Road Safety Audit Case Studies:

USING THREE-DIMENSIONAL DESIGN VISUALIZATION IN THE ROAD SAFETY AUDIT PROCESS

U.S. Department of Transportation
Federal Highway Administration

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FHWA-SA-14-003

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Technical Documentation Page

1. Report No. FHWA-SA-14-003	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Road Safety Audit Case Studies: Using Three-Dimensional Design Visualization in the Road Safety Audit Process		**5. Report Date** July 2013 **6. Performing Organization Code**
7. Author(s) Dan Nabors, Jon Soika		**8. Performing Organization Report No.**
9. Performing Organization Name and Address Vanasse Hangen Brustlin, Inc. 8300 Boone Boulevard, Suite 700 Vienna, VA 22182-2626		**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.**
12. Sponsoring Agency Name and Address Federal Highway Administration Office of Safety 1200 New Jersey Ave. S.E. Washington, DC 20590		**13. Type of Report and Period Covered** Final Report July 2013 **14. Sponsoring Agency Code**

15. 1 Supplementary Notes

The Federal highway Administration Office of Safety sponsored the study of the Road Safety Audits reported in this document. The Task Manager for this report was Rebecca Crowe (FHWA Office of Safety). The three-dimensional visualization work was completed by Chris Dubois and graphic design was provided by Jorge Quinones.

16. Abstract

Road Safety Audits (RSAs) are a formal safety performance examination of an existing or future roadway or off-road facility and are conducted by an independent, experienced, multidisciplinary team. The purpose of the Road Safety Audit Case Studies: Using Three-Dimensional Visualization in the Road Safety Audit Process is to help Federal, State, local, and Tribal agencies understand the benefits of utilizing interactive three-dimensional (3-D) visualization to assist an RSA team in assessing the safety effects of potential roadway designs. This case study document provides a review of the RSA process, a 3-D visualization overview, and four case study examples of planning and design-stage RSAs where 3-D visualization was used. The case studies include photographs, a project background, key RSA findings and suggestions, and the benefits of the 3-D visualization. These case studies will help jurisdictions integrate this innovative technology into their RSA process.

17. Key Words Road safety audit, 3-D visualization, 3-D model, design visualization, innovative technologies, roadway design	**18. Distribution Statement** No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	**20. Security Classif. (of this page)**	**21. No. of Pages**	**22. Price**
Unclassified	Unclassified	62	

Form DOT F 1700.7 (8-72) Reproduction of form and completed page is authorized

ACKNOWLEDGMENT

Information obtained for this document involved transportation agencies at the Federal, State, and local levels. The Federal Highway Administration (FHWA) and the authors greatly appreciate the cooperation of the Rhode Island Department of Transportation, The Aquidneck Island Planning Commission, the Montana Department of Transportation, the Prince William County Department of Transportation, the Virginia Department of Transportation, the Riverside County Transportation Commission, and the California Department of Transportation.

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Executive Summary

The purpose of this document is to help Federal, State, Tribal, and local agencies understand the benefits of utilizing interactive, three-dimensional (3-D) visualization to assist a road safety audit (RSA) team in performing a safety performance examination of potential roadway designs. This effort included performing four pre-construction stage RSAs in four different regions of the country that incorporated 3-D visualization in the standard eight-step RSA process (see Table 1).

Table 1: Pre-construction Stage RSAs Conducted Using 3–D Visualization

Location and Host Agencies	RSA Design Stage	Facility Type	Focus
Middletown, RI; Rhode Island: Rhode Island Department of Transportation (RIDOT), Aquidneck Island Planning Commission, US Navy	Preliminary Concept (0 – 1%)	Two-lane limited access connector road	New roadway and alternative intersection designs.
Belgrade, MT; Montana Department of Transportation (MDT)	Conceptual (1 – 25%)	Expressway interchanges	New Interstate highway access.
Prince William County, VA; Prince William County Department of Transportation, Virginia Department of Transportation (VDOT)	Advanced (90%)	Two-lane road widened to four lanes	Roadway widening and curve flattening and realignment.
Perris, CA; Riverside County Transportation Commission (RCTC), California Department of Transportation (Caltrans)	Preliminary (40 – 80%)	Expressway interchanges; multilane arterial	New complex interchange design.

Three-dimensional models of the proposed concepts and designs were developed using digital terrain models, design surface models, associated 2-D or 3-D computer-aided design (CAD) files, and other information necessary to create a detailed rendering of the proposed roadway and surrounding environment. This included traffic control signs, pavement markings, lane configurations, major landscaping, roadside appurtenances, traffic signals, and other items within the right-of-way to render a realistic visualization of the roadway and its environment. The 3-D models were exported to a 3-D PDF format that allowed them to be viewed using Adobe software that is both free and readily available to the general public. Furthermore, the 3-D PDF controls were easy to use for someone with basic computer skills. The user could easily rotate 360 degrees while virtually “walking” or “driving” through stations spaced 100 feet apart along the proposed alignment. Using the technique of creating the model in the 3-D PDF format enabled the RSA team and roadway owner to share and review the 3-D models to ensure their accuracy.

The use of this tool during the RSA allowed team members to visualize the project designs and identify elements that may pose a safety concern to future road users. These elements can then be further discussed and evaluated during design phases, allowing changes to be more easily made to plans rather than after the roadway has been constructed.

Three-dimensional visualization can be a useful tool in assisting RSA teams to make a more thorough assessment of safety. When used effectively, the 3-D model is a tool that will save the RSA team time and yield a heightened awareness of safety issues related to the design project. In general, the benefits associated with 3-D visualization include the following:

- Enabling persons who are not proficient at reading roadway design plans to comprehend the proposed improvements This is particularly important for large, complex projects, innovative designs, significant differences in elevation and/or grade, unusual designs, and understanding key engineering concepts.
- Illustrating how proposed features (e g , signs, structures, and traffic signals) will affect the roadway environment.
- Allowing users to view the proposed conditions from a countless number of vantage points which may reveal issues not otherwise obvious from a review of standard 2-D plans.
- Providing visual support of the RSA team's findings and recommendations to the project owners, stakeholders, and others.
- Helping to maximize the effective time of the RSA team members.
- Understanding and visualizing inaccessible locations (due to weather, terrain, security restrictions, etc).
- Identifying potentially significant impacts to community, cultural, or historic interests and other sensitive areas.
- Providing another set of collective eyes to review the project designs and engineering studies.
- Promoting a holistic design process, ensuring that, if done early, potential design issues are identified and can be addressed in a timely manner, rather than late in the design process when changes can be timely and costly.

Moving forward, techniques are continually advancing the ability to utilize 3-D visualization. Future tools will be more efficient and graphic capabilities more advanced, which will allow the further integration of 3-D visualization in the RSA and other safety processes. It is recommended that 3-D visualization continue to be incorporated within RSAs of future/potential construction projects.

Background

Road Safety Audits (RSAs) are an effective tool for proactively improving roadway safety. The Federal Highway Administration (FHWA) defines an RSA as a "formal safety performance examination of an existing or future road or intersection by an independent, multidisciplinary team." The primary focus of an RSA is safety, while working within the context of other aspects, such as mobility, access, surrounding land use, and aesthetics. By using an independent and multidisciplinary team to perform a comprehensive review and an evaluation of physical, operational, and human-factors-related safety issues for a given study area, promote an holistic approach to evaluating roadway safety. The RSA team is typically composed of at least three members having expertise in road safety, traffic operations, and road design. Other potential team members may have a background in (but not limited to) enforcement, emergency medical services, maintenance, human factors analysis, transportation planning, pedestrian safety, and bicyclist safety.

RSAs can be done at any stage in a project's life:

- ***A Pre-Construction RSA (planning and design stages)*** examines a road before it is built. This could occur at the system or project planning, feasibility, or project development stage or could occur during the design state beginning with preliminary design stage and ending with final design stage. An RSA at this stage identifies potential safety issues before crashes occur. The earlier a preconstruction RSA is conducted, the more potential it has to effectively remedy possible safety concerns. For example, a planning stage RSA can examine a system of roads before a specific project has been identified for project development, design, and construction. The transportation system is assessed at this earliest point to identify, assess, prioritize, and program projects and activities that would considerably enhance traveler safety, in the context of and in collaboration with other multi-modal transportation investments.
- ***Construction RSAs (work zone, changes in design during construction, and preopening)*** examine temporary traffic management plans associated with construction or other roadwork and changes in design during construction. RSAs at this stage can also be conducted when construction is completed, but before the roadway is opened to traffic.
- ***A Post-Construction or Operational RSA (existing road)*** examines a road that is operating and is usually conducted to address a demonstrated crash problem.

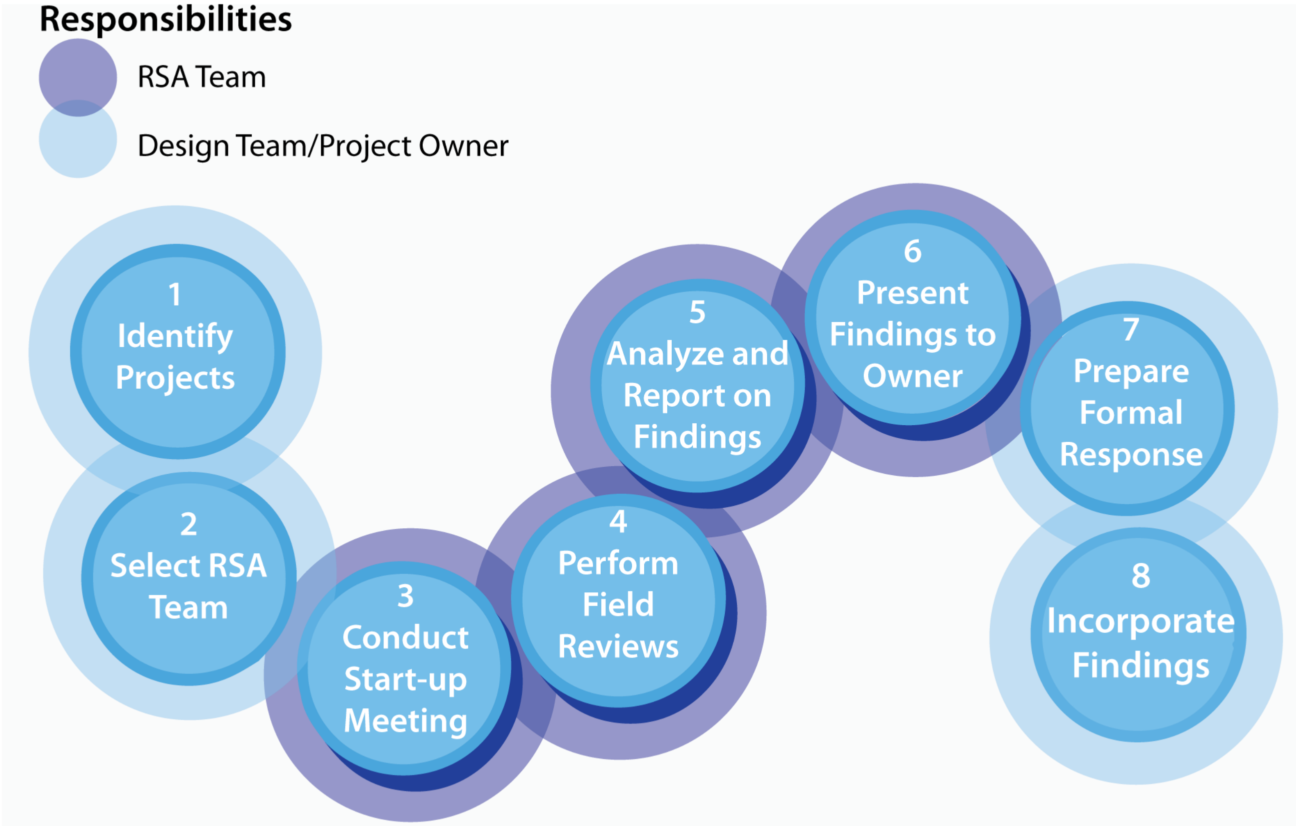


Figure 1: Typical eight-step RSA process

Eight Steps of an RSA

The eight steps of an RSA are shown in Figure 1 and follow the procedures outlined in the FHWA *Road Safety Audit Guidelines* document (Publication Number FHWA-SA-06-06).

The RSA Projects were pre-selected for this case studies document and the RSA teams were interdisciplinary, typically including engineering, planning, enforcement staff (Steps 1 and 2) from various levels of government to include Federal, State, municipal, and metropolitan planning organizations (MPO).

All meetings and site visits for the RSAs in the case studies document were conducted over two or three day periods. The RSAs typically began with a start-up meeting (Step 3) attended by the Project Owner and/or Design Team (hereafter referred to as the Owner), and the RSA team:

- The Owner described concerns regarding the roads and intersections to be assessed, why the sites had been chosen for an RSA, and any constraints or limitations Typically, the reasons for the RSA site selection centered on high-profile crashes or public safety concerns
- The multidisciplinary RSA Team then described the RSA process This included an overview of the RSA process with examples of safety issues that are typically encountered and mitigation measures to address them
- Additional issues, such as planned roadway improvements, can be discussed during this step

Following the start-up meeting and a preliminary review of the design or site documentation, the RSA Team conducted a field review (Step 4). The purpose of the field review was to observe the ambient conditions in which the proposed design would operate (for the planning-stage RSA), or to observe geometric and operating conditions (for the RSAs of existing roads). The RSA Team observed site characteristics (such as road geometry, sight distances, clear zones, drainage, signing, lighting, and barriers), traffic characteristics (such as typical speeds and traffic mix), surrounding land uses (including traffic and pedestrian generators), and link points to the adjacent transportation network. Human factors issues were also considered by the RSA team, including road and intersection "read-ability," sign location and sequencing, and older-driver limitations. Field reviews were conducted by the RSA Team under a variety of environmental conditions (such as daytime and night-time) and operational conditions (such as peak and off-peak times).

