DEVELOPING SCENARIOS TO DETERMINE EFFECTS OF DRIVER PERFORMANCE: TECHNIQUES FOR AUTHORING AND LESSONS LEARNED

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ABSTRACT

This paper overviews the development process for driving simulation scenarios used to obtain information about driver performance. The scenarios were targeted for use on the NADS. The development process entails the conversion of the original experimental requirements into specific interactions between the driver and the traffic or roadway. These interactions, along with the measures that would categorize performance during the interaction, are mapped into sequences that meet the experimental criteria. Following the interaction definition, the NADS scenario authoring tools were used to orchestrate the traffic so that the interactions took place reliably, consistently and independent of individual driver differences. This process, even though eventually successful, turned out to be more challenging than originally anticipated. The paper describes some of the issues that complicated this development and how these issues were addressed. In addition, the paper includes a couple of relevant examples. Interesting trends and lessons learned from this process are described in the paper in the hope that they will benefit developers and researchers faced with similar challenges.

INTRODUCTION

In most driving simulator studies, researchers expose participants to specially designed virtual environments within which they encounter specially designed situations. Participant's responses during these situations are then measured and analyzed in order to validate a hypothesis. In the real world, drivers encounter and react to hundreds of situations daily. The situations vary greatly from one driver to another and it takes a significant amount of driving until a given driver is exposed to similar situations that require similar responses. In a simulator however, researchers would like the participants to encounter a known number of specific situations within a relatively short amount of time so their responses to those situations can be measured. The goal of scene and scenario design is to create a virtual driving environment that will naturally create the required situation in a driving simulator within the relatively small amount of time that the participant drives the simulator.

The difficulty of developing these scene and scenarios varies greatly depending on the researcher's requirements. In general, it has been our experience that severe or emergency reactions, from the participant, are far easier to elicit when compared to more subtle "behavioral" reactions. For example, it is relatively easy to elicit an emergency response such as hard braking or steering than it is to elicit a lane change. Specifying the details involved in authoring such mundane events becomes more of a challenge.

This paper describes the process by which scenarios are developed for use in the National Advanced Driving Simulator (NADS). The goal of most studies is to assess some measure of driving performance. In preparations for these studies, scientists use the original research hypothesis to identify a broad class of events that provide sensitive measures to validate the hypothesis. Graphical database designers convert these events into a scene and scenario designers produce a scenario specification document which they use to design and implement the actual scenarios. There are several challenges involved in this process, the biggest of which entails the actual conversion from the original events, whose description is given in a narrative form, into a detailed technical specification document that a developer could use to author the scenarios. Several lessons are learned during this entire process, and we believe they are applicable to any high fidelity driving simulator project that involves sophisticated scenarios as part of a research study.

The remainder of the paper is organized as follows. The first section provides a brief overview of the NADS tools and how they are used for scenario development. In addition, this section defines some terminology that is very critical in properly communicating the scenarios. The general scenario requirements for the project are described, followed by challenges that are encountered during the development. The developed scenes and scenarios are then described followed by a conclusion that includes various lessons learned during the process.

SCENE AND SCENARIO DEVELOPMENT AT NADS

Scene and scenario development at NADS utilizes several graphical tools that allow developers to rapidly develop the necessary data files and other artifacts needed for the simulator. As long as a detailed and consistent specification exists, the time it takes to actually develop the scenes and scenarios has been drastically reduced when compared to previous experiences when such tools were not available (*1*). In general, we talk about scene and scenario development as two different things, even though conceptually they are tightly related. Scene development refers to the development of the static aspects of the virtual environment. This primarily includes the roadway geometry, cultural features and any static traffic elements such as signs or stationary vehicles. Scenario development refers to the development of the dynamic aspects of the virtual environment. This includes moving traffic, traffic lights, pedestrians etc.

Generally, scene development must take place before scenario development can proceed. For example, a road must exist before traffic can be placed on it. Unlike other scenario authoring systems where the scene is defined procedurally (*2*), scenery at NADS is represented as multiple correlated databases that must be created before hand. Specifically, the NADS tools make use of a library of individual tiles that can be combined into larger areas with little effort. Each tile may span a city block, a section of highway, or a group of far-away buildings. Tiles are grouped according to their location, so there are highway tiles, urban tiles, city tiles etc. The tool that combines tiles into larger scenes knows when tiles can be placed adjacent to each other by looking at their edge compatibility. When tiles with compatible edges are placed adjacent to each other they provide a seamless transition so that a driver cannot tell that they cross a tile boundary. If necessary, new tiles can be created to fulfill specific project requirements (such as curves with specific curvature), but once built they can easily be re-used as necessary.

