Title
Development Of Vehicle Simulation Capability

Permalink
https://escholarship.org/uc/item/4km1f8d3

Authors
Stoner, James W.
Evans, Douglas F.
Mcgehee, Daniel

Publication Date
1997

CALIFORNIA PATH PROGRAM
INSTITUTE OF TRANSPORTATION STUDIES
UNIVERSITY OF CALIFORNIA, BERKELEY

Development of Vehicle Simulation Capability

James W. Stoner
Douglas F. Evans
Daniel McGehee

California PATH Research Report
UCB-ITS-PRR-97-25

This work was performed as part of the California PATH Program of the University of California, in cooperation with the State of California Business, Transportation, and Housing Agency, Department of Transportation; and the United States Department of Transportation, Federal Highway Administration.

May 1997

ISSN 1055-1425

Final Report
University of Iowa Subcontract
Center for Computer Aided Design
Development of Vehicle Simulation Capability
Agreement 20794MB

January 1997

James W. Stoner, Douglas F. Evans, and Daniel McGehee

Abstract

Development of Vehicle Simulation Capability

James W. Stoner, Research Associate, Center for Computer Aided Design

The University of Iowa

Key words: Human Factors, Driving Simulations, Computer Simulation

This report summarizes the work performed at the University of Iowa to develop simulation databasing tools and procedures to support driving human factors experiments. The simulator requirements are specified, and a complete description of the resulting Iowa Driving Simulation facility are provided. The specification and description of the visual features of the ORCHIDS data base illustrate the capabilities generated. Subsystems necessary to support simulation, including vehicle dynamics, scenario control, motion control, audio cueing, and data collection are described. Experimental design procedures are outlined from initial experiment descriptions and simulation release specification, through database fly throughs and pilot testing. Finally an example scenario illustrates the potential for applying driving simulation as a research tool to examine driver performance and vehicle design issues.

Executive Summary

Ground vehicle simulator database design and development presents a number of unique challenges. Aside from the high density and complexity of the visual scenes and the driver's close proximity to modeled natural and cultural features, there is yet a greater challenge in creating accurate and effective representations of the complex 3D roadway surfaces found in real-world driving environments. Since the geometries of roadway surfaces have dramatic effect on the behavior and performance of drivers and their vehicles, supporting realistic road surface models is critical to the overall usefulness of a simulation . Road geometry determines, for example, the magnitude of the steering side-forces that tires must generate in order for vehicles to negotiate curves. The surface geometry also impacts driver comfort and sight distance, and influences vehicle performance, handling, and ride characteristics.

Over a period of sixty years, strict highway engineering design standards have been established to assure driver comfort and safety, and to support efficient traffic flow for the target vehicle/driver population. If a virtual driving environment presents roadway geometries that are significantly different from real-world roadways, it should not be expected that the drivers or their vehicles will perform as they would in the intended real-world corollary.

Designing a virtual driving environment is both an art and a complex engineering task. The driving environment model needs to support the data requirements of important computational processes, as well as the exterior visual information requirements of a driver who must follow road paths, make navigational decisions, respond to signing and other control devices, and interact with other dynamic vehicles, objects, or conditions.

The Orchids database was designed to support a variety of driver performance and traffic safety studies on the Iowa Driving Simulator. The large exterior loop is a six-lane freeway with a total length of approximately 25 miles. It passes through two urban areas, named Canyon City and Valley Park, where it has freeway to freeway interchanges with the six mile long East-West connector. The Freeway, called Route 1 has an interchange with the two lane rural highway north of the canyon, providing access to a small town. The East-West Connector, called Route 2, has an interchange with the southern rural highway, providing exit and entrance to another small town.

The City portions are populated with textured facades and background features, because of the need to economize due to the texture and polygon budgets that are available. The off-freeway areas are not meant to be driven. Adequate detail is provided to give the impression of travel through an urban area, complete with all appropriate freeway signing and route information. Portions of the urban freeway areas are modeled as sunken freeway to simplify the culture requirements.

The rural segments of the highways have super elevated horizontal curves, and a loop has been added with vertical curvatures leading to a top of a hill where it passes through farmland.

The success or failure of a research simulator, regardless of the application, is directly related to the success of supporting the development of experiments that use the device. Nearly all research studies will require development simulation subsystems that will provide a unique visual scene, road geometry or surface characteristics, vehicle performance, or data collection procedure. Experimentalists will not be able to use a single release, or even one that is able to be modified. The potential for piggy backing experiments is limited because of the special needs of each research study. The efficiency of simulator operation, and in the end the economic viability of the simulator is directly related to the effort of support teams to develop experiments. The time line for development can be as long as 18 months after the contract approval process. A well documented procedure for supporting the development and testing of a simulation release and experimental plan is necessary to insure economic viability of a high fidelity driving simulator.

The capability of creating a high fidelity virtual environment for real time simulation does exist. The display and interrogation of that environment has typically required specialized image generation and parallel computing hardware. Extremely sophisticated software is required for sub-system models, communications, and data collection. The cost factors for the required equipage are declining as published performance figures are increasing. Consequently, the opportunities for applying operator in the loop techniques to product developing and testing are rapidly growing.

This report has defined the requirements of the synthetic environment, and the attributes of a simulation device to attain high fidelity. It must be remembered that the quality and realism of the database defines the fidelity of the system, not just the hardware capabilities.

Table of Contents

Abstract ii

Executive Summary iii

Table of Contents v

1. Project Description 1

2. Requirements for High Fidelity Driving Simulation 1

3. Description of the Iowa Driving Simulation Facility 3

    3.1. Intergrated Hardware and Equipment 3

    3.2 Software Subsystem Design 6

4. IDS Simulator Database Development 9

    4.1. Creating Virtual Environments 10

    4.2. Realism and Efficiency for Image Generation 11

    4.3. High Speed Access to Analytic Surface Data 11

    4.4. Support for Interactive Traffic Simulation 12

    4.5. Roadway Modeling Tools for Real-Time Databases 13

5. ORCHIDS Database Description 14

    5.1. Database Organization 14

    5.2. Subsystem Specification 16

6. Scenario Development 17

    6.1. Reconciling the Study Requirements and Simulator Capability 17

    6.2. The Development of Scenes and Scenarios on IDS 18

    6.3. Scenario Examples 20

    6.4. Data Acquisition 24

    6.5. Pilot Testing 25

7. Conclusions 25

Development of Vehicle Simulation Capability

1. Project Description

The initial project objectives were to create a simulation capability to support driver performance studies to be performed by researchers from the University of California at Berkeley and University of California at Davis. This would require the Center for Computer Aided Design at the University of Iowa to create visual and scenario control databases, experimental designs and data collection and reduction capabilities to support pilot experiments. The simulation capability was essentially completed in 1993, however the projects that the simulation release was to support were not funded. This report details the development of the databases, modeling techniques, and technology created under this agreement.

2. Requirements for High Fidelity Driving Simulation

Simulator technical development since the 1930s has focused on traditional flight training applications. Ground vehicle trainers using interactive simulation have only recently been developed, and a small number of research simulators have had to create their own software specific to their applications. Cueing system hardware such as motion bases, image generators, and host computers that were originally designed for flight simulators have been adapted to serve ground vehicle simulation purposes.

Visual system display specifications, such as luminance, contrast, and resolution, are based upon flight training certification requirements. Driving Simulation imposes an entirely new set of requirements with respect to required visual resolution to insure that detection and recognition distances for traffic control systems are appropriate. High resolution depth cues are important for many driving maneuvers. High visual update rates are necessary to display close proximity moving models. The display configurations in terms of viewports or channels is quite different. Ground vehicle applications will severely stress the capabilities of the current generation of high fidelity image generators. Manufacturers of Computer Image Generation (CIG) systems will be asked to provide products capable of much higher levels of scene complexity, near field level of detail, texture mapping capability, model selects, and dynamic coordinate system control than available in the present systems.