The team conducted the RSA analysis (Step 5) in a setting in which all team members reviewed available background information (such as traffic volumes and collision data) in light of the observations made in the field. On the basis of this review, the RSA Team identified and prioritized safety issues, including features that could contribute to a higher frequency and/or severity of crashes. For each safety issue, the RSA Team generated a list of possible measure to mitigate the crash potential and/or severity of a potential crash.

At the end of the analysis session, the Owner and the RSA Team reconvened for a preliminary findings meeting (Step 6). Presenting the preliminary findings verbally in a meeting gave the Owner the opportunity to ask questions and seek clarification on the RSA findings, and also provided a useful forum for the Owner to suggest additional or alternative mitigation measures in conjunction with the RSA team. The discussion provided practical information that was subsequently used to write the RSA report.

In the weeks following the on-site portion for the RSA, the RSA Team wrote and issued the RSA report (also part of Step 6) to the Owner documenting the results of the RSA. The main content of the RSA report was a prioritized listing and description of the safety issues identified (illustrated using photographs taken during the site visit), with suggestions for improvements.

The Owner was encouraged to write a brief response letter (Step 7) containing a point-by-point response to each of the safety issues identified in the RSA report. The response letter identifies the action(s) to be taken, or explains why no action would have been taken. The formal response letter is an important "closure" document for the RSA. As a final step, the Owner was encouraged to use the RSA findings to identify and implement safety improvements when policy, manpower, and funding permit (Step 8).

RSAs: Benefits and Costs

RSA Benefits

The primary benefits of RSAs are the reduction of crashes and associated crash costs as road safety is improved. The costs of automotive crashes are estimated by the US Department of Transportation as:

- $9,197,370 for a traffic fatality (category K)
- $5,454,040 for a critical injury (category A1)
- $2,446,500 for a severe injury (category A2)
- $965,724 for a serious injury (category B1)
- $432,276 for a moderate injury (category B2)
- $27,592 for a minor injury (category C)
- $6,500 for property damage only (PDO)

Other benefits of RSAs include reduced life-cycle project costs as crashes are reduced, and the development of good safety engineering and design practices, including consideration of the surrounding land use and development in combination with the potential multimodal safety issues and integrating human factors issues in the design, operations, and maintenance of roads. Additional benefits may include enhanced traveler experience and access management, reduced travel delay and travel time, and improved travel reliability.

FHWA sponsored a study of nine RSA programs and five RSA projects, and results are published in the FHWA report *Road Safety Audits: An Evaluation of RSA Programs and Projects (FHWA-SA-12-037).* The evaluation documented key strategies underpinning the success of the nine RSA programs as well as the quantitative safety benefits of specific improvements implemented as a result of the five specific RSA projects. Other local and regional studies have been completed to quantify the benefits of RSAs; practitioners are encouraged to consult partnering agencies with regard to the success in implementing RSAs.

RSA Costs

Three main factors contribute to the cost of an RSA:

- RSA Team costs
- Design team and Owner costs
- Costs of design changes or enhancements

The *RSA Team costs* reflect the size of the team and the time required for the RSA, which in turn are dependent on the complexity of the RSA project.

RSA teams are typically composed of three to four persons although they can be larger when multiple owners are involved.

Opening and closing meetings, site visits, and RSA analysis sessions are typically conducted in a two – or three-day period for each RSA. Prior to and following the on-site portion of the RSA, time is required for analysis (such as analysis of collision records, and research on applicable design standards or mitigation measures) along with writing the RSA report.

The design team and owner costs reflect the time required for staff to attend the start-up and preliminary findings meetings, and to subsequently read the RSA report and respond to its findings. In addition, staff time is required to compile project or site materials for the RSA team.

The final cost component is that resulting from *design changes or enhancements,* which reflect the number and complexity of the issues identified during the RSA.

Purpose

The purpose of this document is to help Federal, State, Tribal, and local (such as municipal and county) agencies understand the benefits of utilizing interactive three-dimensional (3-D) visualization to assist an RSA team in assessing the safety effects of potential roadway designs.

The Federal Highway Administration defines 3-D visualization - also known as design visualization (DV) - as the simulated representation of a design concept and its contextual impacts or improvements.

Innovative technologies and methods, such as those presented in this document, are supported by the Federal transportation bill, Moving Ahead for Progress in the 21st Century Act (MAP-21). Section 1304 of the bill specifically addresses the use of innovative technologies and states that it is, "in the national interest to promote the use of innovative technologies and practices that increase the efficiency of construction of, improve the safety of, and extend the service life of highways and bridges."[1] An example of an innovative technology includes the use of 3-D visualization technologies.

Section 1503 states that transportation projects that receive Federal funding are encouraged to use advanced visualization technologies during environmental, planning, financial management, design, simulation, and construction process. These advanced visualization technologies include 3-D modeling that can enhance the detail and accuracy of project designs, increase safety, accelerate construction and reduce construction costs, or otherwise expedite project delivery with respect to transportation projects that receive Federal funding.

FHWA further supports the use of 3-D modeling through the second Every Day Counts (EDC-2) initiative and the second Strategic Highway Research Program (SHRP 2). EDC-2 initiatives are aimed at the use of new technologies and innovative processes that can shorten the completion time of highway

1 Moving Ahead for Progress in the 21st Century Act (MAP-21). Available: http://www.gpo.gov/fdsys/pkg/PLAW-112publ141/html/PLAW-112publ141.htm

projects and a 2012 initiative included the use of 3-D modeling.[2] The goal of the SHRP 2 program is to research methods of expediting highway work with minimal disruption to the community.[3]

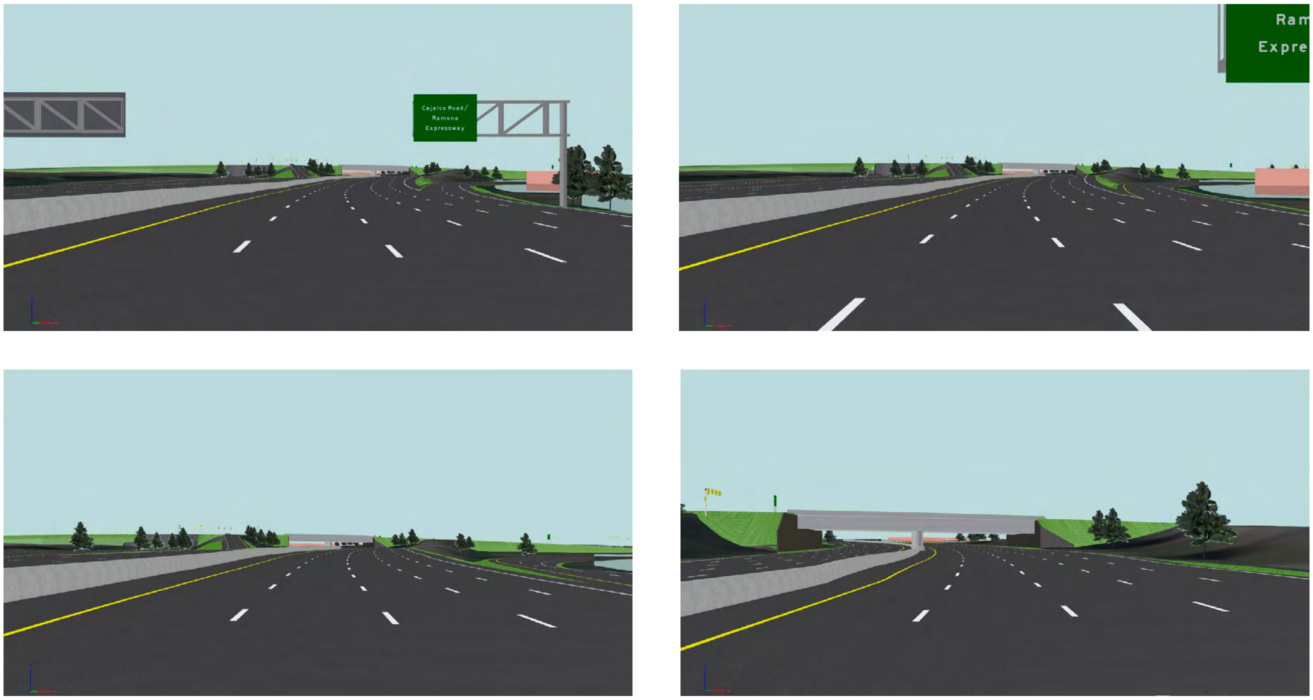


Figure 2: Three-dimensional visualization enables an RSA team to drive through a project in the design stage

3–D Visualization Overview

There were three primary goals for the four RSAs conducted for this project:

1. To evaluate whether existing issues contributing to crashes were addressed through proposed designs.
2. To identify design elements that may be modified or included to further enhance safety.
3. To address potential safety concerns associated with existing alignments beyond the proposed design projects.

To aid in achieving these goals, the RSA team utilized 3-D visualization techniques to model the proposed designs (see Figure 2).

Three-dimensional models of the proposed concepts and designs were developed using digital terrain models, design surface models, associated 2-D or 3-D computer-aided design (CAD) files, and other information necessary to create a detailed rendering of the proposed roadway and surrounding environment. This included traffic control signs, pavement markings, lane configurations, major landscaping, roadside appurtenances, traffic signals, and other relevant

2 FHWA's Every Day Counts Initiative. Available: http://www.fhwa.dot.gov/everydaycounts/edctwo/index.cfm
3 FHWA's FOCUS, SHRP 2: Accelerating Utilities Innovations. Available: http://www.fhwa.dot.gov/publications/focus/10mar/05.cfm

items within the right-of-way to render a realistic view of the roadway. The model was created in PDF format so that it could be used by nearly anyone with access to a computer, since Adobe PDF software can be downloaded for free; in other words, team members did not have to purchase specialized design software to view the 3-D models. Furthermore, the controls were easy to use for someone with basic computer skills. The user could easily rotate 360 degrees while “walking” or “driving” through stations spaced 100 feet apart along the proposed alignment. The use of this tool during the RSA allowed team members to visualize the project designs and identify elements that may pose a safety concern to future road users. These elements can then be further discussed and evaluated during design phases, allowing changes to be more easily made to plans rather than after the roadway has been constructed. The methodology used for creating the 3-D models utilized in this effort is described in Appendix B.

The 3-D model was reviewed by the RSA team during the start-up meeting (Step 3 in the RSA process) and during the RSA analysis workshop (Step 5 in the RSA process). During the start-up meeting, one person familiar with navigating the controls of the 3-D model virtually “drove” through the project and pointed out some basic design features and area landmarks to familiarize the RSA team with the design. Later, during the RSA analysis workshop, a more detailed virtual “drive-through” was conducted using the model (see Figure 3). The objective of this review was to more thoroughly analyze and discuss the various aspects of the design.

Figure 3: RSA team reviewing a 3-D model

These RSA projects for this effort are summarized in Table 2; detailed information about each RSA project is included in Appendix A.

Table 2: Pre-construction stage RSAs conducted using 3–D visualization

Location and Host Agencies	Design Stage	Facility Type	Focus
Middletown, RI; Rhode Island Department of Transportation (RIDOT), Aquidneck Island Planning Commission, US Navy	Preliminary Concept (0 – 1%)	Two-lane limited access connector road	New roadway concept and potential alternative intersection designs.
Belgrade, MT; Montana Department of Transportation (MDT)	Conceptual (1 – 25%)	Expressway interchanges	New Interstate highway access.
Prince William County, VA; Prince William County Department of Transportation, Virginia Department of Transportation (VDOT)	Advanced (90%)	Two-lane road widened to four lanes	Roadway widening and curve flattening and realignment.
Perris, CA; Riverside County Transportation Commission (RCTC), California Department of Transportation (Caltrans)	Preliminary (40 – 80%)	Expressway interchanges; multi-lane arterial	New complex interchange design.

Three-dimensional visualization should not be confused with microsimulation or advanced computer traffic simulation techniques that are performed by traffic microsimulation programs, such as Synchro, CORSIM, or VISSIM. Microsimulation is used to assess the impact of traffic flow and determine vehicular delay results. These programs also enable the user to visualize traffic operations on the roadway network but are not designed for detailed assessments of designs.

Cases in which RSAs May Benefit from 3-D Visualization

Three-dimensional models may require significant time and effort to create and, therefore, may not be cost-effective on all types of projects. Specific characteristics of projects that may benefit from 3-D visualization as a cost-effective tool to improve safety are as follows:

- Large or complex projects
- Innovative or unusual designs
- Significant differences in elevation and/or grade
- Inaccessible locations
- Vital public involvement

Benefits of 3-D Visualization

Generally speaking, the incorporation of 3-D visualization into the RSA process offers a number of tangible benefits:

- ***The 3-D model enables members of the RSA team who are not proficient at reading and interpreting roadway design plans to grasp the proposed improvements.*** A typical roadway plan sheet includes a variety of information types, including existing topographic features; existing right-of-way and easements; existing drainage facilities and utilities; property lines; construction baselines; proposed roadway improvements; proposed right-of-way and easements; proposed drainage facilities and utilities; etc. Linework will vary in type, thickness, and color to represent specific components of the roadway environment, and there are various textual and numerical details presented on the sheet. To unfamiliar eyes, a roadway plan sheet may represent little more than "information overload," as the reviewers may not be able to directly decipher the material before them. Because 3-D visualization strives to replicate real-world conditions, it is more easily comprehended by persons of limited roadway design experience.