Once the scene is developed, scenarios can be authored. The term *scenario* is often used to mean everything that happens in a simulator, however, within the context of the NADS development process it refers to a set of specific attributes as follows:

- Ambient traffic and its attributes
- Ambient environment and simulation conditions
- Research participant starting position and route
- Series of events that will occur while the participant drives along the route
- NADS specific parameters.

Ambient Traffic

By definition, ambient traffic is traffic that has little or no intentional interaction with the participant. Typically, traffic on the opposite lane on a divided highway or traffic that is located far ahead or behind the driver is considered ambient traffic. Note that it is possible to have interactions between ambient traffic and the participant, but conceptually, we refer to traffic as ambient when there is no *intent* of interaction. Ambient traffic serves many purposes. It provides familiarity and normalcy for the research participant in situations where traffic is expected such as city or urban/arterial streets. It also enhances the degree of realism of the overall experience. When located on the same road as the driver, the density of traffic puts the participant in a specific driving mode. Finally, ambient traffic can also be used to provide a specific vehicle that will create a specific interaction with the driver.

Specification of ambient traffic is often done with some composition specification (i.e., 80% cars, 20% trucks) and a composite density figure, for example vehicles per mile per lane. However, numerous additional parameters could be specified depending on the fidelity of the driver model used to implement the traffic. In the NADS, in addition to density and composition, several additional vehicle specific parameters can be specified, either as specific values or as ranges within which randomization occurs. These parameters include percent deviation from the speed limit, follow behavior in terms of follow distance/time and reaction delay, lane deviation behavior, and lane change behavior.

Ambient Conditions

Associated with each scenario are a set of ambient environmental conditions, along with simulation specific parameters. Time of day, visibility, precipitation, and wind velocity are just a few examples of parameters that can be specified under this category. In addition, the disposition of collisions can also be specified. Collision disposition is important because under certain circumstances, such as when the participant is not aware that they collided with a scenario vehicle, it may be beneficial to continue the simulation after a collision.

Starting Position and Route

With few exceptions, all scenarios take place on a known route, and as such, the initial position as well as the route must be specified. An important component of each scenario is the method by which the participant is guided through the intended route. Verbal instructions, especially simple ones such as "always go straight", can be used, although other methods such as following signs or following a given road can also be employed. Another important aspect of the scenario is how the participant is instructed to begin driving. Depending on the scenario organization, it may be necessary for the driver to wait until a certain vehicle goes by or until some other event has initiated.

Series of Events

The series of events that the driver encounters is by far the most important aspect of the scenario. Here, the term *event* refers to a specific interaction between the participant and the roadway, own vehicle, or other scenario vehicles. Events can occur sequentially or in parallel. Note that we differentiate between specific events and random interaction that the participant may encounter with ambient traffic. It is important that events occur consistently for all drivers exposed to the same scenario.

In general, events can be as simple as driving along a curve or may involve complicated interactions between the participant and multiple scenario vehicles. In all cases however, events involve exposing the participant to a situation and measuring their response to that situation. Using the NADS scenario authoring tools, events requiring interaction among multiple entities are generally authored by using triggers. Triggers can be thought of as <predicate, action> pairs. A given trigger continuously monitors its predicate and when it is true, it performs a set of actions. For example, one can author a trigger that turns a traffic light yellow when the driver crosses a certain point on the road. In this case the predicate would be the driver crossing a point on the road and the action would be the change in the traffic light state. Related to the notion of triggers are the notion of an *instigator set* and the *candidate set*. The instigator set is the set of entities, generally other scenario vehicles, which can cause a trigger's predicate to become true. The candidate set is the set of entities that can potentially be affected by the trigger's actions. In the prior example, the instigator set would include the driver and the candidate set would include the traffic light.

Even though triggers are simple in principle, they can be extremely powerful depending on how flexible the predicates and the associated actions can be. Similarly, the flexibility in selecting the instigator and candidate sets can dramatically increase the authoring power of triggers as well as the authoring complexity. When using the NADS tools, predicates include, but are not limited to the following:

- Crossing a specific point on the road network
- Traffic lights arriving to a specific state
- Simulation time reaches a threshold
- Time to arrival of an entity to a fixed point is equal to a threshold

Actions can be selected from a wide variety of options. Generally, some actions involve specification of a candidate set whereas in other actions the candidate set is implicit. Actions can include the following:

- Create a new scenario vehicle
- Delete an existing traffic element
- Change the state of a traffic light
- Play a pre-recorded sound
- Cause vehicle failures (blown tire, failed brakes etc.)
- Force an autonomous entity to behave in a specific manner that may be contrary to its autonomous behaviors. This includes any of the following:
    - Change speed based on a given acceleration profile, including accelerating, braking, tracking the driver's speed or following a periodic speed pattern
    - Change lane
    - Turn on or off any of the scenario vehicle lights
    - Force a specific lane deviation
    - Take a turn
    - Track another moving object by maintaining a fixed longitudinal distance relative to it
    - Produce a sound (i.e., honk)

In addition, selection of the instigator set can be done by vehicle type, entity name, geometric position, lane position, or selected by one's relative position to the participant. Similarly, the candidate set can be selected with similar methods or can be set to be equal to the instigator set.