Research on the importance of motion cues and the proper performance specification to support either ground vehicle or flight simulation is limited and of questionable value. Only two driving simulators currently have six degree of freedom motion systems, so the amount of empirical research is limited. Cue masking and the nature of false cues are very different from flight. Adaptive washout algorithms and motion control software tuned for driving simulation are only now being developed. The ability to represent the high frequency motion associated with pavement slab joints, curbs, potholes, wind buffeting, and other special effects is absolutely necessary. The motion must also be correlated with visuals, vehicle dynamics, and audio.

Audio cues must represent accurate, three dimensional sound sources to distinctly represent tire, power train, wind, and traffic noises. The audio must be correlated with the other simulation sound systems so that both full directional location of the cue and front to rear and side to side dynamic panning (including Doppler shift) is provided.

Control loading systems such as steering, acceleration, and braking must be directly coupled to vehicle dynamics. The software to model power steering, brakes, and power train in real time is only now being developed.

Vehicle dynamics must run in real time and be based on multi-body, basic principles models in order to represent limit handling conditions. Integration rates of 150 to 300 Hz are required for numerical stability. Accurate computation of steering rack forces are necessary for the realistic control loading that will allow the vehicle to be controllable by the driver. The geometry and layout of the steering linkage cannot be approximated. Tire models require very high rates of integration that is only achievable through multi-rate algorithms. Tire spin dynamics must be integrated for ABS and ASR applications. Simple point follower models will not allow high frequency inputs such as curbs and potholes.

Roadway Geometries must be correct with respect to engineering roadway specification. Vertical and horizontal geometries, as well as cross sectional elements must be absolutely correct. Super elevation and spiral transitions, and tangent runout on curves must be represented, which will require multiple levels of detail and a large number of textured polygons. Terrain and road surface representation must be within the contact patch of the four tires, and all four tires will need to sample the road surface at very high update rates. All subsystems will require a knowledge of the precise road geometry and roughness to insure absolute correlation. The update rate on the CIG and visual data base will be inadequate to provide the necessary information, so a correlated surface mesh with high frequency interrogation capability will be required.

Scenario control subsystems will impose a large computational load and will stress any current CIG system. Scene authoring must be flexible and able to accommodate a wide variety of experimental requirements. Hundreds of smart vehicles and pedestrians must be modeled not only as visual objects, but as smart interacting entities with varying behaviors and responses. Moving models must be have both scripted and random behaviors. All simulations must have a deterministic replay capability.

3. Description of the Iowa Driving Simulation Facility

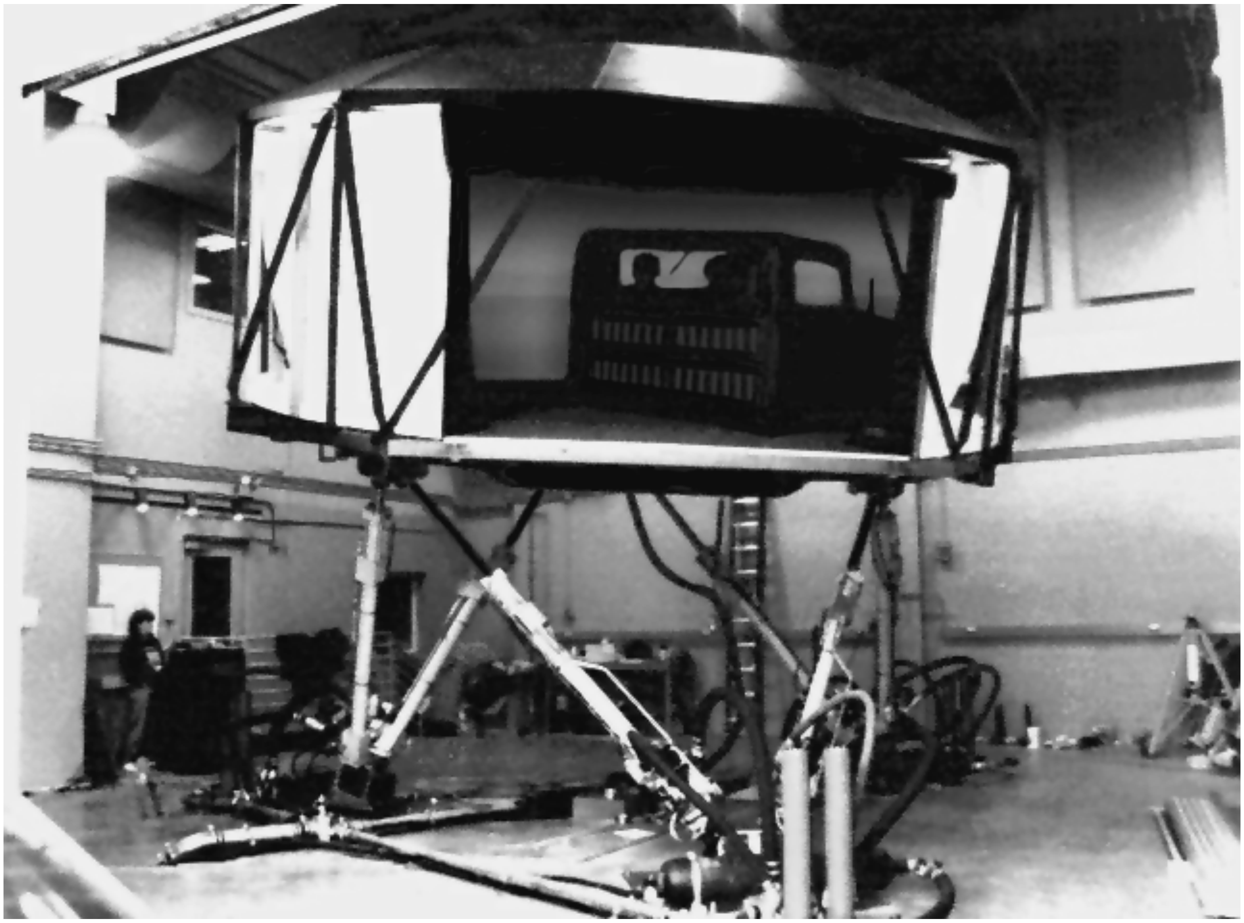


Figure 1. Iowa Driving Simulator

3.1 Integrated Hardware and Equipment

The Iowa Driving Simulation Facility (IDS) is located at The University of Iowa. A range of simulators includes a hexapod motion platform, shown in figure 1, with changeable cabs and 300 degree projection dome, a fixed base simulator with a 220 degree screen display, generic driving cabs with single PC and SGI graphics systems, and three dimensional imaging for construction and agricultural experiments. A high-quality four channel textured graphics computer image generation system is used to create realistic real-time images from a visual data base. A host parallel computer achieves real-time simulation of vehicle dynamics using models that retain a high level of fidelity. In addition, this facility employs a modular simulator software environment that provides flexibility in adapting to a myriad of research environments encountered in both on-road and off-road vehicle virtual prototyping, training, and research applications . All simulation vehicle platforms use pin for pin compatible instrumentation interfaces for data collection and can be re-configured to use the appropriate visual, vehicle dynamics, host computer, and scenario control, systems.

Integration of the IDS system required an evaluation of the various hardware components of the system (visual system, motion system, vehicle dynamics), to determine an appropriate operating environment, and an evaluation of each subsystem for interface, computational, memory, and latency requirements. Figure 2 is a schematic diagram of the IDS software and hardware systems as it existed in 1993.