- ***The 3-D model can be used to illustrate exactly how the roadway environment will be affected by signs, structures, guardrail, and other key features that are supplemental to the roadway itself.*** While the characteristics of a roadway's horizontal geometry may be effectively conveyed through a roadway plan sheet, the vertical components of other features may be lost in this traditional 2-D vantage. The 3-D model conveys not only the vertical qualities of the roadway itself—namely its superelevation and the incidence of crest and sag vertical curves—it can also illustrate the 3-D characteristics of other features of the existing or proposed environments. These features may include trees, fence lines, guardrail, and concrete barrier. Furthermore, the accurate incorporation of proposed or existing signs can also be invaluable in allowing the reviewer to observe how the positioning and size of the signs may affect their perceptibility (and, ultimately, their effectiveness) with regard to approaching drivers.
- ***The 3-D model allows users to view the proposed conditions from any number of vantage points, which may reveal issues not otherwise obvious from a review of standard 2-D plans.*** A traditional 2-D rendering could be developed to capture the perspective of a driver at a specific location looking at a specific point or in a specific direction, and such a rendering may prove useful to a reviewer. However, if the reviewer then wanted to observe a slightly different vantage (e.g., for a driver positioned 20 ft. to the west or pivoting 15 degrees to the left), then a brand new rendering must be created to accurately recreate that perspective. The development of a series of similar renderings would require significant time and effort. Conversely, the models created here are truly 3-D and allow the user to turn 360 degrees and move about throughout the virtual environment; as such, the models provide the users with essentially every possible vantage that they may desire. This array of available perspectives ranges from an on-the-ground street view to an overhead view and includes every vantage in between. By capturing screen images of various perspectives, users can create a vast collection of viewpoints of the proposed or existing conditions to use for a number of purposes.
- ***The 3-D model can be used by the RSA team to provide visual support of its findings and recommendations to the project owners, stakeholders, and others.*** Regardless of whether a recommendation of the team was based on a review of the 3-D model, field observation, or another exercise, 3-D visualization often serves as an effective tool to explain and support that recommendation to the project stakeholders. The unrestricted movement allowed within the parameters of the model affords the team the opportunity to "bring" the stakeholders to the location and vantage in question. One need not rely on the audience members' ability to visualize the roadway environment within their own minds, as that very roadway environment can be explored collectively using 3-D visualization.

- ***The 3-D model can help to maximize the effective time of the RSA team members.*** A typical RSA is conducted over two to three consecutive days, with its beginning and ending proceedings—the kickoff and preliminary findings meetings, respectively—scheduled well in advance. These meetings serve as bookends to the multi-day process and establish a finite time frame in which all group activities must transpire. It is, therefore, essential that each group activity is completed in as efficient a manner as possible to maximize the reach of the team in its short time together. By streamlining the process of familiarizing itself with the roadway environment through the review of the 3-D model, the team spends less time comprehending the conditions and more time pondering the potential safety concerns and associated mitigating actions related to those conditions, which, of course, is the overarching goal of any RSA.
- ***The 3-D model affords the RSA team the opportunity to provide another set of collective eyes in reviewing the project designs and engineering studies.*** The main purpose of the 3-D visualization is to bring a static design to life for its audience. The RSA team is able to evaluate and validate the appropriateness of many of the design and engineering components because the model brings multiple portions of the design together in an easily comprehensible format. First, it allows the coordinated review of the horizontal and vertical alignments because it presents both simultaneously. Second, because the 3-D model is analyzed in light of other key engineering components beyond the geometric design, it can also bring those pieces to life. For instance, reviewing a traffic impact assessment while simultaneously driving the corridor via the model will assist the RSA team in giving more thoughtful consideration of the projected traffic demands than if that document were viewed independently of the visualization.

There were also several specific benefits realized for the particular projects analyzed here:

- ***In Rhode Island, the 3-D model helped the team to visualize and understand key engineering concepts.*** One of the potential benefits of a modern roundabout is a traffic calming effect on vehicular speeds at the intersection. While the departure legs are designed to allow vehicles to exit the circle efficiently, an element of horizontal deflection is incorporated into the design of the approach legs such that drivers are obliged to reduce their speeds in order to navigate the geometry ahead. Excessive speed was a major concern on an urban four-lane arterial considered during the Rhode Island RSA. Posted at 25 mph, this roadway was characterized by exceptionally wide travel lanes (i.e., 15-18 ft) and commonly-observed speeds greater than 40 mph. During the team's comparison between a roundabout and traffic signal along this corridor, 3-D visualization was invaluable in illustrating how the geometric deflection applied to each approach of the roundabout would in essence slow every vehicle that traversed this intersection. The team "drove" in a virtual sense along each approach and observed directly how the horizontal deflection would combine to command deceleration and a heightened awareness of the impending intersection.

- ***In California, the 3-D model promoted a holistic design approach.*** Traditionally, the early stages of roadway design focused primarily on establishing "line and grade" (i.e., horizontal and vertical alignments). Oftentimes, little attention was paid to other vital components of the roadway environment (e.g., signs, pavement markings, roadside barriers, etc.) until much later in the design process. At the heart of the California RSA was a complex interchange between an existing Interstate highway and a proposed high-speed multi-lane facility. The 3-D model enabled the RSA team to virtually "drive" along several of the paths within the study area, including the Interstate mainline, several of the interchange ramps, the crossing streets, and a frontage road paralleling the Interstate. Reviewing the model highlighted just how critical the pavement markings and overhead guide signs would be to the safe and efficient operation of the proposed intricate roadway system. As a result, the RSA team recommended that the design team make it a priority to progress the overhead signing plan from a conceptual level to a more advanced state to ensure that critical wayfinding measures can be provided. Additionally, the team discussed the impact of sign structure locations and grading practices on the extent and type of roadside barrier that would be required throughout the project limits. In summary, because it combined all elements of the proposed design, 3-D visualization for California highlighted the importance of a holistic approach to design by simultaneously considering all design features that affect roadway safety—pavement markings, signing (and supporting structures), roadside barriers, etc.
- ***In Montana, the value of the 3-D model was fully realized when the RSA team considered two separate interchange designs—one of which was modeled while the other was not.*** Across the four RSAs that comprised this effort, there was a sense that the 3-D visualization offered a real benefit to the RSA team. There was no clearer case presented for this sentiment than the Montana RSA that involved two separate interchange designs. The scope of the visualization effort allowed only one of the alternatives to be modeled; thus, the RSA team had one modeled design and unmodeled design at their disposal. The team was able to conduct a more thorough review and generate a series of detailed recommendations for the interchange design that was modeled. Conversely, for the design alternative not modeled, the team conducted a more basic assessment and was more limited in the overall project visualization and associated depth of potential improvements. The RSA team concluded that the modeling of the second alternative would have enabled it to complete a much more thorough evaluation of the two designs.
- ***In Rhode Island, the 3-D model allowed for the review of locations that were not readily accessible to the RSA team.*** A bypass corridor was being considered as a way to alleviate congestion on Aquidneck Island, and the conceptual alignment of this new roadway bisected the secured Naval Station Newport (NAVSTA). Because some sections of the alignment were well within the security fencing at NAVSTA, the RSA team was unable to walk the entire path of the bypass route. However, the 3-D model allowed the team to virtually "drive" the whole corridor and get a general sense of the future roadway environment.

- ***In Virginia, the 3-D model helped clearly visualize impacts of proposed designs in sensitive areas.*** The 3-D model was an important element in demonstrating the proposed changes to the public. Since the project passed directly behind houses and a neighboring community, it was important to be able to show the impacts on homeowners and the adjacent community. The extents of the proposed roadway widening and realignment as well as landscaping and fencing placement were all critical to demonstrating the overall project impact. Furthermore, realistically depicting existing features, such as a highly-recognizable convenience store, was key to building confidence in the accuracy of the model. Ultimately, the model was utilized in a public meeting to illustrate the project to all stakeholders.

Visualization Development Efforts

The models developed for these four RSAs were created using Microstation V8 and V8i and then exported to a 3-D PDF format. This technique was used because the 3-D PDF format is easily accessible. The PDF platform is commonly used by many people and can be downloaded for free. During the course of this project the RSA team and roadway owner were able to share and review the 3-D models to ensure their accuracy. In no way is this an endorsement of this or any of the design tools used to create these models. There are many other design visualization design tools and methods that can be used to create a 3-D model. The FHWA Office of Federal Lands Highway Design Visualization Guide provides information on other design visualization techniques and procedures. Detailed information on the techniques used for this project is in Appendix B. A basic review of this process and effort is provided as follows:

- The effort expended in the development of the 3-D models for the four RSAs varied from 100 to 200 person-hours The same individual developed the visualization models for each RSA and estimated his efficiency increased by as much as 40 percent from the first to the last
- Trimble 3-D warehouse was used to secure some of the supplemental elements, such as light poles
- Information requested from the project design team included a variety of files:
  - Proposed CAD linework (both 2-D and 3-D, if available) for all improvements, including pavement markings.
  - Existing and proposed digital terrain models (DTMs) or triangulated irregular networks (TINs).
  - Supplemental files, such as pavement marking plans and typical sections for bridge designs.
  - PDF of the entire plan set.
- For the RSA conducted in Rhode Island, DTMs were not provided Rough elevation information was pulled from an on-line mapping resource, which increased the overall level of effort needed to create the 3-D model

- For the RSA conducted in Montana the proposed on ramp design was not provided in CAD and therefore had to be created in the 3-D model, thereby increasing the overall level of effort needed

Conclusions and Recommendations

The purpose of this document is to help Federal, State, Tribal, and local agencies understand the benefits of utilizing interactive 3-D visualization to assist an RSA team in assessing the safety effects of potential roadway designs. This effort comprised a series of four RSAs in four different regions of the country that incorporated 3-D visualization into the standard eight-step RSA process. Developed from various electronic files provided by the designers of each roadway project, the 3-D models were based in a common PDF format that allowed them to be viewed using Adobe software that is both free and readily available to the general public. A minimum of 100 man-hours were expended in the development of each model.

RSA projects that may be prime candidates for 3-D visualization are those characterized by any of the following:

- Large or complex projects
- Innovative or unusual designs
- Significant differences in elevation and/or grade
- Inaccessible locations (due to weather, terrain, security restrictions, etc)
- Potentially significant impacts to community, cultural, or historic interests

The use of 3-D visualization in the RSA process provides the following benefits to the RSA team:

- Enabling persons who are not proficient at reading roadway design plans to comprehend the proposed improvements
- Illustrating how proposed features supplemental to the roadway (e g , signs, structures, traffic signals, etc) will affect the appearance of the roadway environment
- Allowing users to view the proposed conditions from a countless number of vantage points
- Providing visual support of the RSA team's findings and recommendations
- Helping to maximize the effective time of the RSA team members

This case study document summarizes the key benefits of 3-D visualization observed for the four RSAs conducted under this effort, but additional benefits may be realized for other types of projects. This may be especially true for designs with complex vertical elements. For example, a good candidate for visualization may be an existing at-grade intersection in an urban or suburban environment at which grade-separation has been proposed. Additionally, the combination of roadway attributes may be difficult to assess from a safety standpoint without a clear picture of how these elements come together. These elements include changes in the roadway, introduction of grade alterations, elevated structures that may limit sight distance or roadway perception, and the interactions of many types of roadway users.

Three-dimensional visualization can be a useful tool in assisting RSA teams to make a more thorough assessment of safety. Using 3-D visualization resulted in support for improvements identified during the RSA resulting in those changes being incorporated into the construction plans. The 3-D model assists the RSA team in understanding a future design. When used effectively, 3-D visualization is a tool that will save the RSA team time and yield a heightened awareness of safety issues related to the design project. It is recommended that 3-D visualization continue to be incorporated planning stage and design stage RSAs.

APPENDIX A: CASE STUDIES

Defense Highway/Burma Road Corridor, Middletown, Rhode Island

RSA No. 1—Defense Highway/Burma Road Corridor, Middletown, Rhode Island

Project Overview	
Project Location	Coddington Highway (in the vicinity of Gate 10) and Gate 17 Access Road from Gate 23 to Gate 32
Planned Improvements	• New two-lane, limited-access connector road to provide bypass route • Intersections at either end of connector (Alt. 1 – signalized intersections; Alt. 2 – roundabouts)
Project Environment	Suburban
Project Design Stage	Preliminary Concept (0 to 1%)
Project Owner(s)	Rhode Island Department of Transportation, Aquidneck Island Planning Commission, US Navy
RSA Overview	
Date of RSA	August 2 – 4, 2010
RSA Stage(s)	Pre-construction (planning) and operational stage and RSA of existing roads
RSA Team	Representatives from the Federal Highway Administration , Middletown Police Department, Naval Station Newport, Rhode Island Department of Transportation, and Vanasse Hangen Brustlin, Inc.
3-D Visualization Overview	
Level of Effort	100 hours were expended to model the connector road alignment, and an additional 40 hours were spent modeling the two pairs of intersection alternatives.
Information Provided by Designers	• Existing conditions and proposed improvements in CAD format • Latest signing and pavement marking plans

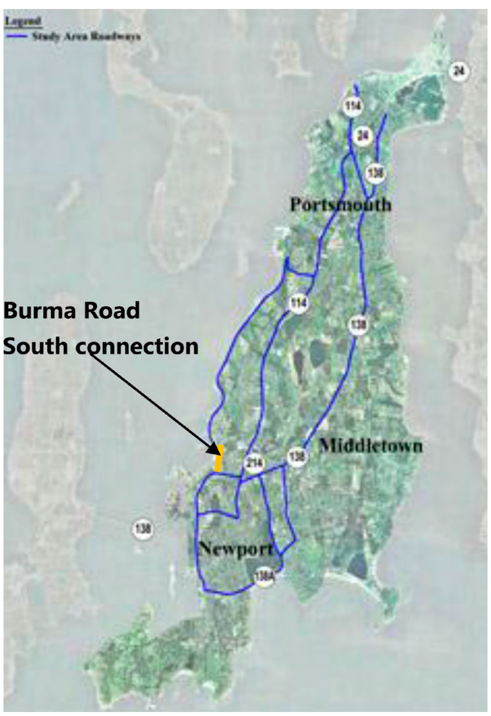


Figure 4: Graphic showing primary routes in Aquidneck Island Transportation Study

Project Background

The objective of this study—which was cosponsored by the Rhode Island Department of Transportation (RIDOT) and the Aquidneck Island Planning Commission through the Aquidneck Island Technical Steering Committee and funded by the Federal Highway Administration (FHWA) Office of Safety—was to complete an RSA for a possible future bypass corridor in Middletown, Rhode Island on Aquidneck Island. The subject corridor included a preliminary concept 2/3-mile-long roadway alignment across the US Navy's Naval Station Newport (NAVSTA), the third largest employer in the state, which would provide a critical north-south link between Coddington Highway and Gate 17 Access Road.

