Table 2 is typical of cornering at right angle intersections. The smallest curvature (largest radius) might be found on high-speed highways. Geometry hazards can be evoked by having a curvature with a critical speed well below the speed limit. Performance measures might include longitudinal acceleration profiles in approaching the curve and lateral and longitudinal acceleration profiles within and when exiting the curve.

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### Intersections and Traffic Control Devices

Examples of intersection events are illustrated in Figure 3. Intersections can be set up with traffic, pedestrians and traffic control devices to test subject situation awareness, hazard detection and decision-making. Road geometry is used in combination with intersections as illustrated in Figure 3 to control sight distance that is an added issue of complexity. Traffic, pedestrians and signals can be set up with critical timing as discussed later to present critical hazards to subjects.

**FIGURE 3 Intersection Examples**

### Limited Sight Distance

Critical hazards can be set up in a variety of situations that involve limited sight distance. The key element in setting up critical hazards is to deterministically control perceptual and timing variables. Sight distance restrictions can be setup so that, given a speed limit the time to reveal hazards such as traffic, pedestrians or in-road obstacles is within critical values for perception/reaction time. Perception/reaction time can range from 0.75 to 3.00 for driving depending on the perceptual and decision making tasks, e.g., (*15*). Limited sight distance situations can require some iteration to develop critical timing.

Figure 4 shows how limited site distance can be produced in a scenario by several different means. Two scenes include the use of roadway geometry where a combination of horizontal and vertical curvature and side slopes can obscure upcoming hazards such as intersections, vehicles or other objects in the roadway. Using atmospheric conditions such as fog can also provide limited sight distance effects. Another example provided is the use of other vehicles or objects in the environment. In Figure 4, one scene shows how a walking pedestrian (circled) is obscured by the parked bus as the vehicle enters the intersection.

### Timing

Critical hazards can also be determined by controlling the timing of signals and the motions of traffic and pedestrians relative to the subject's vehicle. For example, pedestrians and vehicles can be timed to encroach on the subject's path based on vehicle speed. Some encroachment scenarios are illustrated in Figure 3 and Figure 5 involving signals, pedestrians and vehicles. If the subject is traveling at a forward velocity of $U_s$, then the signal timing or encroachment can be controlled to a critical time $T_c$ by triggering it at a distance $D_c$ where

$$D_c = U_s \bullet T_c$$

For traffic signals, the trigger time is set close to the yellow light interval to required the subject to make a stop or go decision (i.e. the yellow light dilemma). Adjacent and approaching vehicles can be commanded with motions relative to the subject vehicle speed and separation distance to move into the subject's lane as illustrated in Figure 5. Vehicles traveling in the same direction can also be commanded to decelerate with their brake lights activated or not. For two lane road scenarios, passing tasks can be set up as illustrated in Figure 5 where a slow vehicle is impeding the subject's progress. Gap lengths can be set in an approaching vehicle procession based on the speed of the slow lead vehicle that dictates the time required to pass. Gap lengths can be varied to teach subjects to correctly judge adequate spacing. Cross traffic at intersections can be set up similarly with critical gaps as illustrated in Figure 5 to teach gap acceptance. In this case adequate field of view is required so that the subject can see approaching vehicles.


**FIGURE 4 Limited Sight Distance**

**FIGURE 5 Situations Involving Vehicle Timing**

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**Situation Awareness**

Situation awareness involves monitoring the roadway environment for hazards or in anticipation of maneuvering. The subject must pay attention to roadway geometry, traffic control devices, and other traffic, pedestrians and obstacles. Situation awareness is probably the skill that takes the longest to develop in new drivers, and deficiencies in this skill are probably at the root of the high accident rate during the first few years of driving (*9*). Scenarios for training situation awareness need to emphasize cognitive complexity with limited site distance, traffic control devices, and interacting traffic and pedestrians as illustrated in Figures 3 and Figure 6. As part of this complexity adjacent vehicles can be positioned in the subject vehicle's blind spots to complicate lane changing. Other traffic is then programmed to force the subject vehicle to maneuver. These situations require the subject to monitor TCD's, traffic and pedestrians through the windscreen and rear view mirrors in order to maintain safety and performance in the driving scenario.


**FIGURE 6 Examples of Circumstances Requiring Situation Awareness**

**Look and Feel**

Given that events have been assembled to evoke and/or train behaviors discussed above, driving scenario design finally comes down to visual appearance. The appearance might relate to objectives depending on how visual distraction is desired in the scene, or could be required by the intended geographical setting. Scenes for various geographical settings and road conditions are shown in Figure 7. Some of the appearance derives from the horizon scene, lighting effects and ground plane texture which are specified globally through configuration variables as discussed elsewhere (*16*). Specific models must also be prepared or supplied to vary the geographical local and setting illustrated in Figure 7. Horizon scenes and model elements (buildings, flora, pedestrians and animals) can be defined to be appropriate for the setting. Pedestrians and animals are animated and the speed of animation can be varied within the SDL commands in order to vary the apparent walking velocity. An animation could also be prepared for running if required in a scenario. The movement velocity is an appropriate consideration for setting event timing in critical situations.

**FIGURE 7 Variations in Scenario Appearance**

**Performance Measures**

Global performance measures are available for every scenario as summarized in Table 3. Performance measures include the number of occurrences of various safety related events, and the minimum time-to-collision (TTC) and closest approach distance during encounters with all vehicles in the scenario. If the subject has a closing range and range rate of $R$ and $\dot{R}$ with respect to another vehicle then $\mathrm{TTC} = R / \dot{R}$. The minimum TTC and associated range are saved for each vehicle encounter. The minimum TTC typically occurs prior to minimum range when the closing range rate is near its maximum. Dynamic data blocks can also be saved over specific distances to capture data surrounding a specific event (e.g., the lateral and longitudinal accelerations associated with a curve encounter). The data is collected in a text file that can easily be exported to spreadsheets for further manipulation and interfacing with standard statistical analysis packages, e.g., (*17,18*).

**TABLE 3 Global Performance Measurement Summary**

- Total number of off road accidents
- Total number of collisions
- Total number of pedestrians hit
- Total number of speed exceedances
- Total number of speeding tickets
- Total number of traffic light tickets
- Total number of stop signs missed
- Total number of centerline crossings
- Total number of road edge excursions
- Total number of stops at traffic lights
- Total run length
- Time-to-collision (TTC) and minimum distance for each vehicle encounter

## CONCLUDING REMARKS

Scenario development is key to providing driving tasks and environments for research, assessment and training. Driving scenarios must be designed to test the full range of driver behavior including perception, psychomotor response and more cognitive behavior. Procedural methods as discussed herein simplify the scenario design process. Performance measures are key to research, assessment and training objectives and are included as part of the SDL (scenario design language). Procedural methods for scenario development simplify the process of programming and modification. Useful elements can easily be incorporated in new scenarios. The SDL text syntax discussed here is relatively easy to use, and GUI's have been developed to allow composing the text files with point and click methods. Future work will be devoted to increasing the number of available scenario events, data base models and performance measures and the development of GUI's for further simplification of the procedural process for designing driving scenarios.

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