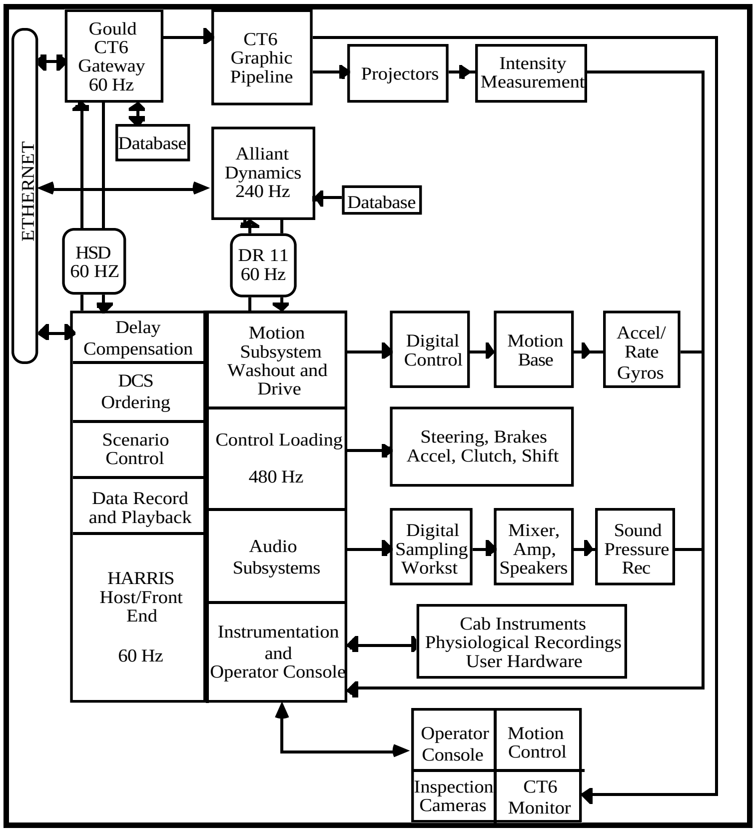


Figure 2. IDS System Configuration

A Harris Nighthawk parallel computer serves as the host, using a real-time operating system that allows deterministic periodic scheduling. An Alliant FX2800 parallel super computer, with 26 high-speed RISC I860 based processors, provides the power to perform real-time dynamics and complex scenario control. High-speed data interfaces are used to connect the Harris host computer with the Alliant and the image generator host computer. A simulator operating system authored by the University of Iowa allows a well defined and expandable interface between subsystems, supporting both subsystem intercommunication and synchronization. This development process allowed simultaneous development of the simulation control program and the associated sub-system software for visuals, control loading, scenario control, vehicle dynamics, audio, data collection, and instrumentation. Interface modules were installed in the Harris computer for analog and digital communication with the instrumented vehicle cab and with the motion system.

The motion base used in the IDS is a Singer-Link, Heavy Payload system, capable of generating motion with six degrees of freedom. The response characteristics of this motion system are:

Maximum Payload	10,872 kg(24,000 lb..)
Linear Acceleration	1.1 g
Linear Travel	+/-1.14 m(45 in.)
Angular Acceleration	$200^{o}/sec^{2}$
Angular Travel	+/-30°
Frequency Response	8Hz

The motion control algorithm approximates motion cues that the driver would normally feel in the vehicle, while avoiding commands that produce motion outside the envelope. Both classical washout algorithms and adaptive algorithms are used. Chassis linear accelerations and angular rates are high pass filtered to maintain high frequency onset cues that are required for vehicle control, while eliminating low frequency large amplitude motions that produce sustained accelerations. Tilt coordination is used to provide coordinated low frequency cues that are lost due to filtering. The filtered accelerations and angular rates are integrated to obtain chassis orientation of the simulator cab and transformed into the coordinates of the individual actuators.

Ford Taurus and High Mobility Multipurpose Wheeled Vehicle (HMMWV) cabs have been instrumented, with simulation controlled instruments including speedometer, tachometer, fuel and temperature gauges, and indicator lights. Potentiometers on the brake, accelerator, and gear shift and a digital encoder on the steering wheel provide control position information. Output from the potentiometers is sent to A/D converters on the Harris host computer. The model used for control loading is coupled with vehicle dynamics that provide forces on the tie rod ends, which are in turn fed to a model of the steering system. The calculated torque is translated into an appropriate voltage that is sent to a DC servo disk motor connected to the steering column, providing torque feed-back to the driver's hands.

3.2 Software Subsystem Design

The high fidelity computer images are provided by an Evans & Sutherland ESIG 2000 system. Visual data bases are created and supported by visual database development and modeling tools and visual data management software. Images are rendered in real time, based on eye point, moving model, and environmental information from the simulator's scenario control and vehicle dynamics systems. The Image Generator (IG) provides up to four configurable channels of high-resolution textured graphics. The system can support simultaneous high scene density and smoothness of motion. Both systems allow for multiple levels of detail for database models, and provides smooth fading transitions between levels. A wide range of atmospheric effects can be controlled, including variable sun-angle, illumination, fog, and lightning.

Moving models are supported in the visual system by control of up to 256 dynamic coordinate systems, allowing for individual or chained moving elements. Thus, simple single body vehicle models or fully articulated models can be presented. Each dynamic coordinate system may be associated with up to 128 moving models. Models may be sequenced to create animated special effects. The IDS vehicle library currently provides representations of 25 unique automobile, truck, bus, and motorcycle models, each of which can be instanced multiple times within a database for simulation of interactive traffic. A fully animated walking pedestrian model is also available.

The display system mounted on the motion base uses 5.5 m (18 feet) diameter dome segments and four hardened high performance multi-sync projectors that are mounted as part of the dome structure. Three of the projectors are used in a cross-fire configuration to provide a forward field of view (FOV) of 180 degrees horizontal by 35 degrees vertical. A fourth projector provides either a rear view or a segment of interest view on the appropriate dome segments. This approach provides high quality graphics, as well as adequate mechanical rigidity to withstand accelerations and forces that are imposed by the motion system.

Databases may be constructed to be map-correlatable to real-world locations, or they may be entirely fictional. Among the specialized database development software already obtained and implemented to meet IDS visual database needs are an advanced procedural modeling system from Evans & Sutherland, a workstation-based interactive modeling package from Software Systems (called MultiGen), and a number of custom modeling algorithms developed at The University of Iowa for automating construction of particular database features.

An IDS modeling package constructs highly realistic textured roadway models for driving databases. It facilitates the creation of complex roadways, including constructions involving parabolic vertical curves and banked horizontal curves with variable rates of super elevation. Supporting the basic road surface modeling routines are mechanisms for providing various center stripe combinations, roadside markers, street lights, shoulders and ditches, and a full library of traffic signs and control devices. Software System's MultiGen provides automatic terrain model generation, based on digital topographical information from either the US Geological Survey or the Defense Mapping Agency. It also includes interactive texture creation, editing, and application tools for both synthetic and photo-derived texture maps.

The audio systems produce the auditory cues that are necessary for realism in the driving environment, including engine, wind, road, and passing car sounds. The audio system uses off-the-shelf, MIDI-based digital sampling systems. The digital approach permits the use of source audio data that are recorded from the real vehicle environment. To ensure accurate reproduction, microphones are placed in the actual vehicle to record each sound type individually. A series of digital recordings, using digital analog tape to reduce signal loss, are made that cover the entire envelope of operation. Digital samples of each sound type are then made at several discrete operating points. During simulation, vehicle dynamic and environment state variables are evaluated and individual sound samples are dithered and blended, to produce representative sounds.

The audio system consists of a 16 voice digital sampling workstation, a MIDI controlled mixer, and eight speakers placed around the vehicle cab on the simulator platform. The system, using the mixer, supports cross channel fading and phasing of sounds to give sound directionality. The sampler is capable of reproducing 16 bit audio samples at 44K Hz, producing an output bandwidth of 20-20K Hz with a dynamic range of over 95 dB.

The IDS vehicle dynamics subsystem receives inputs from the operator via the vehicle controls. It then predicts the vehicle motion and generates output for IDS visual, motion, audio, and scenario control subsystems.

The vehicle equations of motion consist of differential and algebraic equations, known as DAE, that are derived based on multibody dynamics formulations. In addition to general multibody dynamics, vehicle subsystems such as steering, brake, power train, and aerodynamics have been modeled for several vehicles and are implemented in the multibody dynamics computer code to predict the motion of the vehicle. The relationship of dynamics with other subsystems is shown in Figure 3, where outbound arrows communicate vehicle state information and returning arrows generally provide forces acting on the vehicle.