Currently there are two primary north-south routes on Aquidneck Island that connect Newport in the south with Portsmouth to the north: W. Main Road (SR 114) and E. Main Road (SR 138) (see Figure 4). In general, both facilities have a four-lane cross section with two lanes in each direction. The large number of intersecting streets, driveway access points, and traffic signals, coupled with few exclusive turn lanes, creates significant delay for traffic seeking to go from one end of the island to the other. In response to this congestion, a preliminary concept alignment of a new limited-access roadway across the NAVSTA facility was proposed. (Note that "limited-access" refers to the use by the general public, as the access and operations with respect to the US Navy and its facilities must not be adversely affected in any way.) The proposed roadway—referred to as Burma Road South—would parallel W. Main Road and connect intersecting roads Coddington Highway and Gate 17 Access Road. The corridor would continue north on Burma Road until it ends at Stringham Road in the north. As part of the Aquidneck Island Transportation Study, it was noted that a new alignment will be considered to extend Burma Road to the northeast and ultimately connect to Route 24.

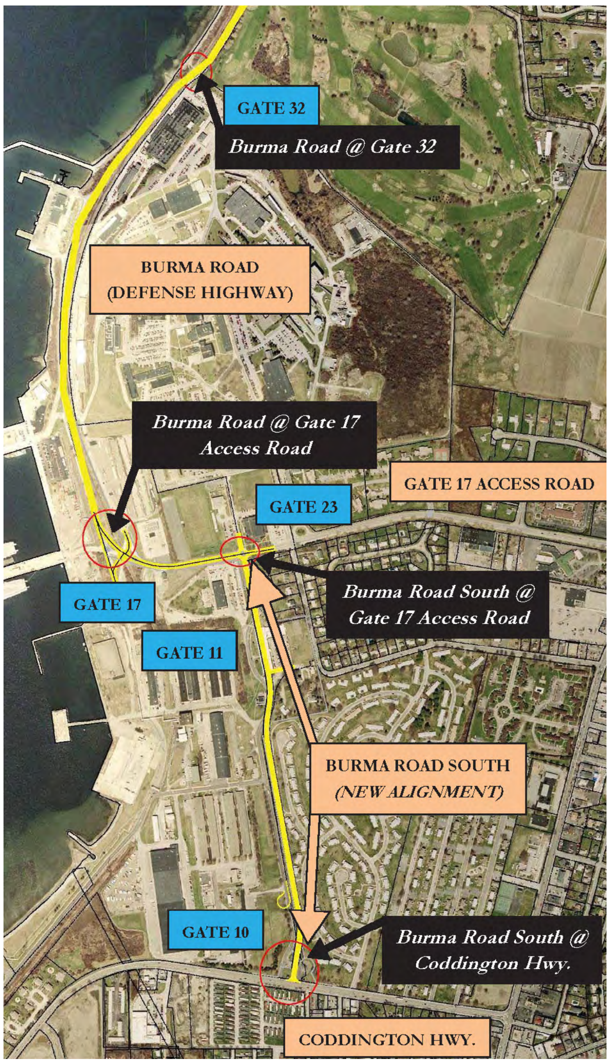


Figure 5: Limits of the entire study area for the RI RSA, including NAVSTA gates 10, 11, 17, 23, and 32

Because the construction of the new Burma Road South would likely provide an appealing alternative route to W. Main Road and E. Main Road, an additional and entirely different set of users may begin to utilize the adjacent roadways (including Coddington Highway and Burma Road) as a bypass corridor to avoid the congestion of W. Main Road. Consequently, these roadways were analyzed during the RSA, not only in consideration of their existing conditions but also how the new "bypass" use may present an additional set of safety concerns.

The RSA included a field analysis of Coddington Highway at Gate 10, Gate 17 Access Road at Gate 11, Gate 17 Access Road at Burma Road, and Burma Road at Gate 32, as well as a thorough review of the 3-D model of the preliminary concept Burma Road South alignment. Figure 5 shows the full extent of the RSA study area, and Figure 6 depicts the limits of the area incorporated in the model.

Not only did the 3-D visualization bring to life a roadway that was in the preliminary concept design stage, it also enabled the RSA team to traverse (in a virtual sense) portions of the secured NAVSTA facility to which it did not otherwise have access. While the confines captured by the model were limited to the planned Burma Road South and its northern and southern termini, the total RSA study area exceeded the modeled area significantly along the north-south corridor.

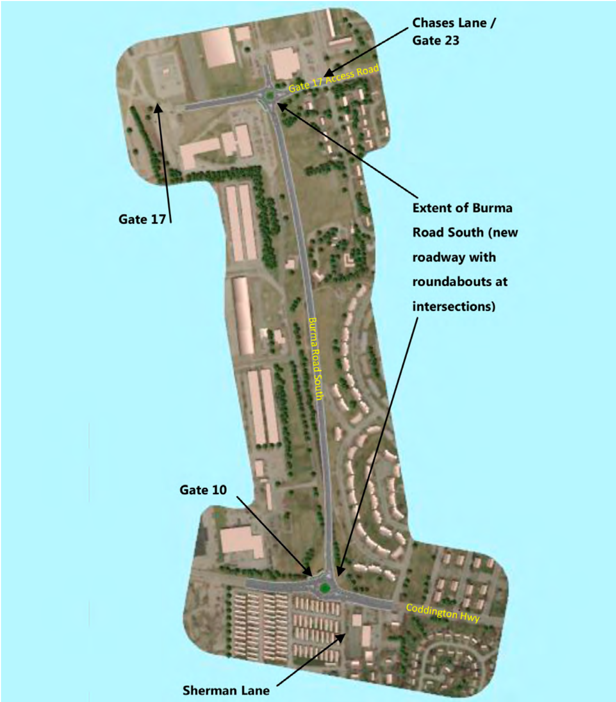


Figure 6: Plan view of area modeled as part of the RI RSA (roundabout alternative)

The RSA included a field analysis of Coddington Highway in the vicinity of Gate 10 and Gate 17 Access Road, as well as a thorough review of the 3-D model of the preliminary concept connector road alignment. Two alternatives were reviewed as part of the preliminary concept design of Burma Road South: the first included signalization of the intersections at the north and south limits, while the second included roundabouts. Figure 7 shows an image of Coddington Highway at the proposed connector road as viewed from each 3-D model.

Information used by the RSA team to conduct the review included the following:

- Crash data (2007-2009)
- Existing (2009) Average Daily Traffic (ADT)
- Projected (2030) ADT

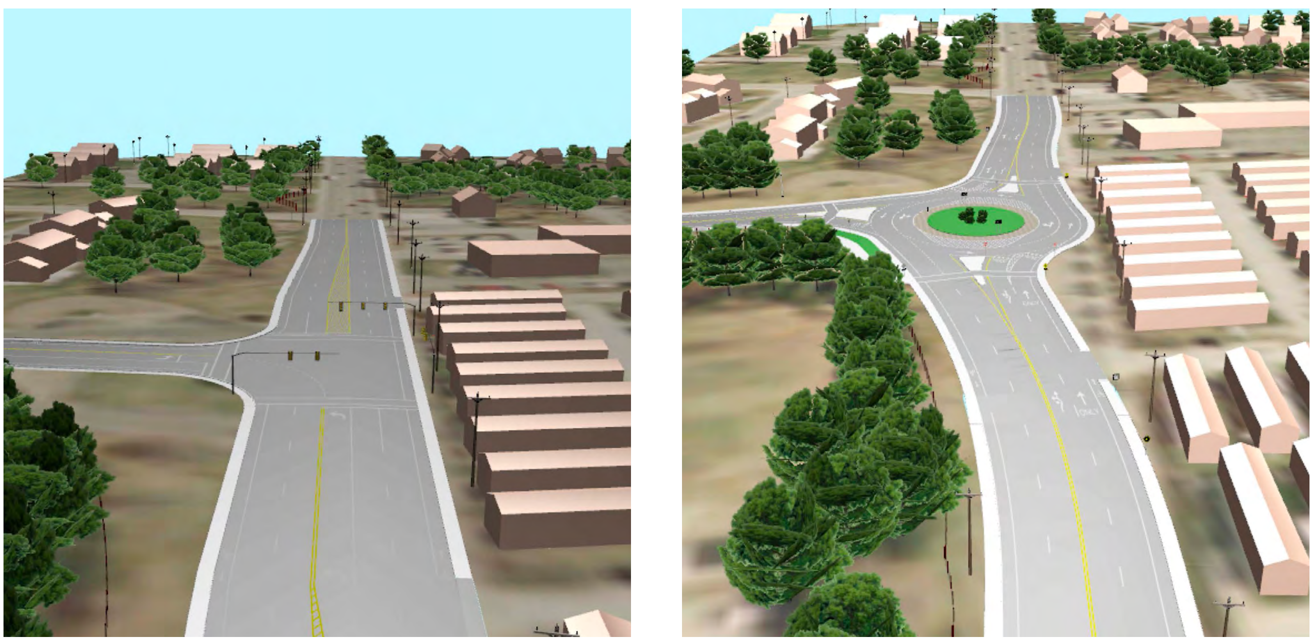


Figure 7: Images from both 3-D models comparing the signalized intersection and roundabout alternatives at Coddington Highway and the proposed connector road (Burma Road South)

Key RSA Findings and Suggestions

Three-dimensional visualization was instrumental in the RSA team's identification of a variety of potential safety issues—and not just those exclusive to the proposed designs.

Table 3 presents some key safety concerns and suggested actions along existing roadways that were either detected or reinforced by review of the 3-D visualization.

Table 3: Selected safety issues and suggested mitigating actions on modeled section of roadway

Selected Safety Issue	Suggested Action
Excessive speeds Overall pavement width of Coddington Highway is 55-60 ft, including outside travel lanes that measured 15-18 ft wide. Wide travel lanes encourage speeds in excess of the posted speed limit of 25 MPH.	*Near-term* Restripe Coddington Hwy to provide three-lane cross section (a through lane in each direction and two-way left-turn lane [TWLTL]) with bike lanes. If roadway is restriped, consider conducting speed study to evaluate appropriateness of posted speed limit.
Sight distance limitations and visual detractors Vertical crest curve on Coddington Highway just east of Sherman Lane limits sight distance for drivers traveling westbound from W. Main Road. Driver sight distance is hindered at the intersection of the connector and Gate 17 Access Road by combination of factors, including trees, poles, and sun-glare at dawn and dusk.	*Near-term* Restripe existing pavement on Coddington Hwy to provide three-lane cross section (through lane in each direction and TWLTL) with bike lanes. The TWLTL would remove left-turning traffic from inside through lanes. Install backplates on the traffic signal heads for Gate 17 Access Road. *Intermediate-term* Consider removal/relocation of sight distance obstructions from the intersection of Gate 17 Access Rd/Gate 11. *Long-term* Consider rebuilding Coddington Hwy to flatten vertical curve. Consider installation of roundabout at Coddington Hwy/Sherman Ln/Burma Rd South to eliminate traditional left turns at intersection and slow approaching traffic through deflection-based design. Consider installing raised median along Coddington Hwy west of Burma Rd South to eliminate left turns. Consider installation of roundabout at intersection of Gate 17 Access Rd/ Gate 11; being a feature of the roadway itself, roundabout would lower the driver's line of sight compared to a traffic signal, thereby lessening the impact of the sun's glare.
Access management concerns Close proximity of access points along Coddington Hwy.	*Near-term* Restripe Coddington Hwy to three-lane cross section with bike lanes. *Long-term* Consider roundabout installation at Coddington Hwy/Sherman Ln/Burma Rd South. Consider installation of raised splitter islands on Coddington Hwy to control left turns.
Peak-hour turning movements Because of the proximity between Chases Ln/Gate 23 and Burma Rd South along Gate 17 Access Rd, the heavy peak-hour turning volumes at the former can queue into the through lanes.	*Near-term* Extend the eastbound Gate 17 Access Rd left-turn lane at Chases Ln to provide additional storage for turning vehicles. *Long-term* If the existing traffic signal is removed and a roundabout is constructed at the intersection with Burma Rd South, consider the installation of a second roundabout at Chases Ln/Gate 23 to help the intersection operate more efficiently while increasing safety through the elimination of traditional left turns.

Table 4 presents several suggestions pertaining directly to the preliminary concept designs that were made as a result of the review of the 3-D model. The final suggestion pertains to nonmotorized users along the Burma Road South corridor, and Figure 8 illustrates the sidewalk accommodations provided in the preliminary concept design.

Table 4: Suggestions on preliminary concept designs for proposed Burma Road South

Suggestion
Shift proposed Coddington Hwy roundabout to the east so that Sherman Ln can become fourth leg; this should also improve sight distance at the vertical crest curve by moving the roundabout further up the hill.
Incorporate lighting in roundabout design to improve nighttime visibility and awareness of conditions.
Emphasize deflection in approach leg geometry to enhance speed reduction for oncoming vehicles.
Because there may be future short-term need for NAVSTA to utilize Gate 10, design should accommodate a suitable connection.
Characteristics of pedestrian and bicycle traffic should be considered in the design of Burma Rd South. As a limited access facility, vehicle speeds will likely be high and expectancy of pedestrians may be low. Therefore, a parallel shared use path may be preferable to accommodate pedestrians. Bicyclists may also be accommodated on this facility, especially less-experienced bicyclists. Commuter bicyclists, already present on Burma Road to the north, could use a paved shoulder, which would also provide a safety benefit to motorists. A shared use path to the east of the proposed roadway will also provide connectivity to the neighboring residences. (Likewise, a pedestrian facility on the west side – either a sidewalk or a shared use path – would not be able to access NAVSTA and is therefore less critical.) In addition, Coddington Hwy and Burma Rd both currently have (or will likely have in the future) designated bike lanes, therefore a bikeable shoulder would provide consistency with the rest of the corridor. Further discussion with the stakeholders regarding the accommodation of pedestrians and bicyclists is warranted.