As an example, one can use a trigger that will fire when the driver is 30 seconds away from arriving at the intersection and when the trigger fires it can force the vehicle ahead of the driver to accelerate while forcing another vehicle that happens to be ahead but on the left lane to change lanes to the right, in effect cutting in front of the driver.

NADS Specific Parameters

In addition to general scenario features, the NADS authoring tools provide some facility specific capabilities that may or may not be relevant in other high fidelity simulators. Specifically, it is possible to pre-position the NADS motion base to improve the motion cue fidelity based on the knowledge of upcoming scenarios. It is also possible to change selective characteristics of the motion base, again to accommodate upcoming events. Generally, such parameters have no visible effect on the scenario.

SCENE AND SCENARIO DEVELOPMENT ISSUES

Given access to various tools that allow rapid development of scenes and scenarios, one can easily author such scenarios given a precise specification. However, precise technical specifications have to be derived from initial requirements, and there are several issues that hinder this conversion process. This section discusses some of these issues along with potential mitigating factors. A common mitigation factor for all of these issues is performing small pilot studies to assess the success of a given scenario.

Describing outcomes as opposed to situations

When thinking about a scenario, it is very tempting to think about the desired eventual outcome as opposed to a situation that could lead to that outcome. Even though knowing the outcome is useful, there is significant design work involved in the development of the situational opportunity that may or may not lead to the desired outcome. Usually, more than one method exists to reach a given outcome but only a few of these methods may be consistent with the overall experimental design. Furthermore, by only describing the outcome there is no guarantee that there is a consistent way of causing the desired outcome at the required frequency during the relatively short simulator drive.

As an example, consider an "event" that consists of the participant performing a lane change. This description alone provides the outcome, not the framework within which the participant will have an opportunity to perform the lane change. A better way to specify this event is to provide the context within which the lane change interaction can take place. For example, specifying that a lead vehicle will slow down in order to cause the driver to lane change is much more useful as an event specification. Other methods for causing that event may include shutting down a lane, putting up a sign warning of an upcoming lane closure. One can see how each of these techniques may or may not be applicable in a given research study, so specifying the contextual framework as early as possible is very important. Researchers and scenario developers must develop a common language for discussing the alternative techniques and their associated specification requirements.

Underestimating a Participant's Unwillingness to Engage

A lot of events require the driver to engage in some activity, driving or otherwise. Different drivers' willingness to engage in the same activity can vary greatly. As a result, events that depend heavily on the driver engaging, or even accepting, to be part of a given situation can be problematic unless explicit steps are taken. As an example, consider an event that requires a lead vehicle to brake, at a known lead time (i.e., 1 sec), ahead of the participant. If the participant follows the lead vehicle at 1 second, then causing the event is easy, however, getting the lead vehicle to the right position can be very challenging if the participant is unwilling to follow so close. Having a vehicle located directly ahead of the driver slow down until it reaches the desired lead distance will certainly cause the participant to slow down in order to maintain their comfort following distance. Another example of situations of that nature includes assuming the participant will drive a certain speed or that they make a phone call at a given point.

Addressing this issue depends heavily on the situation. In general, events must be designed so that participants are not put into a situation in which they feel undue pressure to perform a task that they are not comfortable performing. Strategies to help the participants deal with complicated events can take the form of simply telling them exactly what to do, but it has been our experience that in a high fidelity simulator the ambient realism is such that participants will flat out refuse to do things that they consider unsafe. Specific to achieving a specific following distance, we have found that having a vehicle pass from the left and perform a lane change in front of the driver, much like a cut-in, is much more acceptable than a far ahead vehicle slowing down. A far ahead vehicle slowing down will almost always cause the participant to slow down. Other mitigation strategies include providing participants with monetary incentives.

Incorrectly Predicting Participants Reactions

When presented with the same situation, different drivers will react differently. Even though it is possible to require scenarios where the driver's decision is the measurable outcome (when a lead vehicle brakes, will the driver brake or steer?), more often the driver is expected to behave within a relatively narrow set of conditions that are to be measured for the particular study (when the lead vehicle brakes, the driver *will* brake in order to measure brake force). The problem in such situations is that the driver may react in a way that was not originally anticipated.

Addressing this issue requires that the design of the event constrains the driver choices to fall within the range of acceptable responses. This has to be done in a way that the driver is not aware that their choices to an upcoming event are constraint. For example, if the required response to a lead vehicle slowdown is braking, a vehicle placed on the left lane blocking steering can help ensure the participant will perform as expected. Note that the participant may decide to steer to the right onto the shoulder. This leads to the next issue.