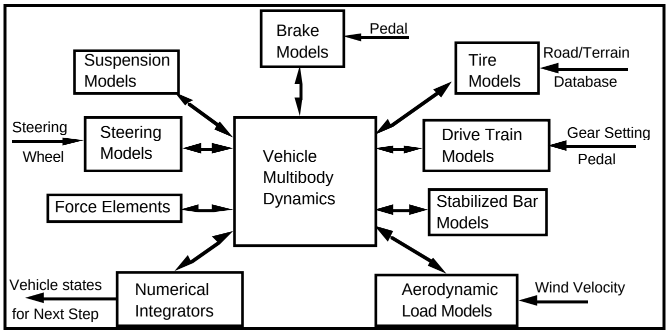


Figure 3. Vehicle Modeling Structure

The scenario control system is implemented in software resident on the host computer, which is responsible for the management of all controllable features or elements within the simulator databases. This definition includes control of simulated traffic, dynamic traffic control devices, environmental conditions (weather and illumination), animated special effects, and any other dynamic or transient features.

The scenario control system is designed to provide pseudo-random (random, but repeatable) distributions of autonomous vehicles that interact and behave in a near-natural fashion, having awareness of each other and of the simulator subject's vehicle, as well as awareness of the rules of the road. Many vehicles may be simultaneously managed, including the introduction and removal of vehicles from activity. Each vehicle may be pre-programmed to specify behavioral characteristics, including the speeds and headways it prefers to maintain, and individual gap acceptance tendencies. All moving objects are controlled by way of position and orientation commands that are passed to the image generation system for the appropriate dynamic coordinate systems and their associated models. Each vehicle model also has control provided for proper dynamic display of its brake lights and turn signals.

In addition to this type of general traffic simulation, the system allows for the programming of specific pre-planned vehicular or object behavior, to meet custom experimental design requirements. Such behavior might include, among a myriad of possible examples, a pedestrian or other unexpected obstacle coming into the path of the operator's vehicle under certain triggering conditions. Dynamic traffic control devices can be programmed to operate on fixed time intervals, or to be based on current traffic conditions. The system could be programmed to control standard semaphores, turn lights, flashing red or yellow lights, or even train crossing control devices. Environmental effects that are managed by the scenario control system include sun position and illumination level, visibility and ground fog effects, sky color and cloudiness, wind direction and strength, and lightning.

The system models the behavior of various objects within a given scenario, as defined by a scenario file and a number of road database files. The scenario file is used to provide experiment specific definitions and controls. Road database files are made of space-curve lane and surface definitions that are based on global roadway specification, matching exactly the roadway models of the visual database.

4. IDS Simulator Database Development

The University of Iowa has developed several correlated database sets for use in simulation releases created for specific projects and experiments. As stated above, the databases have been created using the road tools developed at Iowa, created specifically to build models to support driving simulation.

The most significant effort to date is the Churchville and Munson test courses at the Aberdeen proving grounds in Maryland, USA. This ARPA sponsored project focused on the development of a virtual proving ground to be used in vehicle evaluation for acquisition. The Churchville test course is approximately four miles in length, covering a wide variety of terrain. Twenty-nine percent vertical grades combined with sharp horizontal curves cause the curve to snake across the rural, heavily wooded terrain. The road surface data base presents a high level of detail of surface elevation required, including imbedded berms in the road surface allowing the vehicle to go airborne. The Munson test course includes a torture track with 6 inch high sinusoidal bumps with a 6 foot period, and a skid pad for evaluating road holding and lateral accelerations.

An automated highway network was created for studying the use of automated traffic lanes on expressways. The Interstate-level network's automated lane carried vehicles in varying length vehicle strings at speeds of 65 to 95 mph with extremely short vehicle space headways. The non-automated lanes carried traffic at varying densities, maintaining specific headway distributions, with a variety of driver behaviors. The network included both tangent and curved segments with standard interchanges occurring at specified intervals. This simulation was used to study the performance of drivers of various ages and experience when attempting to execute exit and entrance maneuvers on an automated highway.

Another significant modeling effort was used to study the human factors of various in-vehicle warning devices and displays for improved route guidance and navigation, collision warning, and single vehicle run-off-the-road conditions. This data base had a variety of two lane rural roadways with horizontal curves of varying radius and length. An expressway segment required the drivers to enter the freeway on a standard entrance ramp and then execute several gap acceptance and collision avoidance maneuvers.

4.1 Creating Virtual Driving Environments

Ground vehicle simulator database design and development presents a number of unique challenges. Aside from the high density and complexity of the visual scenes and the driver's close proximity to modeled natural and cultural features, there is yet a greater challenge in creating accurate and effective representations of the complex 3D roadway surfaces found in real-world driving environments. Since the geometries of roadway surfaces have dramatic effect on the behavior and performance of drivers and their vehicles, supporting realistic road surface models is critical to the overall usefulness of a simulation . Road geometry determines, for example, the magnitude of the steering side-forces that tires must generate in order for vehicles to negotiate curves. The surface geometry also impacts driver comfort and sight distance, and influences vehicle performance, handling, and ride characteristics.

Over a period of sixty years, strict highway engineering design standards have been established to assure driver comfort and safety, and to support efficient traffic flow for the target vehicle/driver population. If a virtual driving environment presents roadway geometries that are significantly different from real-world roadways, it should not be expected that the drivers or their vehicles will perform as they would in the intended real-world corollary.

Designing a virtual driving environment is both an art and a complex engineering task. The driving environment model needs to support the data requirements of important computational processes, as well as the exterior visual information requirements of a driver who must follow road paths, make navigational decisions, respond to signing and other control devices, and interact with other dynamic vehicles, objects, or conditions. Without high-fidelity road models, real-time driving simulation could not be used to effectively study the behavior and performance of drivers or of their vehicles. It is thus critical that driving simulation developers have modeling tools available to them that are capable of supporting realistic roadway designs.

Providing effective road modeling support for driving simulation presents challenges in three principal areas. These areas are defined by three real-time computational processes that must be supported in an advanced driving simulator and which require detailed characterizations of the simulated roadways. These processes are real-time image generation, vehicle dynamics computation, and scenario control.

4.2 Realism and Efficiency for Image Generation

Critical in the support of effective image generation and simulator usefulness is the creation of graphical roadway models that are (1) adequately realistic in their 3D geometry and appearance, and (2) efficient enough for real-time rendering. In addition to quality roadway models, databases must include effective representations of the terrain and significant natural and cultural features, as previously mentioned.

4.3 High-Speed Access to Analytic Surface Data

It is insufficient for simulated road surfaces to merely be visible; they must also be *driveable* by the subject's vehicle. Surfaces must be interrogated, analyzed, and interacted with by the simulator's vehicle dynamics subsystem. To support the computational needs of a high-fidelity multibody vehicle dynamics model, surface data may need to be accessed for multiple tire points at rates of 120 Hz. or higher yielding surface query rates of at least 480 Hz. for a four wheel vehicle. Each query must access not only topographical data, but also a characterization of surface type and properties. These requirements point to a need for an analytic surface model, designed to support vehicle dynamics computations and carefully correlated with the visual model of the driving environment.

Utilizing the visual database alone as the source of analytic surface data can only be appropriate for low-fidelity driving simulators, since the vehicle dynamics will be limited to the crude approximation of a single-point surface tracking scheme with an update rate equal only to that of the visual system (typically 30 to 60 Hz.) and strictly limited to the polygonal resolution of the visual database. Advanced simulators require an auxiliary correlated database that can support effective high-speed surface data queries for tire-road interaction computation.

4.4. Support for Interactive Traffic Simulation

Advanced driving simulation systems should not just provide a visual presentation of terrain, roadways, and features, but must also to allow the driver to interact meaningfully with many moving vehicle models in addition to the driver's own vehicle. Presentation and management of all secondary moving vehicles, as well as other dynamic elements or conditions are orchestrated by a scenario control subsystem. The interactive traffic simulation managed by a scenario control system requires not only sophisticated vehicle control and driver behavior algorithms, but also detailed geometric and logical roadway definitions. These definitions, just as those for vehicle dynamics computations, must correlate flawlessly with the visual models presented to the subject driver by the image generator.