Figure 8: Proposed crosswalk and sidewalk accommodations along Burma Rd South, looking north from Coddington Hwy (left) and south from Gate 17 Access Rd (right)

Selected Issues beyond the 3-D Model

While the use of 3-D visualization constituted a major part of the study, the Defense Highway/Burma Road Corridor RSA also included a traditional field review of existing conditions in portions of the study area that did not include design visualization. In addition to the areas already mentioned, the RSA analysis also focused on the intersections of Gate 17 Access Road/Gate 11 and Burma Road/Gate 32. Table 5 presents a few such safety issues and suggested actions.

Table 5: Selected safety issues and suggested actions for areas beyond the 3-D model

Selected Safety Issue	Suggested Action
Horizontal curvature There is a very sharp horizontal curve for the through movement at the intersection of east-west Gate 17 Access Road and the north-south Burma Road, with no advance warning of the curve for approaching drivers. Near Gate 32, Burma Road crosses the railroad tracks at-grade via a pair of reverse horizontal curves. Because of their low design speed, the curves are posted at 25 MPH, which violates driver expectancy since the remainder of the Burma Road corridor is posted at 35 MPH.	*Near-term* Install advance curve warning signs for each approach of the through movement along Gate 17 Access Rd near Gate 11. *Long-term* Consider realigning the through movement of Gate 17 Access Rd near Gate 11 to provide a larger radius and higher design speed at the intersection. *Burma Road/Gate 32:* Consider "swapping" locations of the rail line and Burma Rd between Gate 17 and Gate 32 such that the rail line would lie to the west of the roadway for the entire corridor. This would eliminate the reverse curvature and the at-grade crossings of Burma Rd. Note that this will require extensive coordination with NAVSTA, as such action could significantly impact Gate 17 and Building 119 and present new security risks to the secured naval facilities. Consider the redesign of the reverse curvature along Burma Rd near Gate 32 to flatten the curves and increase the design speed such that the posted speed limit of 35 MPH may remain uninterrupted throughout the corridor.
Multiple at-grade rail crossings Several aspects of the existing rail line location were observed to present safety issues, such as being located at the bottom of a downgrade and being adjacent to a busy intersection near Gate 11, and introducing two at-grade crossings along Burma Road within less than a mile (at Gate 11 and Gate 32).	*Long-term* Consider "swapping" locations of the rail line and Burma Rd between Gate 17 and Gate 32 such that the rail line would lie to the west of the roadway for the entire corridor and the two at-grade crossings of Burma Rd would be eliminated. Note that this will require extensive coordination with NAVSTA, as such action could significantly impact Gate 17 and Building 119 and present new security risks to the secured naval facilities. Evaluate the long-term usefulness of the rail line in the overall Aquidneck Island Master Plan and consider removing it entirely if appropriate. On the other hand, if the railroad tracks can play a role in the enhancement of the area's transportation network, then consider upgrading and improving the rail infrastructure throughout the corridor.
Inadequate signing and delineation The RSA team noted that the 25 MPH speed limit sign was missing along southbound Burma Rd just north of Gate 32, and there were no delineators found on the existing guardrail near the Gate 32 intersection.	*Near-term* Replace the missing 25 MPH speed limit sign (the post was present but the sign was not) and install delineators along the existing guardrail near the intersection, which will improve nighttime conspicuity.

Benefits of the 3-D Visualization

The 3-D model helped the RSA team to visualize and understand key engineering concepts, in this case the potential safety issues associated with different elements of the preliminary concept design and differences between the signalized intersection and roundabout alternatives. One of the potential benefits of a modern roundabout is a traffic calming effect on vehicular speeds at the intersection. While the departure legs are designed to allow vehicles to exit the circle efficiently, an element of horizontal deflection is incorporated into the design of the approach legs such that drivers are obliged to reduce their speeds in order to navigate the geometry. Excessive speed was a major concern on Coddington Highway, which is a four-lane arterial with a 2009 ADT of 18,600 vehicles per day. Posted at 25 mph, this roadway was characterized by exceptionally wide travel lanes (i.e., 15-18 ft) and commonly-observed speeds greater than 40 mph. During the team's comparison between a roundabout and traffic signal along this corridor, the 3-D model was invaluable in illustrating how the geometric deflection applied to each approach of the roundabout would in essence slow every vehicle that traversed this intersection. The team virtually "drove" along each approach and observed directly how the horizontal deflection would combine to command deceleration and a heightened awareness of the impending intersection (Figure 9). The visualization of the roundabouts led to a better understanding of their benefits and, ultimately, to their selection as a preferred alternative over the signalized intersection.

Figure 9: Driver's-eye view approaching roundabout along Coddington Highway

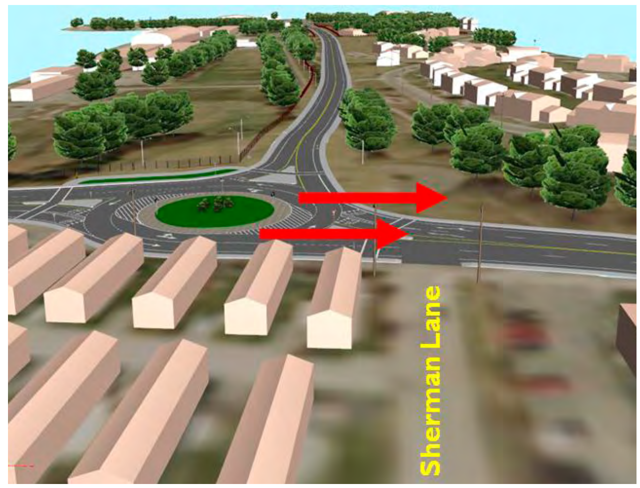


Figure 10: Image from model showing proximity of Sherman Lane to proposed roundabout

By being able to rotate the model and look at the design aspects from different viewpoints, the RSA team was able to suggest alignments that were more conducive to safety. For example, the model showed the Coddington Highway roundabout located just west of the intersection with Sherman Lane. The team recognized that Sherman Lane could be incorporated as a fourth leg to the roundabout by shifting the circle approximately 100 ft to the east (Figure 10). Such a design revision would eliminate a separate full-access intersection located so close to the roundabout and would accommodate all vehicle movements within the circle.

Figure 11: Early morning sun-glare as seen from eastbound Gate 17 Access Rd

The RSA team was able to see other benefits of the roundabout design as it related to existing issues on the roadway. During the morning and evening site visits, the RSA team noted that sun glare was an issue on several roads in the study area, see Figure 11. Being a feature of the roadway itself, a roundabout would lower the driver's line of sight compared to a traffic signal, thereby lessening the impact of the sun's glare.

The ability to describe the roundabout concept led to a broader discussion among the RSA team members regarding the implementation of roundabouts in pairs with a median installed between them. This scheme enables the conversion of all side streets and driveway access points between the roundabouts to right-in/right-out configurations by prohibiting left turns. Figure 12 presents a simple example of this approach—called the "dog-bone" concept because of its geometric characteristics. In the illustration, a single access point lies on the segment between the two roundabouts. A raised median separates the opposing through lanes on the mainline, which serves to prohibit all left turns between the roundabouts. The blue arrow illustrates the path for a vehicle seeking to turn left from the driveway, while the orange arrow shows the path of a vehicle wishing to turn left into the driveway. The same concept would apply regardless of the number of access points and side streets located within the segment, with all U-turn maneuvers being safely accommodated by the roundabouts.

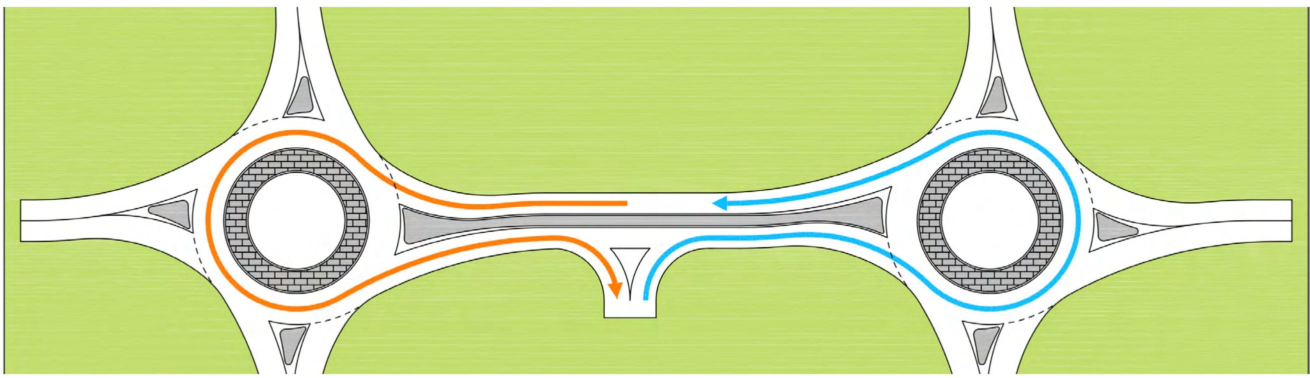


Figure 12: Schematic diagram of the "dog-bone" concept

The RSA team recognized the long-term potential of Coddington Highway's conversion to a roundabout corridor with raised median, but near-term recommendations involving restriping were applied to provide an immediate impact on roadway safety (see Figure 13 and Figure 14). Additionally, as a result of the benefits demonstrated by the roundabout 3-D visualization, the City of Newport and RIDOT are currently designing a roundabout corridor as part of a bridge improvement project and the Town of Middletown and RIDOT considering the future application of multiple roundabouts. A series of roundabouts will be installed along JT Connell Highway and Admiral Kalbfus Road, and construction is expected to begin by 2020.

Figure 13: Recently implemented road diet on Coddington Hwy, Newport per RSA team recommendations (photo, left: August 2010; photo, right: January 2013)

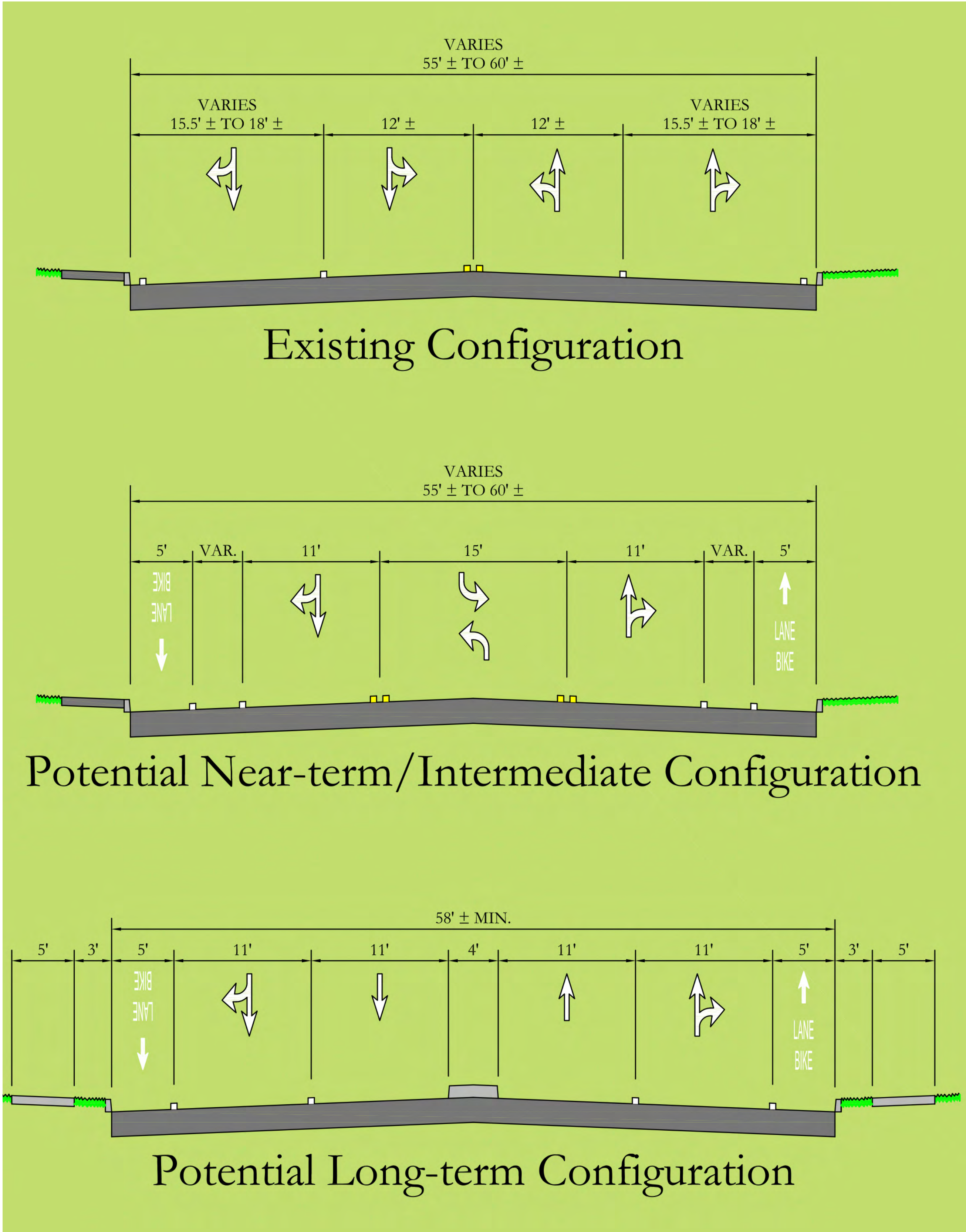
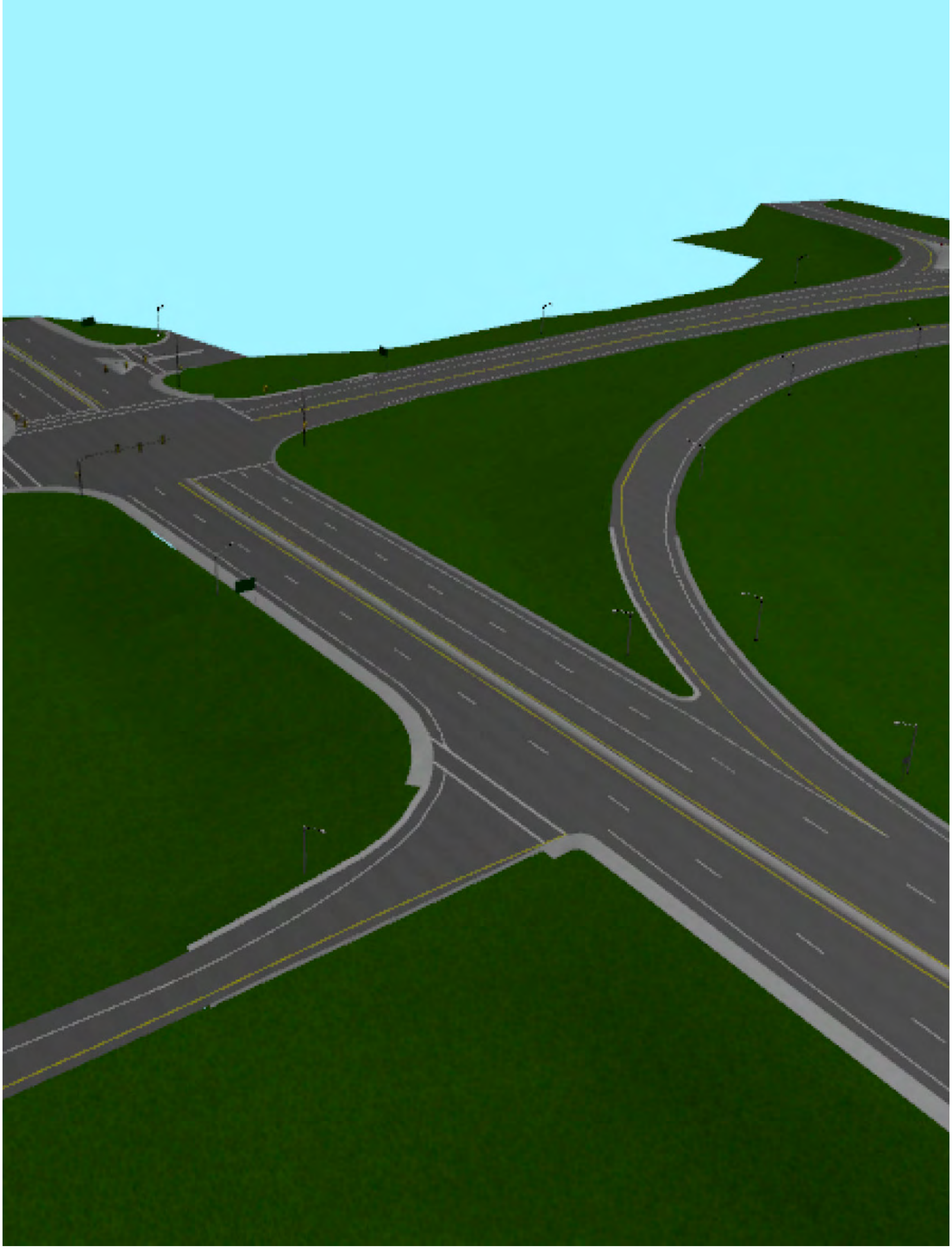