Assuming Events Will Always Work Out

No matter how carefully one plans for an event, sooner or later something will go wrong in a way that invalidates the event. Here, the word "invalidates" refers to an outcome that provides no useful performance data. Whereas missing data for a given event may be a recoverable issue in isolation, an event that did not work out can easily spoil upcoming events causing much more damage than the event itself. As a very simple example consider a participant that misses a turn because they were distracted by a cell phone conversation. If there is no recovery route, then the remainder of that scenario is lost. Similarly, if a missed event is supposed to leave a scenario vehicle in a certain position for use in the next event, the next event is affected as well.

Mitigating this issue requires that there is a recovery plan for each event in a scenario. To some degree, this is a brute force approach solution, but the event design should be such that if the event does not take place, it is still possible to continue with the remaining events in the scenario. In cases where this is impossible, there should be re-start scenarios. A re-start scenario is a subset or the original scenario in the sense that its start point is on the route of the original scenario but beyond the location where some of the events would occur. In case of a problem, the appropriate restart scenario can be used to complete the remaining events.

Incomplete Specification of Ambient Details

Often times, specifications about the characteristics of the ambient traffic or ambient environment are missing or incomplete. This is fine in cases where such characteristics do not affect the outcomes of individual events, but it is often the case that variations in these ambient characteristics of a scenario can make a drastic difference on how participants perceive the scenario. For example, consider the specification of ambient traffic. If only density and composition are specified, then there are numerous other parameters about the ambient traffic behavior that can change the scenario. Another simple example is the use of a dramatic sky texture that includes colorful cloud formations, as opposed to a very basic empty blue sky. Specifying the look of the sky is generally part of any scenario specification, but depending on the situation it may make a difference. A related problem is the fact that different simulators have different capabilities on how much such characteristics can even be controlled or to what degree. Specifically at NADS, we have found that the lane change and lane deviation parameters can make a very big difference in the participant's qualitative perception of the ambient traffic. Enabling lane changes and increasing the lane deviation frequency and amplitude produces very aggressive and challenging traffic environment, especially when vehicles on the same direction as the participant are involved. This increases the perceived workload of the participant, and also tends to distract the participant who may spend time looking at a car weaving left and right as opposed to worrying about the task at hand.

Unfortunately, this is one of the issues whose solution is more of an art than a science. The level of autonomy available for vehicles in the traffic stream is so complex that it is not possible to anticipant how vehicles will interact with each other and with the participant. Thus, to perform experimental research, some realism will need to be traded for experimental control. Determining the nature of this tradeoff is a judgment that must be made by the research team. Awareness of such an issue is a good first step. Establishing a requirement for how "transparent" the ambient traffic and environment in general should be combined with pilot testing can go a long way towards mitigating the issue.

Testing Scenarios Using "Simulator" People

Anyone working with driving simulation quickly realizes that using staff members involved in driving simulation as research participants, or even as preliminary internal subjects has severe limitations. It has been our experience that in general, developers focus on technical issues that most common drivers don't even perceive. Knowledge of a scenario also has a tendency to make people conform to the expectation, something that research participants won't necessarily do. We have had limited success in using staff members that are not aware of a scenario as preliminary test participants, but once they have driver a given scenario a few times, their usefulness in anticipating general population response to the scenario is all but eliminated.

Even though driving a scenario to check out technical aspects of the scenario implementation is possible, there is no substitute for using one or more pilot studies to find out how actual research participants will react to the events in a scenario.

Too Many Events in a Short Scenario

When calculating the total exposure time in the simulator, there is a tendency to sum up individual event durations and coming up with a number that is supposed to approximate the total simulator exposure. The problem with this is that there is significant time involved in re-configuring the ambient traffic after one event so it is ready to participate in the next event. Cramming too many events while trying to maintain a fixed total scenario duration is a symptom of the same fundamental problem, that is, event sequencing takes longer than anticipated.

Generally, early testing of scenario implementation quickly reveals any inconsistencies in timing; however, it is always better when timing estimates can be accurate up front. We have also found out that utilizing non-interactive but real-time animations of traffic can be very useful in estimating reasonable amounts of time for transitioning between events.

SPECIFICATION METHODOLOGY

Whereas individual event specification can be made complete enough to avoid most of the common pitfalls mentioned above, there are a couple of logistical issues that hinder the rapid development of scenarios. First, individual events need to be combined into a single scenario. Second, multiple scenarios containing more or less the same events but in different order must often be developed for a study.