In any given driving database, for all roadways in the network, definitions must be provided to scenario control for each usable traffic lane, as well as intersections and interchanges, speed limits, passing and no-passing zones, and other traffic regulations, so that the traffic models can behave appropriately for the virtual environment presented. These definitions are not comprised of textured polygonal surfaces, like the visual database. Rather, they are comprised of curvilinear lane or path models and logical attribute assignments that together specify the geometric layout and logical rules of the road.

4.5. Roadway Modeling Tools for Real Time Databases

Simulation modeling research at the University of Iowa has resulted in the development of a set of modeling algorithms that allow database developers to create engineering-level-fidelity models of roadways for real-time driving simulation in forms that are effective in each of the three critical data domains outlined above (image generation, vehicle dynamics, and scenario control). The modeling algorithms have since been licensed and distributed commercially through a cooperative arrangement with the developers at MultiGen Inc. They have, in cooperation with the authors, transformed the original algorithms into a broadly usable modeling tool within the kernel of their commercial MultiGen database development software. Not only does this facilitate the support of many different image generator data formats, but it also streamlines the integration of roadway models with terrain and feature development. Perhaps even more significant is the *interactive design* of the road models made possible by the MultiGen development, with near real-time adjustments to roadway geometries, replacing the batch-type modeling process of the original tools.

Another MultiGen extension to the tools is the capability to generate road models with custom, arbitrary cross sections. Cross sections are defined in the X-Z plane for each LOD and are then lofted along the centerline of the road. The possibilities afforded modelers by this functionality are significant, including auto-generation of medians, ditches, shoulders, road crowning, highway dividers, tunnels, and terrain skirts.

In addition to arbitrary cross sections, the tools can instance road-side or on-the-road features at specified intervals and in conformance to the roadway surface. This allows for rapid database decoration with periodic items such as street lights, reflective markers, utility poles, and even trees.

As in the original Iowa algorithms, as the different versions of the road section are generated, they are then automatically positioned within the hierarchical database structures that establish LOD switching and management. Up to ten levels of detail can be automatically constructed. Such automation can yield tremendous savings of time and effort for developers. Once a road setup is defined or selected, the modeler uses mouse and/or keyed entry to interactively define layout control points for each curve, hill, or straight section of road.

Three-dimensional road and feature geometry is immediately generated and displayed as controls are input. Once defined, control points may be freely adjusted and fine-tuned using point and drag mouse controls to accomplish the optimum layout and integration with terrain and other features.

Model inspection is as easy as driving down the road, as the tools include a "drive" mode. In this modified version of MultiGen's "fly" mode, the virtual eyepoint is associated with a selected scenario control spline, and can travel along the centerline of any one of the lanes, following the path and orientation of the modeled road surface.

The final products of the road modeling procedure are formed in three distinct output data sets or models. These models serve the distinct information requirements of the following real-time computational processes of a high-fidelity driving simulator: image generation (visualization), vehicle dynamics (particularly tire-surface interaction computations), and scenario control. The databases formed for these processes can be thought of as different views of the same simulated world. The visual database facilitates the graphical depiction of the world. The vehicle dynamics surface database supports high-frequency road and terrain surface interrogation for elevation, slope, and surface-type information required for the tire models at each iteration. The scenario control database defines the geometric layout and logical rules-of-the-road needed for interactive traffic simulation, as well as for data collection and data analysis relative to the roadway definition. Strict spatial correlation is maintained among these databases to ensure inter-subsystem agreement in environment processing and cue presentation to the driver.

5. ORCHIDS database description

5.1. Database organization

The Orchids database was designed to support a variety of driver performance and traffic safety studies on the Iowa Driving Simulator. Figure 4 is a plan view of the geographical layout. The large exterior loop is a six-lane freeway with a total length of approximately 25 miles. It passes through two urban areas, named Canyon City and Valley Park, where it has freeway to freeway interchanges with the six mile long East-West connector. It also crosses a major bridge over a lake in a wooded area on the south side, and passes through a canyon in the north-west portion of the database. The Freeway, called Route 1 has an interchange with the two lane rural highway north of the canyon, providing access to a small town. The East-West Connector, called Route 2, has an interchange with the southern rural highway, providing exit and entrance to another small town, called Bartelme. Two types of interchanges are used in Orchids; a directional three leg freeway to freeway interchange, and a classic trumpet terminal design from surface street to the freeway.

The City portions are populated with textured facades and background features, because of the need to economize due to the texture and polygon budgets that are available. The off-freeway areas are not meant to be driven. Adequate detail is provide to give the impression of travel through an urban area, complete with all appropriate freeway signing and route information. A number of inner-city ramps are included for the purpose of allowing scenario control to merge additional traffic in the proximity of the test subject’s vehicle. A variety of city buildings and vegetation sets are used to populate the roadside. Portions of the urban freeway areas are modeled as sunken freeway to simplify the culture requirements.

The rural segments of the highways have super elevated horizontal curves, and a loop has been added with vertical curvatures leading to a top of a hill where it passes through farmland.

Figure 4. Plan View of the Orchids Data Base

This area is populated with generic rural cultural features, such as barns, farm houses, trees, and telephone poles. The roads are paved with twelve foot lanes and have standard 6 foot gravel shoulders. A series of four horizontal curves with a 1000 foot radii are found along each of the north-south roadways. Posted speed limits range from 55 to 30 mph. Stop signs are used for traffic control at intersections except for the two signalized intersections in the town, which is a small strip town with two main street and two side streets. There are a variety of small businesses and residential buildings, a city park, trees, and other vegetation, along with parked cars along the street segments. The other town as one stop sign controlled intersection, with the standard town features present.

Pseudo random traffic is simulated throughout the road network as dictated by the scenario control software. The basic background traffic is comprised of autonomous vehicles with individually programmed driving characteristics, and will respond to each other's movements--including the home ship or subject's vehicle. Programmed driving behaviors or hazards can also be provided.

5.2. Subsystem specification

The visual database for ORCHIDS has accurate fully textured road surfaces, with appropriate roadway signs, stripes, and markers. Traffic simulation is supported by a variety of automobile and truck models that are implemented so as to be able to travel throughout the road network as dictated by scenario control. A cellular organization, called DCSWEB, associates the specific movable model sets with the appropriate roadway cells. Simultaneous display of up to 14 vehicle models are supported. All database features include fade level of detail switching to effect smooth model transitions as they come closer to the eyepoint. Vehicle models include switchable head lights, tail lights, and turn signals. All vehicles have simulated ground shadows.

The scenario control software contains a detailed model of the roadway network, including explicit definition of the layout and rules of the road, such as splinar lane and intersection definitions, speed limits, no-passing zones, and other traffic regulation structures. This data is intimately associated with the surface definitions, and correlated with the other subsystems.

Scenario control can provide traffic in either or both of two modes; specific program behaviors (not necessarily constrained by traditional rules of the road) and the randomly distributed autonomous vehicle models. The autonomous vehicles require complete specification of the lane locations and rules of the road for the various roadways. On a simplified level, they behave much like slot race cars. The slots, or lane definitions are provided by a set of splinar space curves generated in the computer database generation process.

The dynamics database provides full definition of all driveable surfaces for the dynamics subsystem. It is composed of numerous data zones where uniform data point grids of various levels of resolution are used to define splinar surface models. High speed x-y based interrogation of the database yields z values and surface normal information for each tire contact point in every computation frame of the dynamics subsystem. The integration rate is typically 120-180 Hz. The dynamics surface data base is constructed using data from the CDG tools and is consequently strictly correlated to the visual and scenario control databases.