Figure 14: Existing and proposed cross sections for Coddington Hwy developed by the RSA team

I-90 Interchanges, Belgrade, Montana



RSA No. 2—Road Safety Audit of I-90 Interchanges, Belgrade, Montana

Project Overview	
Project Location	Belgrade, Gallatin County, Montana
Planned Improvements	• New proposed on-ramp onto Interstate 90E • New proposed exclusive right-turn lane
Project Environment	Suburban
Project Design Stage	Conceptual (1 to 25%)
Project Owner(s)	Federal Highway Administration (FHWA) and Montana Department of Transportation (MDT)
RSA Overview	
Date of RSA	August 31-September 2, 2010
RSA Stage(s)	Design stage and RSA of existing roads
RSA Team	Representatives from the Federal Highway Administration (FHWA), Montana Department of Transportation (MDT), Montana Highway Patrol, and Vanasse Hangen Brustlin, Inc. (VHB)
3-D Visualization Overview	
Level of Effort	Approx. 120 hours were expended to model the overall roadway study area. The proposed on-ramp designs took approximately 80 additional hours, as the 3-D model was created from a conceptual drawing.
Information Provided by Designers	• Existing conditions improvements in 2–D or 3–D CAD format • Digital terrain models (DTMs) and design surface models for existing and proposed conditions • Latest signing, pavement marking, and traffic signal plans

Project Background

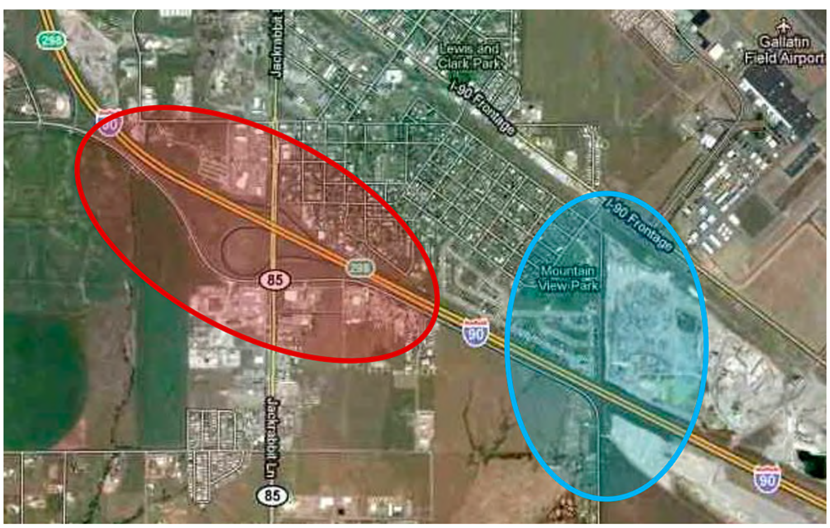


Figure 15: General project study area

The objective of this study was to complete an RSA of several design alternatives for a new on-ramp from Amsterdam Road (U-602) to eastbound Interstate 90 (I-90) and a proposed right-turn lane from southbound Jackrabbit Lane (N-85) to westbound Amsterdam Road in Belgrade, MT. As part of the process, this case study was designed to evaluate two adjacent interchanges: one using the 3-D modeling process, while the other was not modeled. A map showing the general study areas is shown in Figure 15. (The Amsterdam Road/ Jackrabbit Lane location is highlighted in red.)

The construction of an eastbound on-ramp from Amsterdam Road to I-90 was proposed as a result of a traffic study conducted in February 2009. The construction of an exclusive right-turn lane on southbound Jackrabbit Lane was also proposed. The improvements are intended to relieve congestion on Amsterdam Road during the AM peak and on Jackrabbit Lane during the PM peak. The overall purpose of the RSA was to determine if the additional on-ramp to the Interstate would potentially degrade safety when constructed within close proximity to two existing on-ramps from Jackrabbit Lane.

Figure 16: Significant traffic congestion on eastbound Amsterdam Road during weekday morning peak

The initial proposed Amsterdam Road on-ramp alternative and the proposed Jackrabbit Lane right-turn lane are shown in plan view from the 3-D model in Figure 17.

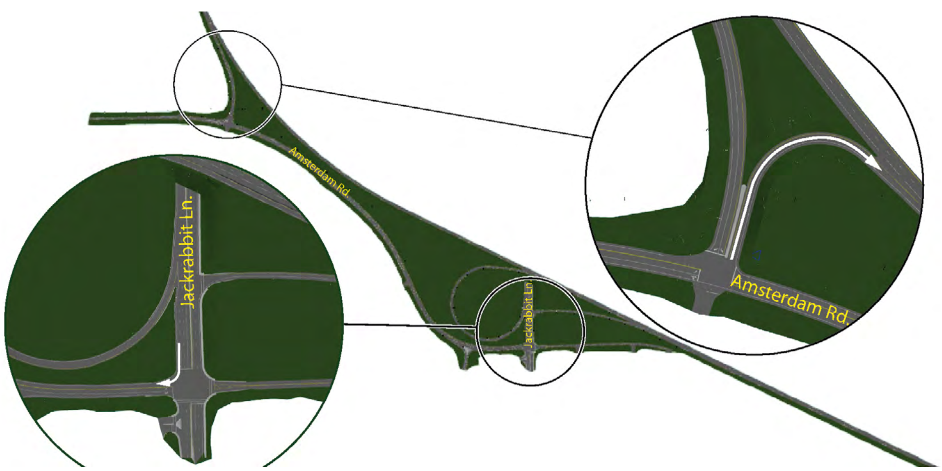


Figure 17: 3-D model plan view of RSA study area with closeups of proposed right-turn at Jackrabbit Lane and proposed on-ramp from Amsterdam Road

Information used by the RSA team to conduct the review included the following:

- Crash data (2004-2008)
- Annual Average Daily Traffic (AADT) for 2009, 2011, and 2031
- AM and PM peak hour intersection turning movement counts and projected AM and PM peak hour ramp volumes for the proposed construction

Key RSA Findings and Suggestions

The RSA team evaluated the entire study area within the project limits to identify potential general safety issues. The general findings and suggested actions discussed during the RSA are summarized in Table 6.

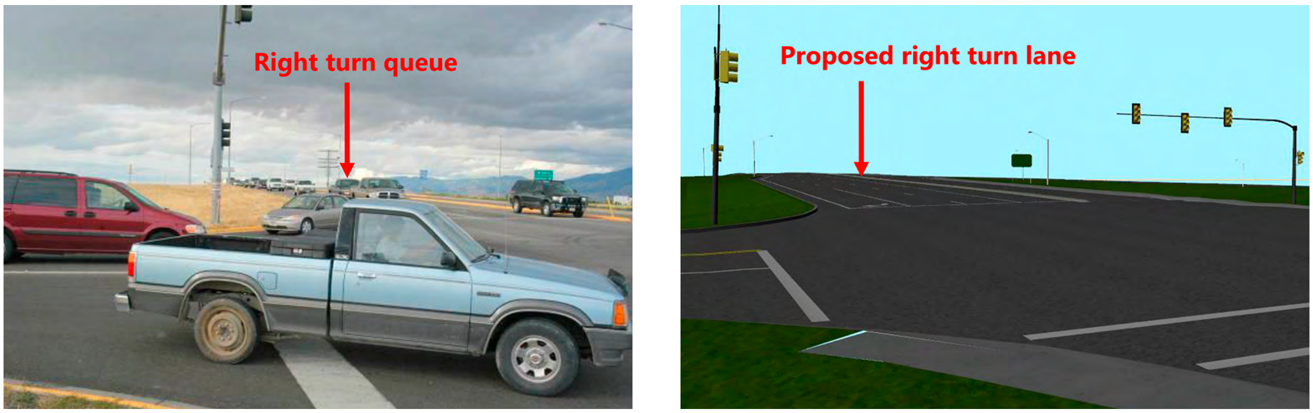


Figure 18: Southbound right turn at the intersection of Jackrabbit Lane /Amsterdam Road – Existing (L) and Modeled (R) Views Significant right-turn traffic volume obstructs view of approaching through vehicles

The RSA team also evaluated several design options for the proposed construction of a new on-ramp from Amsterdam Road to eastbound I-90. The 3-D model was used to visualize existing and proposed conditions, which assisted the RSA team in performing the evaluation. The 3-D model allowed the team to evaluate the potential safety impacts of the initial design, as well as develop other alternatives during the course of the RSA. All alternatives were evaluated during the RSA workshop, including a comparison of the pros and cons associated with each. Table 6 summarizes the primary design alternatives, including advantages and disadvantages, discussed by the RSA team. Several additional variations of these alternatives were also evaluated, but are not summarized in this table.

Table 6: Comparison of the various design alternatives considered by the RSA team

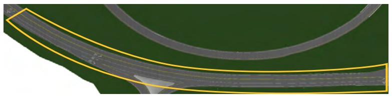
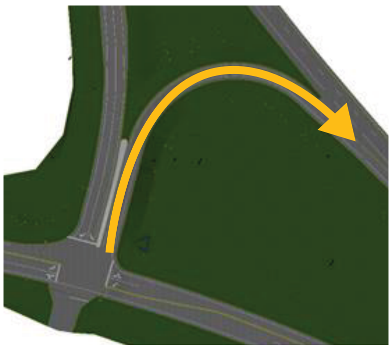
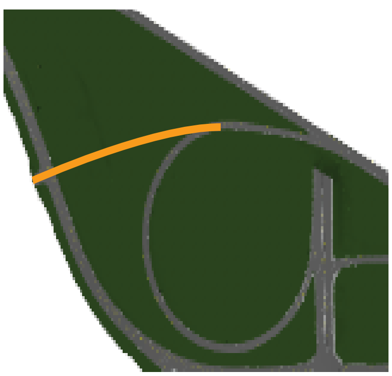
Option	Advantages	Disadvantages
1: Restripe Amsterdam Road (existing) 	• Provides some minimal queue improvement. • Accommodates EB right-turn.	• Provides minimal queue improvement, resulting in red-light running to make EB left turn. • Promotes increased speeds in EB shared through/right-turn lane. • Observed underutilization of shared through/right-turn lane.
2:Construct New EB On-ramp (3 Interstate Access Points) 	• Reduces congestion at Jackrabbit Lane / Amsterdam Road by accommodating 300+ left turns in peak. • Signalization introduces gaps for ramp traffic. • Can be constructed within existing right-of-way.	• Relocates queuing problem into residential community and impacts operations at Thorpe Road. • Introduces additional access / conflict point to Interstate. • Increases potential for off-ramp wrong way driving. • Creates potential speed differential between entering ramp traffic and mainline Interstate traffic (i.e., 25 mph merge into 75 mph mainline). • Does not address long-term growth.
3: Construct New EB On-ramp Connecting Directly to Existing EB Loop On-ramp (2 Interstate Access Points) 	• Reduces congestion at Jackrabbit Lane / Amsterdam Road by accommodating 300+ left turns in peak. • Does not introduce an additional access / conflict point to Interstate.	• Relocates queuing problem. • Creates speed differential between ramp traffic streams. • Impacts retention area in more significant manner than other alternatives. • Conflicts with driver expectancy by introducing ramp traffic entering middle of loop ramp. • Introduces new conflict point on Amsterdam Road, requiring ramp traffic to find adequate gaps in opposing WB traffic. • New ramp queue may spill onto Amsterdam Road, depending on traffic control and volume.
4: Provide Two Through Lanes through Amsterdam Road. Construct On-ramp from Alaska Road. Eliminate Existing On-ramp from NB Jackrabbit Lane (2 Interstate Access Points) 	• Creates additional capacity. • Does not introduce additional access / conflict point to Interstate. • Reduces number of conflict points by converting 4-approach intersection to 3-approach intersection. • Modifies traffic patterns by removing number of left-turning vehicles destined to I-90E. • Introduces slight speed differential between ramp and Interstate traffic streams. • Provides options to adjust peak signal timings by reducing number of phases. • Provides opportunities to improve local road network.	• Requires right-of-way acquisition. • Alters local traffic patterns by creating one-way eastbound traffic on Alaska Road. • Requires trucks exiting truck stop to cross lane of traffic to turn left to access I-90W on-ramp. • Introduces potential merging issues where two through lanes merge prior to joining Interstate. • Requires upgrades to connecting roadways off Alaska Road.