The specification methodology utilized for a study has morphed through several iterations as various studies have been run on the NADS. The current and latest methodology for scenario specification involves providing specific information about each event in isolation. In addition, a sequence of events is established on the route that the participant will take through the virtual environment. Depending on the study, there are several such sequences of events and each one ends up being a different scenario.

Each event is specified in multiple sub-sections. The *baseline* section describes any assumptions about the ambient traffic before the event orchestration even begins. In the study that is described later in the examples, it was decided to avoid the use of truly randomized ambient traffic around the participant. Instead, a cloud of vehicles was created around the participant, with each vehicle serving a specific purpose. Following the baseline section is the *preparation* section. This section involves activities that setup for the actual events, for example placing vehicles in key locations or creating vehicles that will later interact with the participant. In general, the participant is not expected to be aware of the preparation phase. The next section is the actual *event* section, which describes the situation and how it provides the opportunity for the event to take place. Even though not shown in the descriptions provided in this paper, this section lists any quantitative variables (i.e. time-to-collision before a vehicle failure) involved in the event along with their acceptable tolerances. The last section, called the *cleanup* describes what happens after the event. Assumptions and potential outcomes are listed for scenario events that depend on the participant’s actions for successful outcomes. For such events, the “exit” strategy from an event when it is unsuccessful is also discussed.

When stringing events together, one can review the baseline section of second event and compare it with the cleanup section of the first event to ensure that they are compatible. Compatibility here means that through some reasonable preparation, as described in the preparation phase, the exit conditions of one event can be used to setup for the next event.

Finally, the section titled Notes provides a placeholder for general discussion or where concerns or comments regarding the event can be documented. Figures are provided whenever possible to clarify and detail.

EVENT DESCRIPTION EXAMPLE

This section provides an actual description of the events utilized in one of our studies. The description follows the semi-formal format described earlier, and is meant to be used as an example of specifications that are adequate for implementation with a reasonable expectation of success. Note that detailing the experimental rationale for the scenarios is beyond the scope of this paper.

Lane Change Cut-In

Baseline

The participant is traveling on the rightmost lane of a highway with 2 lanes going in each direction as shown in Figure 1a. There are one or more vehicles in the left lane. There should be no vehicles within 200 feet ahead of the driver on the left lane to allow the cut-in vehicle to accelerate.

Preparation

The 2 closest vehicles, ahead of the participant in the left lane, perform a lane change to the right lane as shown in Figure 1b. This clears up the left lane to allow the event.