6. Scenario Development

Evaluating safety-related driver performance in the real world is difficult because of the inability to measure drivers under potential emergency situations. Creating realistic but potentially dangerous driving situations during field tests is unethical due to safety concerns, driving simulation provides a rare opportunity to reproduce these circumstances. With the increase of driving simulator capability, simulated "scenes" and "scenarios" allow researchers to collect more realistic, accurate, transferable and reliable data. Driving simulation scenes are comprised of the layout of the roadways, shape and appearance of buildings and other cultural features, vegetation, the shape and appearance of synthetic vehicles, and the properties of drivable surfaces. Scenarios involve the behavior of the synthetic vehicles, traffic control devices and variations of weather and lighting.

The scenes and scenarios described in this section are only used to illustrate the use of the scenario software and were not used for a specific study performed under this contract. The scenarios were in fact created for the purpose of evaluating lead vehicle behaviors that create the potential for rear-end crashes. The scenes and scenarios described were designed to evaluate 1) basic driver performance without any technological assistance and 2) basic driver performance during lead vehicle changes while using advanced cruise control and rear-end countermeasure systems.

6.1. Reconciling the Study Requirements and Simulator Capability

Simulator capability is a function of hardware and software components of the simulator; the transport delays imparted by computation and communication; sophistication of scenario control; validity of the vehicle dynamics models; and resolution and fidelity of the correlated visual, road surface, and scenario control databases that are used to represent the virtual environment. All of these components are complex and extremely difficult for the human factors researcher or an agency technical monitor to comprehend. Study design requirements are often generated with little knowledge of the capability or limitations of the driving simulator. A research simulator can perform many wondrous tasks, but these are often expensive in terms of both development time and pilot testing. Researchers with previous experience in simulator experimentation created the experimental plan for this study, but their experimental needs had to be translated into a subsystem release specification that identifies the hardware and software

A simulation facility will often have existing complete simulation databases, or a set of previously used scenes and scenarios which can be assembled to create new ones. The outside experimenters should begin by providing a detailed plan view of the database, either from the existing database segments or their own requirements. A terrain map showing the specific terrain elevations and the locations of features, such as vegetation, buildings, and signage, provides the basis for the visual database. A specific roadway geometry can be placed on the terrain, with specified vertical and horizontal geometry. The cross section data provides lane and shoulder width, median with and slopes, as well as side ditch and other road side specifications. Specific sight distances may be called for at curves or intersections. If an actual location is being represented, engineering drawings containing much of this information may be available. It is not adequate for the researchers to leave the road surface and terrain specification to the whims of the modeling team, as the resulting road surface specifications will significantly affect vehicle and driver performance.

6.2. The Development of Scenes and Scenarios on the IDS

A process for developing driving simulation experiments has evolved over time as the needs of experimenters and researchers have become evident. This process is shown as a diagram in Figure 5. The process involves careful specification of simulation release requirements at the early stages of the experimental design. This release specification guides the coordinated development of the required databases and the data collection process.

6.3. Scenario Examples

An example case study of the scenario creation process is best shown by a recent study

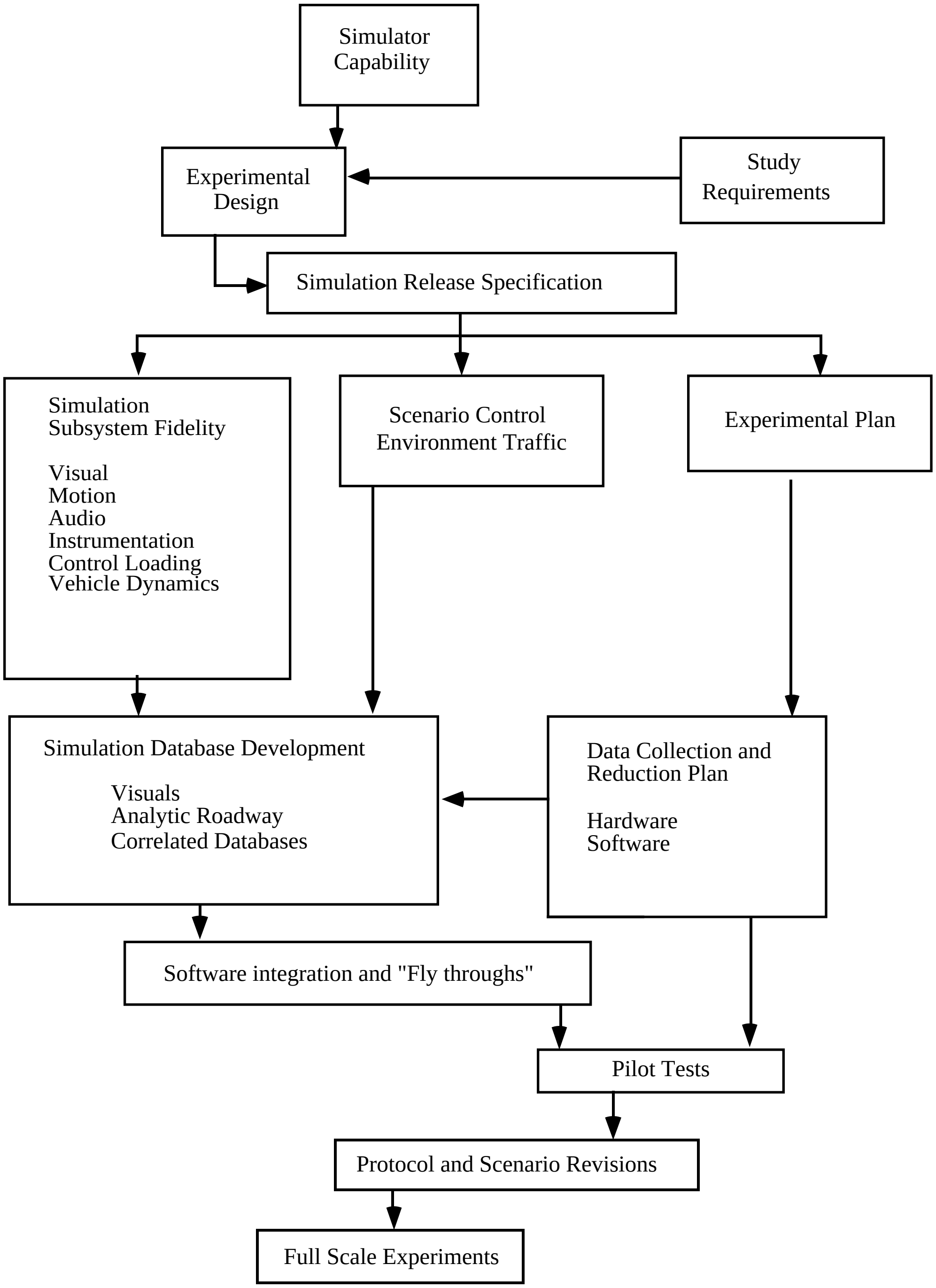


Figure 2. Flow Diagram of the Simulation Experiment Development Process

with the objective of evaluating driver performance under a variety of driver and driving conditions while using advanced rear-end collision countermeasure and adaptive cruise control systems. The primary purpose of this simulation database was to examine basic driver responses during potential rear-end crash avoidance circumstances.