Table 6: Comparison of the various design alternatives considered by the RSA team (continued).

Option	Advantages	Disadvantages
6: Provide EB Dual Left-turn Lanes from Amsterdam Road 	• Increases capacity by adding lane. • Does not introduce additional access / conflict point to Interstate.	• Requires right-of-way acquisition. • Requires geometric changes throughout entire intersection. • Depending on arrival patterns / vehicle mix, creates potential underutilization of lanes.
Provide SB Right-turn Lane from Jackrabbit Lane 	• Removes large volume of right-turning traffic from SB through lane. • Increases sight distance for motorists turning right from EB Amsterdam Road, if channelized. • Can be constructed within existing right-of-way. • Requires less geometric changes throughout intersection than other alternatives (e.g., dual left turns).	• Depending on arrival patterns / vehicle mix, creates potential underutilization of lanes.

As an example of how the 3-D model was used by the RSA team, the initial design alternative (Option 2A) is illustrated in Figure 19. This alternative introduces a third eastbound access point to I-90 within the project limits (highlighted in blue in Figure 19) and signalizes the Amsterdam Road / I-90E off-ramp intersection. The RSA team discussed the possibility of altering the initial design by combining the left-turn and right-turn lanes on the off-ramp into a single shared lane (see area shaded in red in Figure 19). This alteration would provide additional space for the construction of the on-ramp, allowing for a larger design radius and speed as well as for a greater clear zone distance from existing utility poles located to the inside of the curve.

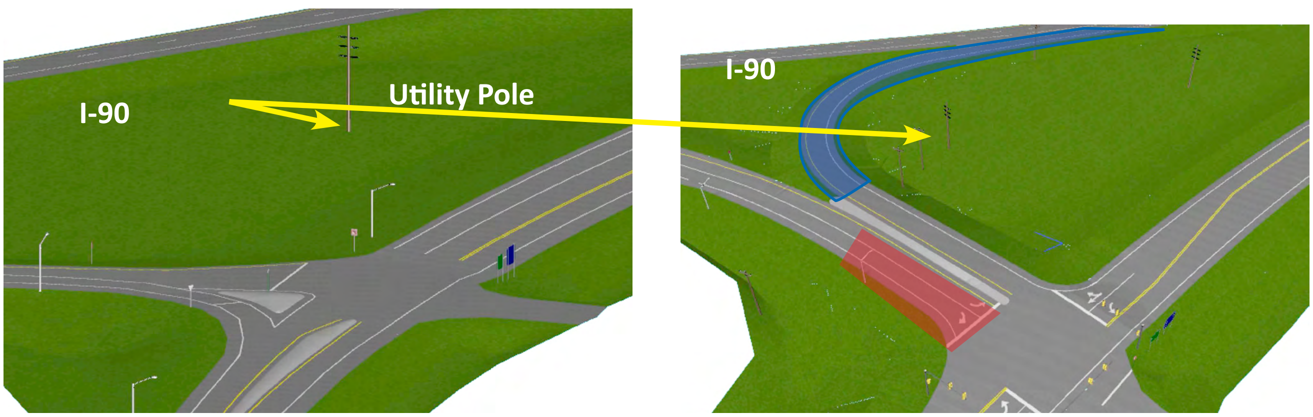


Figure 19: Modeled view of the existing (L) and proposed (R) design at Amsterdam Road and the I-90E on/off-ramp

Benefits of the 3-D Visualization

Use of the 3-D visualization allowed the RSA team to evaluate the safety effects of the initial design plan. The 3-D model assisted all team members with understanding the intended design. The majority of the team had only seen the design in 2–D on plan drawings prior to the RSA. By using the model, the team was able to visualize the "final product" as it may appear within the existing physical conditions of the study area. The 3-D model was also a major asset to team members who were not familiar with the overall RSA process (e.g., law enforcement) or roadway design plans (in 2-D format). Not only did the model introduce these members to the project, but also assisted with instructing the members as to the existing elements the team members would be looking for during the field review. This instruction and understanding increased participation in identifying problematic areas/situations (both existing and proposed) and potential opportunities for improvement.

As seen in the Key RSA Findings and Suggestions, the use of a single 3-D model for an initial design spurred the evaluation of several design alternatives. Using the model, the team was able to compare pros and cons of the various design alternatives brainstormed during the RSA workshop for the interchange with Amsterdam Road / Jackrabbit Lane. The ability to develop alternative scenarios gave the MDT other options to consider for future evaluation, which might not have been available if the RSA had not been conducted and/or the 3-D model had not been utilized. Comparing the pros and cons on the basis of safety and capacity brought an alternative to the top of the list that had not been previously considered. The interest exhibited by the MDT in this process resulted in their personnel inquiring about future possibilities for in-house design visualization to use in the design process.

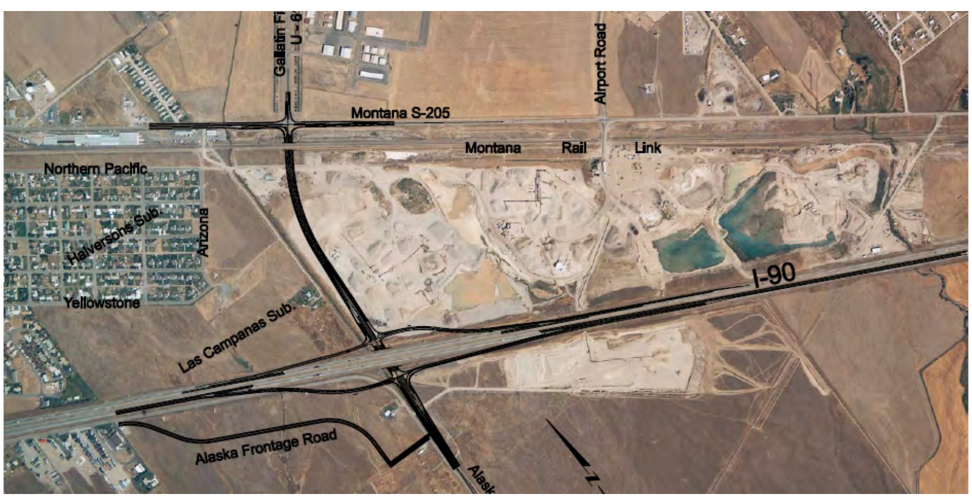


Figure 20: Conceptual illustration of the East Belgrade interchange

The effectiveness of 3-D visualization in the RSA process was further demonstrated with the team's review of a proposed design for the new diamond interchange on I-90 at Gallatin Field Road to the east. This interchange was not modeled using the 3-D visualization tools, so that the team could compare the effectiveness of using different RSA approaches at two proximate sites. The design involved new horizontal and vertical alignments throughout the project limits, which would significantly alter roadway elevations and the surrounding landscape. Furthermore, the project would require the acquisition of right-of-way, including possible residential relocations. A conceptual illustration of the interchange is shown in Figure 20. Basic suggestions of potential safety concerns were provided; however, without a visualization of the proposed design afforded by the 3-D model, the RSA team was unable to identify detailed concerns and suggestions for improvement. The team agreed that creating a 3-D model for the RSA would have greatly helped in the assessment of the safety effects of the proposed design, particularly in terms of the over/under alignment with the railroad tracks, the roundabout configurations, the access to existing surrounding development, and the connectivity to future construction on adjacent parcels.

Purcell Road, Prince William County, Virginia

Purcell Road, Prince William County, Virginia

RSA No. 3—Road Safety Audit of Purcell Road (Route 643), Prince William County, Virginia

Project Overview	
Project Location	Prince William County, Virginia
Planned Improvements	• Roadway widening • Horizontal and vertical realignment
Project Environment	Suburban
Project Design Stage	90% Design
Project Owner(s)	Prince William County Department of Transportation and Virginia Department of Transportation (VDOT)
RSA Overview	
Date of RSA	February 4, 2011
RSA Stage(s)	Design stage <u>and</u> RSA of existing roads
RSA Team	Representatives from the Federal Highway Administration (FHWA), Virginia Department of Transportation (VDOT), Prince William County Department of Transportation, Prince William County Police Department, Fairfax County Police Department, Rinker Design Associates, and Vanasse Hangen Brustlin, Inc. (VHB)
3-D Visualization Overview	
Level of Effort:	Approximately 120 hours were expended to model the proposed designs.
Information Provided by Designers	• Existing conditions and proposed improvements in 2–D or 3–D CAD format • Digital terrain models (DTMs) and design surface models for existing and proposed conditions • Latest signing, pavement marking, and traffic signal plans

Project Background

The objective of this study was to complete an RSA of the proposed realignment and widening plans for Purcell Road (Route 643) in Prince William County, Virginia. The RSA also considered safety issues associated with severe horizontal and vertical alignments at the eastern edge of the proposed project limits. A map showing the general study area is shown in Figure 21.

Figure 21: General project study area

The realignment and widening of Purcell Road is a project identified within Prince William County's comprehensive transportation plan. Ultimately, the vision for this section of Purcell Road is to be a four-lane divided roadway. The first stage of the project is to realign and widen Purcell Road from Dumfries Road to approximately Vista Brooke Drive (Route 3305). The intent of the realignment and widening is twofold: first, the initial phase of the project will establish the ultimate alignment at Dumfries Road for future construction; second, the project will eliminate severe horizontal and vertical alignment changes that may contribute to safety issues along the roadway. The project scope also included improvements recommended in a Highway Safety Project Application submitted by VDOT for a sharp curve at the bottom of a steep downgrade, approximately 0.1 miles east of Vista Brooke

Drive. The application recommended improving superelevation, replacing the existing metal culvert with a longer and wider concrete pipe, strengthening the shoulders, installing a flashing advance curve warning sign, and providing roadway lighting.

The overall purpose of this RSA was to evaluate if existing issues contributing to crashes are addressed through the proposed design, to identify design elements that may be modified or included to further enhance safety, and to address potential safety concerns associated with existing horizontal and vertical alignments beyond the realignment and widening project limits.

The proposed 90% design is shown in plan view from the 3-D model in Figure 22.

Information used by the RSA team to conduct the review included the following:

- Crash data (2005-2008)
- Annual Average Daily Traffic (AADT) for 2005 through2009
- 2008 speed study results

Figure 22: 3-D model plan view of RSA study area on Purcell Road

Key RSA Findings and Suggestions

The RSA team evaluated existing conditions as well as the proposed 90% design. A summary of key safety issues investigated with the assistance of the 3-D model and suggested mitigating actions is presented in Table 77.

Table 7: Key safety issues and suggested mitigating actions

Selected Safety Issue	Suggested Action
Speed The realignment of Purcell Road between Dumfries Road and Vista Brooke Drive significantly straightens and widens the roadway, potentially increasing speed.	*Lane Width* Reduce the lane width from 12 feet to 11 feet throughout the project corridor by adjusting the placement of edgeline striping. *Optical Speed Bars* Apply optical speed bars through severe curves. Optical speed bars are transverse stripes spaced at gradually decreasing distances along the edgelines of a curve. *Raised Pavement Markers (RPMs)* Install snowplowable RPMs through the curves in the vicinity of Rocky Brooke Court. RPMs are reflective devices that provide additional guidance through alignment changes, particularly during low-light conditions.
Convenience Store Access A highly-recognizable convenience store is located in the northeast quadrant of the intersection of Purcell Road/Dumfries Road. The proposed design provides a right-turn lane into the convenience store property from Purcell Road; however, the distance between the access point and the intersection is relatively short. The lane use at the intersection is left only and right only. The situation may arise where an approaching motorist may mistakenly use the right-turn lane for the convenience store as the right-turn lane for access to northbound Dumfries Road.	*Supplemental Signage* Install a supplemental “AT SIGNAL” sign (R10-31P) to the diagrammatic lane use sign assembly in advance of the intersection of Purcell Road/Dumfries Road. *Pavement Marking Messages* Change the spacing of the lane use pavement marking messages on Purcell Road. The placement of this particular marking may indicate to some motorists to make a right turn to the convenience store. Changing the spacing of the pavement marking messages may reduce confusion and unnecessary lane changes. *Offset* Offset the right-turn lane with pavement markings at the convenience store access. The offset pavement markings would further reinforce that the right lane is for the convenience store access. Sight distance improvements could also be expected for vehicles exiting the store, as offsetting the right-turning traffic would increase visibility of motorists destined for Dumfries Road.
Two-Lane/Four-Lane Transition The proposed design transitions from a 4-lane cross section to a 2-lane cross section in the vicinity of Vista Brooke Drive. In the eastbound direction, the transition is accomplished by using the rightmost travel lane as a right-turn “trap” lane into the Vista Brooke community.	*Transition* Begin the lane transition west of Vista Brooke Drive instead of at the intersection. Create a lane drop on Purcell Road in the eastbound direction by striping out a section of the rightmost lane west of Vista Brooke Drive and installing appropriate signing (W4-2, W9-1, W9-2) and lane reduction arrow pavement markings. Downstream of the lane drop, use the rightmost lane pavement as a right-turn lane into Vista Brooke Drive. The right-turn lane “pocket” instead of the right-turn lane “trap” will more clearly indicate the intended use of the lane (i.e., accessing Vista Brooke Drive).