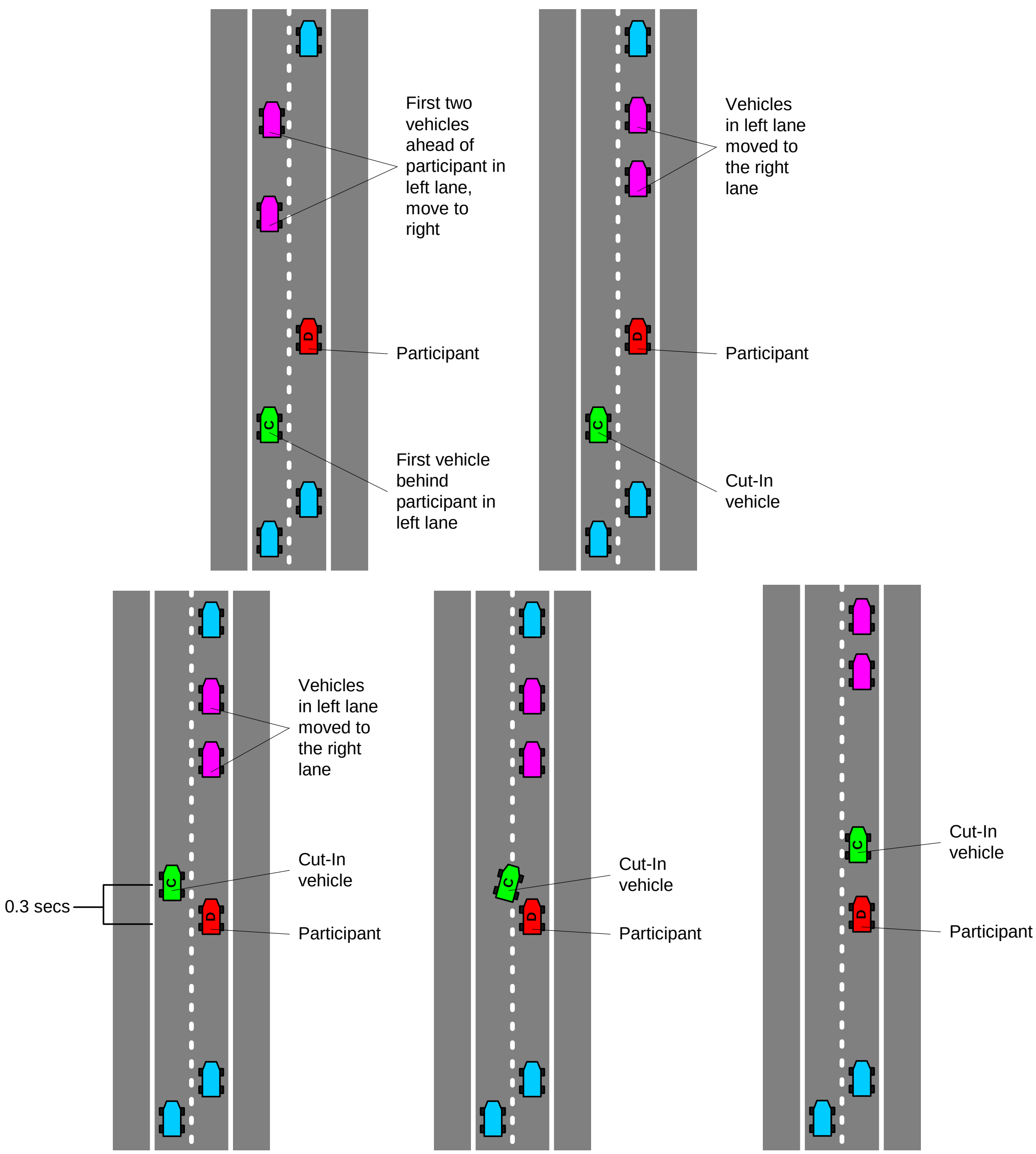

Figure 1 – Lane Change Cut-In Event.

Event Description

The first vehicle behind the participant in the left lane accelerates and positions itself 0.3 seconds ahead of the participant in the left lane (Figure 1c). The vehicle continues this maneuver until it has reached the desired location or 7 seconds have elapsed. A time-limit is necessary as there might be other vehicles blocking its path in the left lane. The vehicle closest in front of the participant in the left lane, sets its own velocity to be the same as the participant at that given moment in time. Finally, this vehicle performs a lane change to the right immediately ahead of the driver thus cutting in front of the driver (Figure 1d and Figure 1e).

Cleanup

The vehicle that cuts in front of the driver accelerates and maintains a gap of 150 ft ahead of the participant in the right.

One potential problem is a driver that goes too fast thus allowing a lot of cars on the left lane to pass. Since scenario vehicles will not lane change on their own, it is possible to get a long string of cars on the left lane that prevent the selected vehicle from reaching its intended gap before the cut-in.

Lead Vehicle Brake

Baseline

The participant is traveling on the rightmost lane of a highway with 2 lanes going in each direction. There are one or more vehicles traveling ahead of the participant in the right lane (Figure 2a).

Preparation

The lead vehicle adjusts its velocity to maintain a gap of 70 ft ahead of the participant at an acceleration rate of no faster than 2.5 m/s2 and a deceleration rate of no faster than 1.0 m/s2 (Figure 2b). This vehicle continues this maneuver until it has reached the desired distance or 5 seconds have elapsed. A time-limit is necessary as some participants may react by reducing their velocities thus forcing the lead vehicle to perform this maneuver for an indefinite period.

Actual Event

The lead vehicle turns on its brake lights and tries to close the gap to the participant from 70ft to 30ft at a deceleration rate no faster than 4.0 m/s2.(Figure 2c). The lead vehicle continues this braking maneuver until it has reached the desired gap or 6 seconds have elapsed. A time-out is necessary as the participant will most likely react by braking and thus forcing the lead vehicle to perform this maneuver indefinitely in order to reach the desired gap. Once the lead vehicle achieves the gap or the time-limit has expired, it turns off its brake lights and accelerates to maintain a gap of 150 ft ahead of the participant in the right lane (Figure 2d).

Cleanup

After a few seconds, the lead vehicle reverts back to normal behavior.

Even though the deceleration rate was tweaked during the pilot study to ensure that participants do not react early, it is possible for participants to decelerate during the initial slow down.