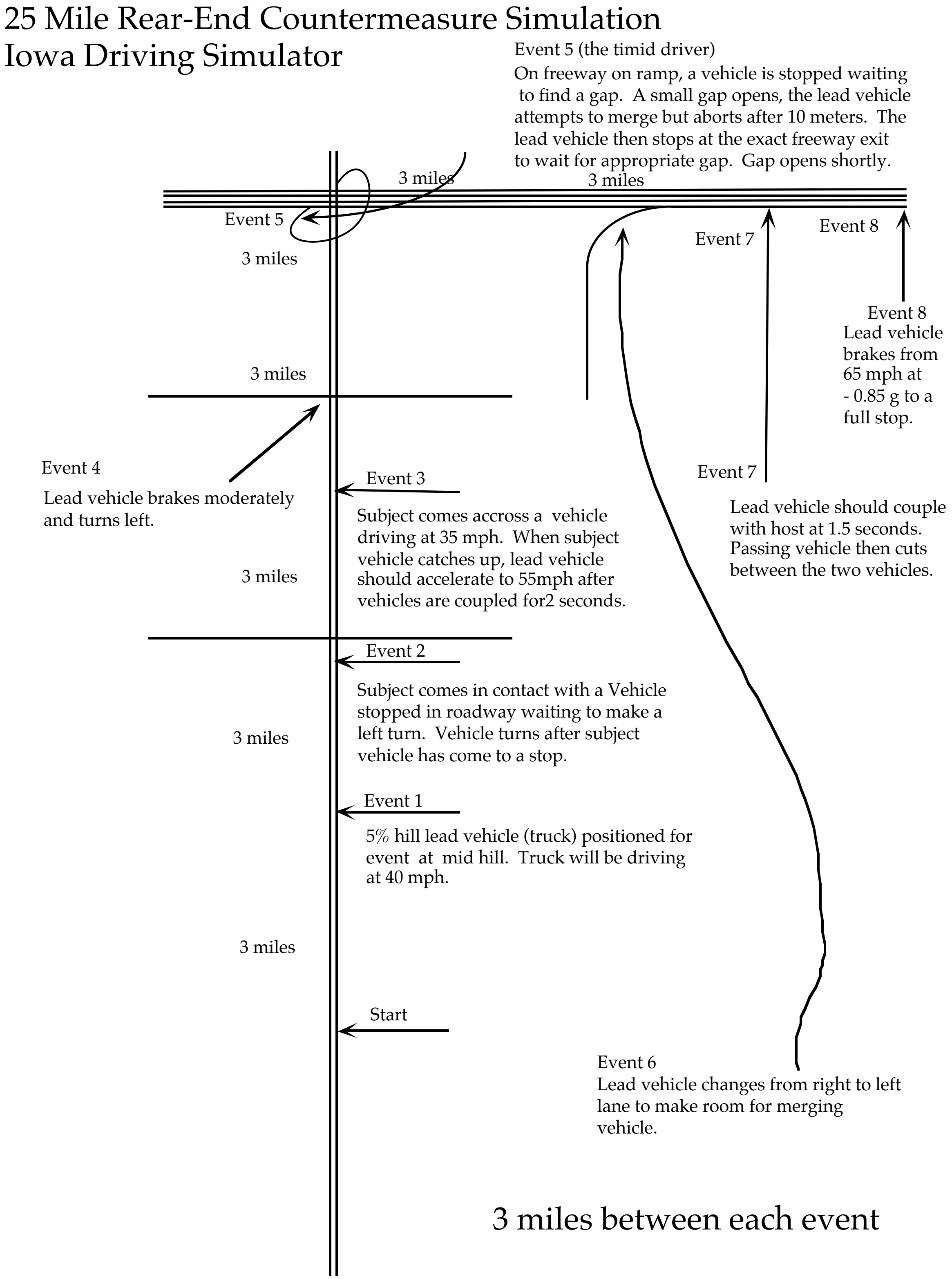
The scenario contains eight events that generate traffic behavior indicative of normal and emergency leading vehicle induced driver response. These eight events take place on a continuous 18-mile long two-lane highway and a 7-mile long four-lane freeway segment (shown in Figure 6). Each event was designed to measure driver response under a specific set of circumstances relating to either driver performance issues (i.e., identifying whether a lead vehicle stationary is moving) or to examine how a countermeasure system mitigates a particular type of hazard. Each scenario event is separated by several miles. During this time, drivers perform a variety of secondary tasks that are usual in everyday driving. The secondary tasks provide a realistic and relatively controlled means to induce eye scanning away from the forward traveled roadway. This technique allows the creation of circumstances of inattention.

It is important to note that researchers were careful to design the behavior of the leading vehicle (or the vehicle in front of the subject car) such that they represent realistic situations and consequently minimize driver anticipation of potentially hazardous lead vehicle changes. The Scenario was intentionally designed to start with relatively benign lead vehicle changes and progress to more aggressive actions.

The following roadway scenes and scenarios make up the 30 minute drive:

Drivers experience the first event approximately three to four miles into the drive. The driver first comes across a tractor-trailer traveling up a 5% hill at 40 MPH. This scenario is designed to evaluate the reaction of a driver to a lead vehicle moving situation. Although this is not the most frequent type of rear-end crash, it can be one of the most severe.

The second event occurs about four miles later when the subject vehicle comes in contact with a vehicle stopped, waiting for a vehicle to make a left turn. This event represents a circumstance where the lead vehicle is stationary and simulates the most common type of rear-end crash.



25 Mile Rear-End Countermeasure Simulation
Iowa Driving Simulator

Event 5 (the timid driver)
On freeway on ramp, a vehicle is stopped waiting to find a gap. A small gap opens, the lead vehicle attempts to merge but aborts after 10 meters. The lead vehicle then stops at the exact freeway exit to wait for appropriate gap. Gap opens shortly.

Event 8
Lead vehicle brakes from 65 mph at - 0.85 g to a full stop.

Event 4
Lead vehicle brakes moderately and turns left.

Event 3
Subject comes accross a vehicle driving at 35 mph. When subject vehicle catches up, lead vehicle should accelerate to 55mph after vehicles are coupled for2 seconds.

Event 7
Lead vehicle should couple with host at 1.5 seconds. Passing vehicle then cuts between the two vehicles.

Event 2
Subject comes in contact with a Vehicle stopped in roadway waiting to make a left turn. Vehicle turns after subject vehicle has come to a stop.

Event 1
5% hill lead vehicle (truck) positioned for event at mid hill. Truck will be driving at 40 mph.

Event 6
Lead vehicle changes from right to left lane to make room for merging vehicle.

3 miles between each event

Figure 6. Iowa Driving Simulator rear-end countermeasure database

The third event occurs three miles after event 2 when the subject vehicle, traveling at or near the posted speed limit of 55 mph, comes in contact with an automobile driving 35 mph. This event is also representative of a lead vehicle moving scenario where the lead vehicle is driving substantially slower than the subject vehicle. This scenario, which is similar to the first, will test driver reaction to a slow moving passenger vehicle instead of to a large truck.

The fourth event simulates a lead vehicle braking moderately and subsequently turning. This scenario begins when the subject vehicle is coupled to the lead vehicle. Just prior to the second intersection (Figure 6), the lead vehicle will brake moderately and turn left.

This fifth event occurs at the entrance ramp to the freeway. As the subject vehicle enters the ramp, the driver comes across a stopped lead vehicle waiting for a gap to open. The subject driver reaction to the lead vehicle will be measured. A secondary event then occurs when the lead vehicle locates a small gap and attempts to merge. The lead vehicle will then abort the merge because the gap was not large enough. It is anticipated that the subject vehicle driver will turn their head to the left and look for a gap and assume the lead vehicle will continue to merge. The purpose of this scenario is to evaluate driver response to lead vehicle braking under conditions of increase attention and driver indecision.

The sixth event occurs several miles after event 5 and prior to a freeway entrance ramp. This event was designed to evaluate how certain types of intelligent or adaptive cruise control systems work under lead vehicle merging circumstances. The scenario begins prior to an on-ramp (refer to Figure 7). The subject vehicle (vehicle A) will be coupled with a lead vehicle (vehicle B) prior to the on-ramp. The lead vehicle will move from the right to the left lane to make room for a merging vehicle (vehicle C)

The subject vehicle will not be able to move to the left lane because of a “shadowing” vehicle (vehicle D). Since, under current intelligent cruise designs, it is anticipated that the subject vehicle will automatically accelerate into the merging vehicle, we are interested in how the driver reacts to such a situation. Driver performance will be compared between conventional cruise control and various intelligent and adaptive cruise control designs.

The seventh event (see Figure 8) occurs when a vehicle (vehicle C) cuts in-between the subject vehicle and the lead vehicle. At the time of the cut-in, the lead vehicle (vehicle B) will be slaved to the subject vehicle (vehicle A) at a 1.5 second headway. This 1.5 second headway is representative of headway planned for some intelligent cruise control devices. This scenario will evaluate driver reaction using conventional cruise control, intelligent cruise control and under baseline driving conditions.

The final scenario occurs 4 miles after scenario 7 and involves the lead vehicle braking at an extreme 0.85 g deceleration. This maximum braking (representative of many ABS equipped vehicles) will measure driver reaction to an extreme lead vehicle braking maneuver.

.

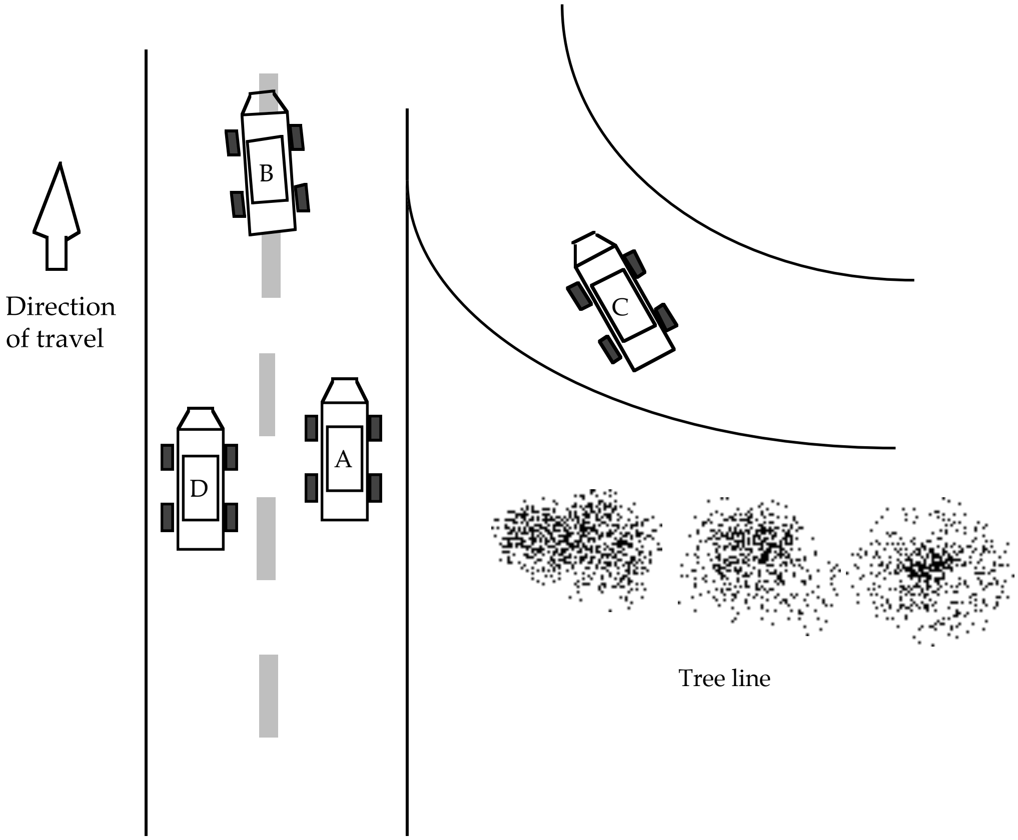


Figure 7. The dangerous merge scenario

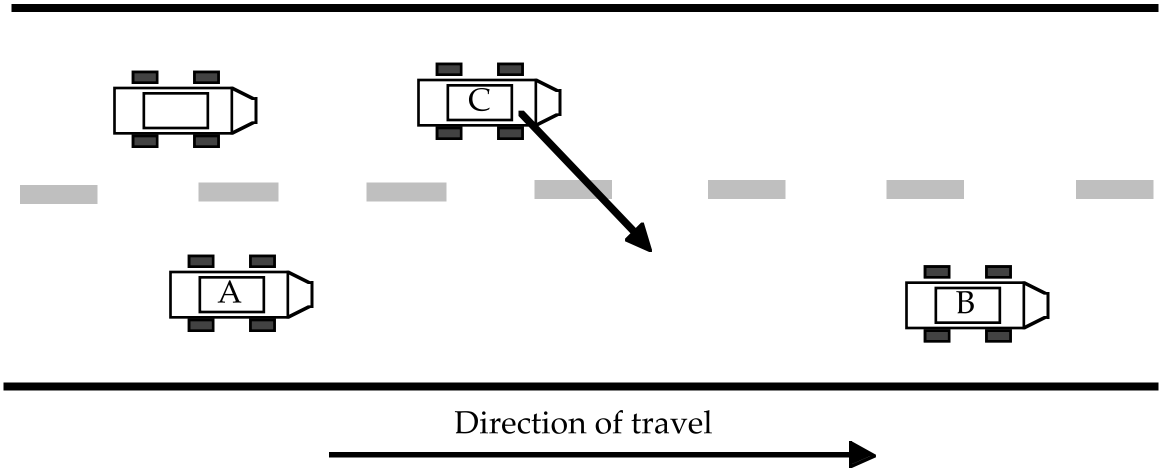


Figure 8. The cut-in scenario

6.4 Data Acquisition

The primary dependent variables of interest center around the drivers response to lead vehicle changes. Driver reaction time is measured relative to a planned lead vehicle change by examining several points of interest along a perception-reaction time-line. For each event, the accelerator pedal release, transition time from accelerator pedal to brake and combined accelerator release and brake sequence will be combined. Driver reaction will also be classified into actions such as "brake", "steer" or "brake and steer". In addition, during each event, steering wheel reversals, driver speed, and headway is evaluated using descriptive statistics. In circumstances where a collision or a "near-miss" occurs, impact or separation distance data is also important.

Data collection is also an important step to carefully specify in the simulator development process. Each experiment will have its own unique requirements. However, researchers can always draw from a pool of proven driver performance variables. One of the most difficult aspects of data collection is quickly locating data of interest relating to a specific event. Recent advances in the display of real-time data help the researcher locate data of interest. As seen in Figure 9, real-time data overlaid onto the driving scene tells a story. The researcher is able to see the steering wheel position, speed, accelerator and brake pedal position, distance to intersection (DTI), and the electronic data frame number. The frame number is one of the most critical elements to data collection since it provides and exact marker in the data set to pin-point a given reaction or behavior.

6.5 Pilot Testing

Another important step in the simulation development process is conducting a pilot test. A pilot test allows a researcher to examine both the subjective and objective performance of drivers to a experiment. This is a also a critical step since the development staff does has a biased mental model of how to react to the simulated drive. Naive drivers provide the researcher with an unbiased view of how the simulation works from both micro and macro levels. Each protocol from subject recruitment, briefing and data collection can be examined.

Figure 9. View of real-time data and video from IDS

Following the pilot test, all protocols should be reviewed. In addition to the review and modification of protocols, scenarios should be modified based on feedback obtained from the pilot test drivers. Some modifications are almost always required.

7. Conclusions

The success or failure of a research simulator, regardless of the application, is directly related to the success of supporting the development of experiments that use the device. Nearly all research studies will require development simulation subsystems that will provide a unique visual scene, road geometry or surface characteristics, vehicle performance, or data collection procedure. Experimentalists will not be able to use a single release, or even one that is able to be modified. The potential for piggy backing experiments is limited because of the special needs of each research study. The efficiency of simulator operation, and in the end the economic viability of the simulator is directly related to the effort of support teams to develop experiments. The time line for development can be as long as 18 months after the contract approval process. A well documented procedure for supporting the development and testing of a simulation release and experimental plan is necessary to insure economic viability of a high fidelity driving simulator.

The capability of creating a high fidelity virtual environment for real time simulation does exist. The display and interrogation of that environment has typically required specialized image generation and parallel computing hardware. Extremely sophisticated software is required for sub-system models, communications, and data collection. The cost factors for the required equipage are declining as published performance figures are increasing. Consequently, the opportunities for applying operator in the loop techniques to product developing and testing are rapidly growing.

This report has defined the requirements of the synthetic environment, and the attributes of a simulation device to attain high fidelity. It must be remembered that the quality and realism of the database defines the fidelity of the system, not just the hardware capabilities. A low- fidelity database on a high fidelity simulator will still result in a low fidelity simulation.