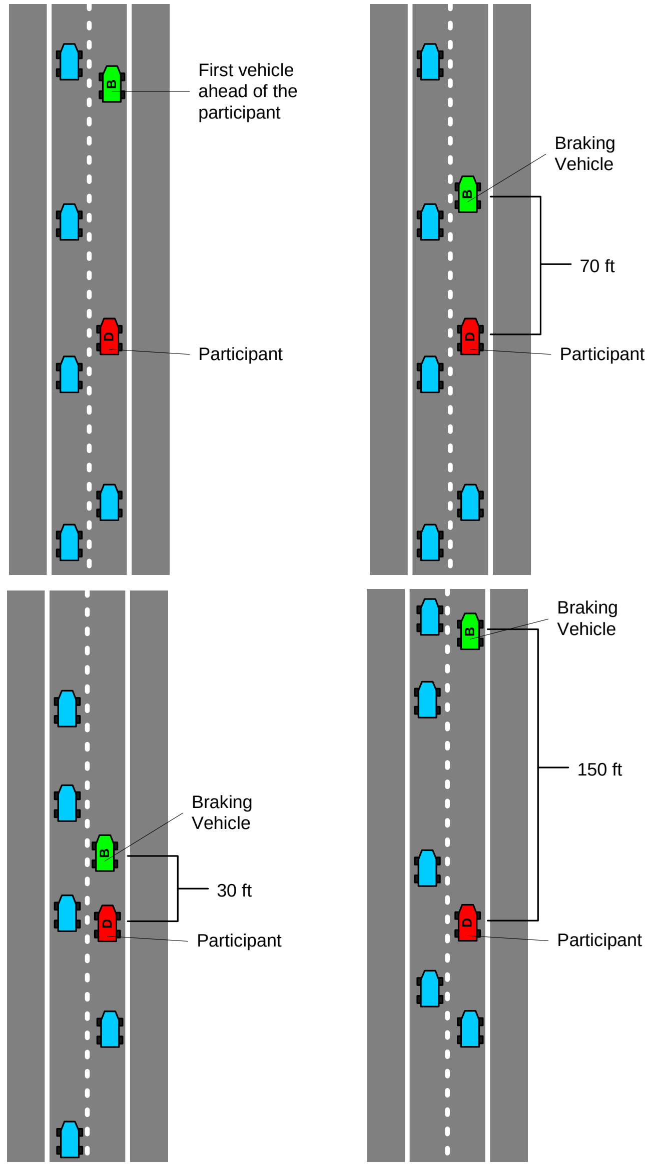

Figure 2 – Lead Vehicle Brake Event.

Follow Lead Vehicle

Baseline

The participant is traveling on the rightmost lane of a highway with 2 lanes going in each direction. There are one or more vehicles traveling ahead of the participant in the right lane. There is a vehicle following the participant at a distance of 100 ft (Figure 3a).

Preparation

The lead vehicle adjusts its velocity to maintain a gap of 150 ft ahead of the participant at an acceleration rate of no faster than 1.5 m/s2 and a deceleration rate of no faster than 1.0 m/s2 (Figure 3b).

Event Description

In this event, the participant has to follow a target vehicle for 60 seconds. The goal of that event is to obtain follow coherence [3]. The target vehicle is a special vehicle that is painted gold and has a bulls-eye painted on the back. This differentiates the target vehicle from any other vehicle in the entire scenario. This target vehicle adjusts velocity to reflect a sinusoidal pattern.

The target vehicle is created ahead of the lead vehicle. In order to make space for the target vehicle creation, the lead vehicle adjusts it's velocity to reduce the gap from 150 ft to 120 ft at a deceleration of no faster than 1.0 m/s2 (Figure 3c). Four seconds later, the target vehicle is created ahead of the lead vehicle traveling at a velocity of 60 mph (Figure 3d). This ensures that the creation is not visible to the driver. After the target vehicle has been created, the lead vehicle performs a lane change maneuver to the left to reveal the target vehicle to the participant (Figure 3e). The participant is given about 10 seconds to adjust his/her velocity to maintain a suitable gap from the target vehicle.

Approximately 15 seconds after the target vehicle has been created, the target vehicle starts to adjust its velocity to reflect a sinusoidal wave that has an amplitude of +/- 7 mph from its baseline velocity of 60mph. The target velocity 2 complete cycles in a duration of 60 seconds (Figure 3f).

The target vehicle changes lanes to the left to indicate the end of this event to the participant

Cleanup

If this event is immediately followed by the Merge Event, then the target vehicle remains in the left lane and travels at a normal velocity until the participant takes the off-ramp. If the following event is not immediately followed by the Merge Event, the target vehicle adjusts its velocity to fall 250 ft behind the participant in the left lane (Figure 3g). Once the target vehicle has achieved this distance, it performs a lane change to the right (Figure 3h). The target vehicle is deleted from the scenario. The participant is unable to see this deletion as the target vehicle is hidden by the vehicle that is currently following the participant at a distance of 100 ft.

Clearly, such behavior requires the explicitly cooperation of the participant. In this project, participants were given training on how to properly follow the target vehicle, along with feedback on their performance. Monetary incentives were associated with the following task in order to ensure the participant's cooperation.

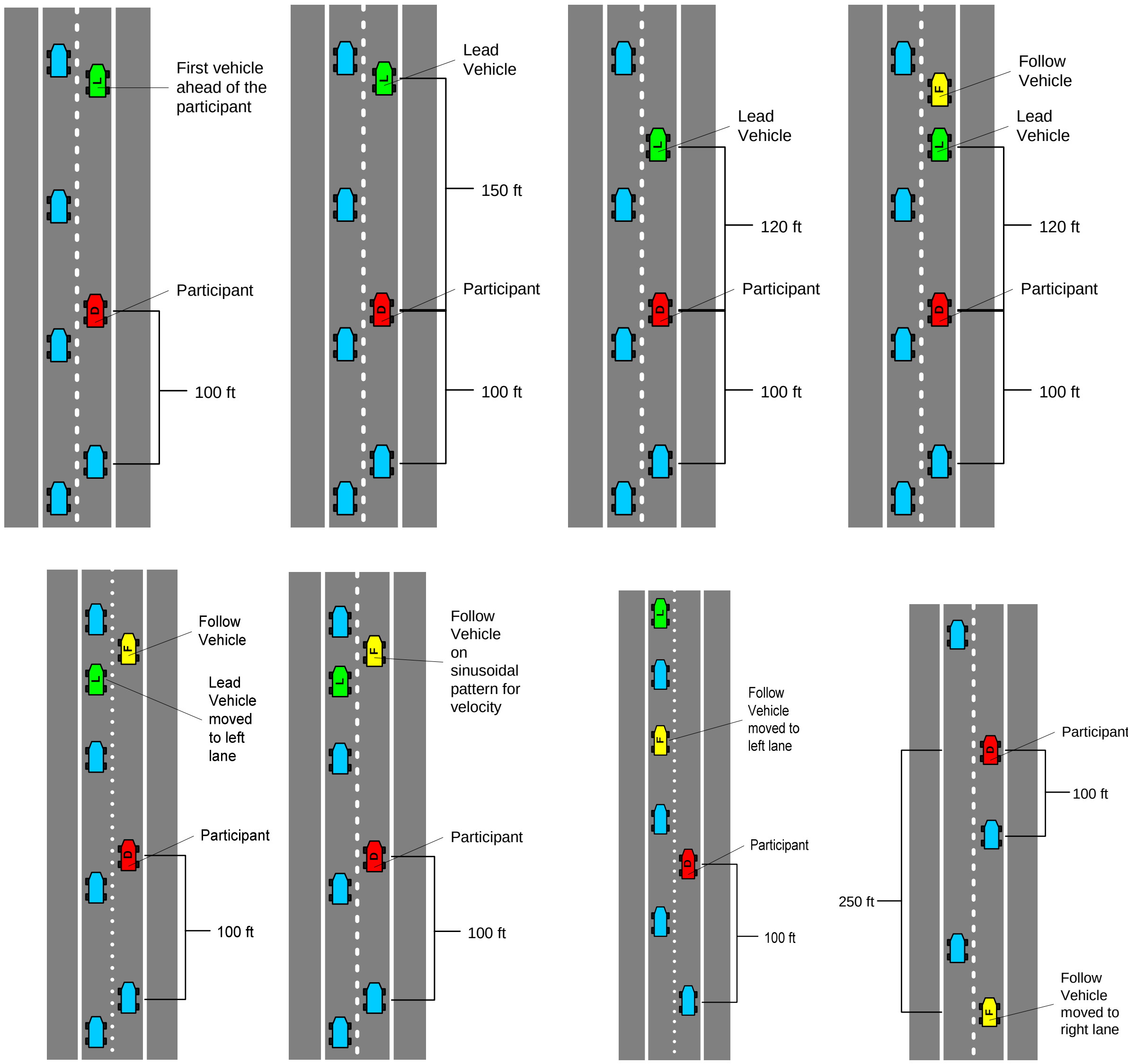

Figure 3 – Follow Lead Vehicle Event.

CONCLUSION

This paper provides an overview of the issues involved in authoring complicated scenarios for high fidelity driving simulation applications. The following are the lessons that we've learned in the process of running research studies on the NADS. Many aspects of scenario development require being able to anticipate the way participants may respond in a given situation. This requires the involvement of behavioral scientists in the design process. Moreover, since all contingencies are unlikely to be identified, pilot studies with naive subjects are necessary. Creating events as a part of scenario development requires an understanding of the overhead (preparation and cleanup) associated with each event. This understanding is obtained iteratively through repeated testing. The extent to which ambient traffic behavior can be predicted depends on the level of autonomy allowed in the scenario. Research studies that require all participants to experience identical situations are likely to necessitate introduction of significant limits to the autonomy allowed by the ambient traffic and scenario vehicles. Finally, the concept of "precise technical specification" needs to be operationalized at the very beginning of the development process so that researchers involved in experimental design and scenario developers have a common understanding of all that needs to be specified to create a scenario that accurately and completely addresses the experimental design. A method for specifying scenarios by decomposition into independent events that can be described autonomously has been given along with an example specification for a few events.

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