One corridor-wide observation was the significant elevation difference between the edge of pavement and the roadside. These areas pose a safety hazard to vehicles drifting off the paved surface. Although shoulder stabilization and roadside rehabilitation are included in the proposed design plan, this safety issue could be considered for immediate attention by maintenance personnel. As a result of this RSA, the roadside drop-offs were immediately addressed, as shown in Figure 23.

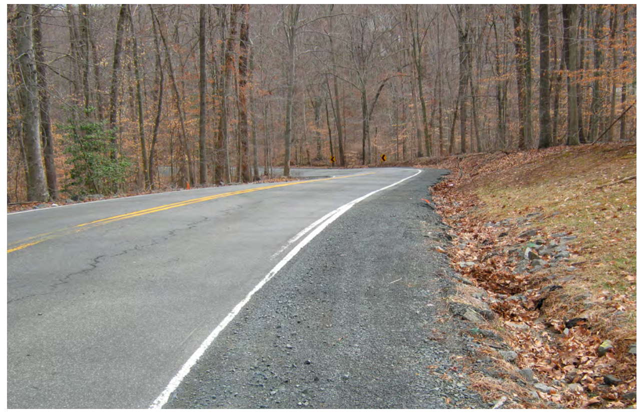


Figure 23: Shoulder with edge drop-off before (L) and after (R) RSA was conducted The edge drop-off was immediately corrected following the RSA workshop

Benefits of the 3-D Visualization

Figure 24: Bird's-eye view of the convenience store and the neighborhood in the background as seen from west of Dumfries Road

Three-dimensional visualization was an important element in demonstrating the proposed changes to the public. Since the project passed directly behind houses and by a neighboring community, it was important to be able to show the impacts on homeowners and the adjacent community. The extents of the proposed roadway widening and realignment as well as landscaping and fencing placements were all critical to demonstrating the overall project impact. Furthermore, realistically depicting existing features, such as the highly-recognizable convenience store (see Figure 24), was key to building confidence in the accuracy of the model. Ultimately, the model was utilized in a public meeting to illustrate the project to all stakeholders. This included a video of the various “drive through” viewports that was continuously looped on a computer screen prior to the formal meeting.

Figure 25: Bird’s-eye view of realigned section of road at the west end of the project

Having the ability to navigate through the corridor and observe different views was helpful in understanding the comprehensiveness of the proposed design. Looking at the project from a bird’s-eye view provided a better understanding of the design, especially the roadside features that were not easily understood when looking at a 2–D plan or even the “drive through” model view (see Figure 25).

“Driving” the corridor using the model was also critical to identifying potentially confusing signing and pavement markings, as well as driveway access concerns. A review of traditional 2–D roadway plans would not have provided the same insights as the 3-D model. For example, the placement of pavement markings combined with the curve of the road and location of trees may confuse drivers traveling westbound on Purcell Road approaching the convenience store and the intersection with Dumfries Road as to the proper lane placement based on their desired destination (see Figure 26).

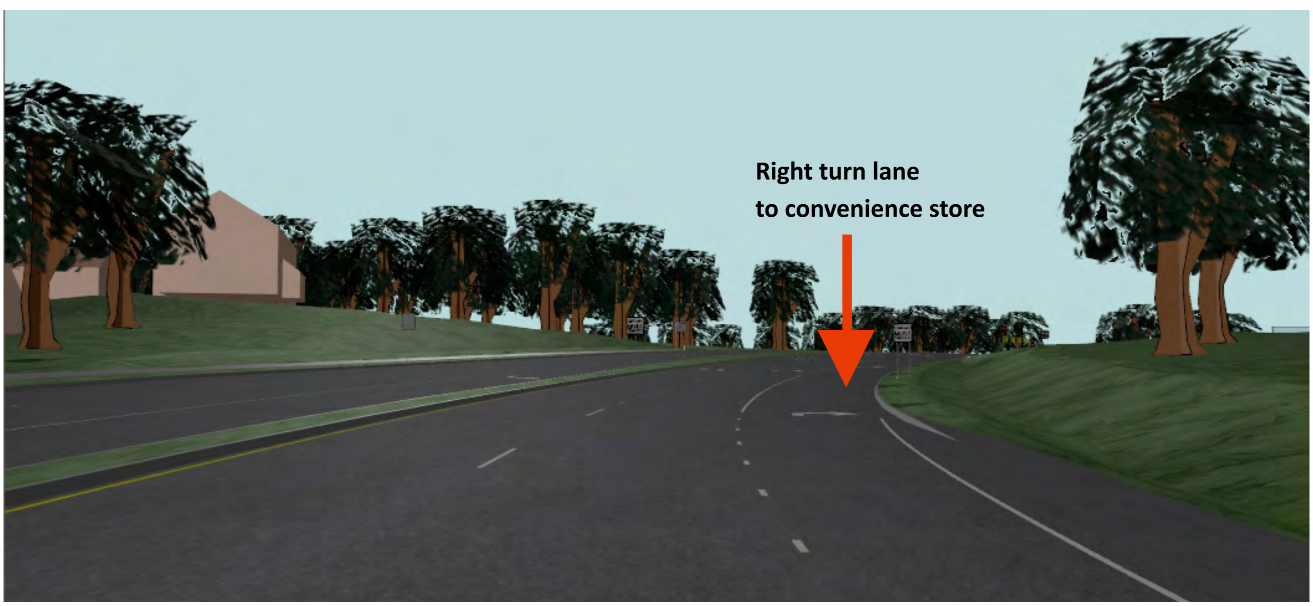


Figure 26: View along westbound Purcell Road approaching convenience store and Dumfries Road

In general, RSA team members commented that the 3-D model “brought the design to life”. Even those members who have been reading design plans for their professional careers appreciated the usefulness of the model, as it helped them to more accurately understand the intended project outcome.


Mid County Parkway, Riverside County, California

RSA No. 4—Western Terminus of Proposed Mid County Parkway, Riverside County, California

Project Overview	
Project Location:	Interstate 215 from Nuevo Road to Harley Knox Boulevard
Planned Improvements:	• New 16-mile limited access, high-speed roadway that will terminate with a freeway-to-freeway connection • Two new interchanges and a redesign of an existing one that will result in multiple interchanges in close proximity to one another • Widening along Interstate to provide as many as six lanes in each direction • Major realignment and signalization of parallel frontage road
Project Environment:	Suburban
Project Design Stage:	Preliminary (40 to 80%)
Project Owner(s):	Riverside County Transportation Commission, California Department of Transportation
RSA Overview	
Date of RSA:	January 31 – February 2, 2012
RSA Stage(s):	Design stage and RSA of existing roads
RSA Team:	Representatives from California Department of Forestry and Fire Protection, California Department of Transportation, California Highway Patrol, City of Perris, Federal Highway Administration, Riverside County Transportation Commission, and Vanasse Hangen Brustlin, Inc.
3-D Visualization Overview	
Level of Effort:	120 hours were expended to build 3-D model.
Information Provided by Designers:	• Existing conditions and proposed improvements in CAD format • Digital terrain models (DTMs) for existing and proposed conditions • Latest signing, pavement marking, and traffic signal plans

Figure 27: Study area for Mid County Parkway RSA

Project Background

The objective of this study was to complete an RSA of a planned interchange between an Interstate highway and a multi-lane, limited-access facility (called the Mid County Parkway) in the City of Perris, Riverside County, California. The Mid County Parkway was proposed to help alleviate existing congestion and to meet the projected regional traffic demands by providing a critical new east-west thoroughfare in Riverside County. As currently designed, Mid County Parkway will be 16 miles long and connect I-215 in Perris to State Route (SR) 79 in San Jacinto. The RSA study area is shown in Figure 27.

Following multiple rounds of environmental analyses, engineering studies, and public meetings, a preferred alignment was identified for the Mid County Parkway. Known as “Alternative 9,” this option included a freeway-to-freeway interchange between Mid County Parkway and I-215 to be located between Placentia Avenue and Nuevo Road (see Figure 28). The interchange would constitute the western terminus of Mid County Parkway.

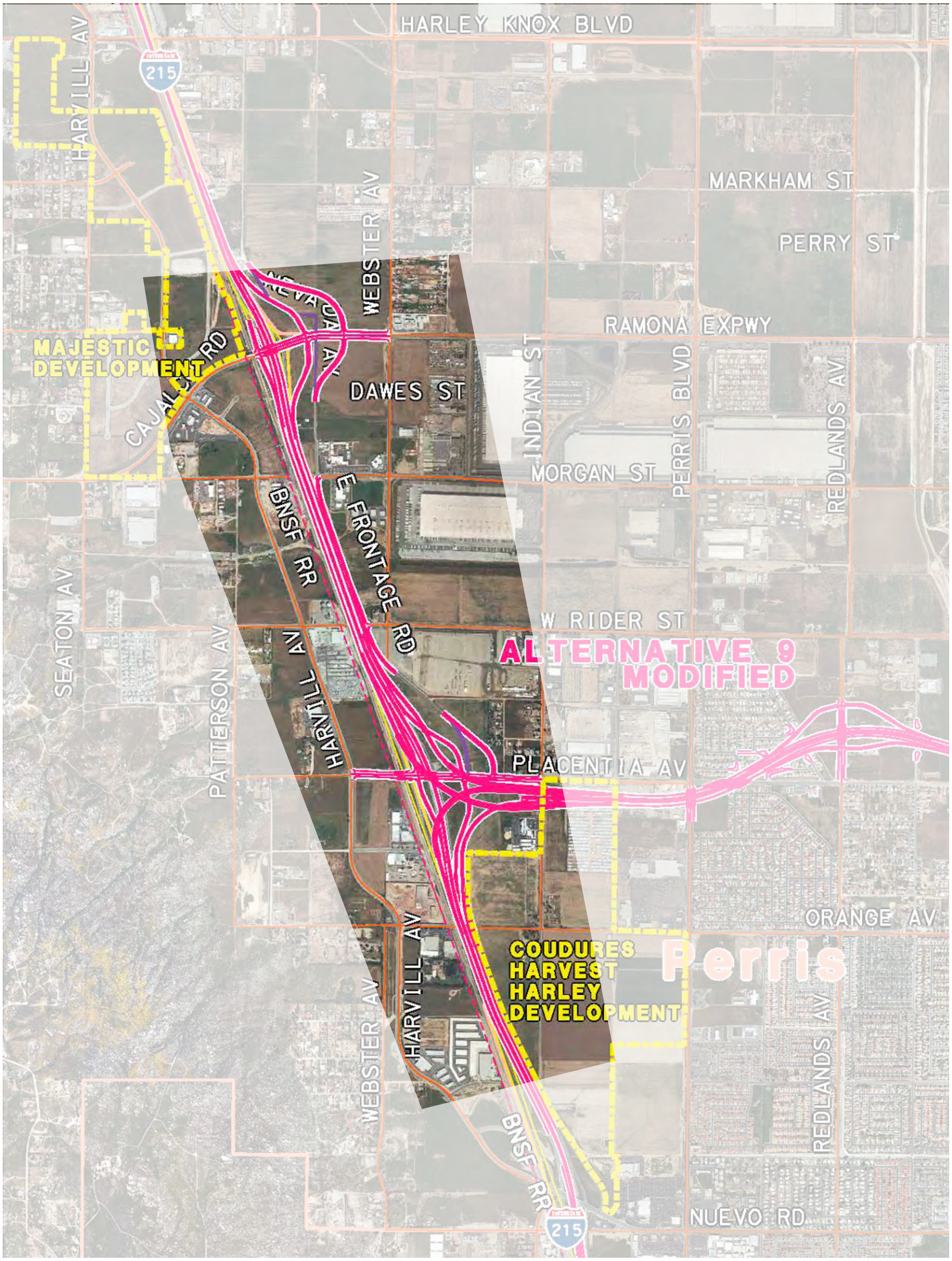


Figure 28: Preferred alignment (Alternative 9) for the western terminus of Mid County Parkway

The RSA and the 3-D visualization effort concentrated primarily on the following areas:

- The proposed freeway-to-freeway connection between Mid County Parkway and I-215, with emphasis on the westbound-to-northbound movement
- A newly-proposed interchange at I-215 and Placentia Avenue
- Interchange improvements at I-215 and Cajalco Expressway/Ramona Expressway
- The proposed realignment of the I-215 East Frontage Road

Information used by the RSA team to conduct the review included the following:

- Crash data (October 2007 – September 2010; for I-215 from D Street to Van Buren Boulevard)
- Existing (2010) average annual daily traffic (AADT) and select peak hour counts
- Projected (2040) AADT and select peak hour movements

Key RSA Findings and Suggestions

A summary of selected safety issues and suggested mitigating actions is presented in Table 88.

Table 8: Summary of select safety issues and suggested actions

Selected Safety Issue	Suggested Action
Inadequate street lighting and delineation Vertical crest curve at Placentia Ave. bridge overpass is unlit and obstructs driver visibility. New series of reverse horizontal curves added to presently unlit Frontage Rd. Potential for nighttime confusion for NB drivers on Frontage Rd. due to realignment.	Provide street lighting at and near the bridge. Enhance delineation at the newly-introduced horizontal curves.
Visibility concerns Close proximity of SB exit ramps to bridge structures will restrict sight distance of right-turning traffic. Safety issues related to the proposed dual right-turn lanes: • Potential failure by drivers to consider pedestrians. • Lead vehicles in left lanes will obstruct sight distance for drivers in both right-turn lanes. • Vehicle in left most right-turn lane must cross multiple lanes. With up to six lanes along I-215, types of guide signs currently in use may be obscured and, therefore, largely ineffective.	Consider prohibiting right turns on red from the SB exit ramps. Install sign bridge structures to allow all critical guide signage to be installed above the Interstate through lanes.
Roadside safety Currently no detailed plans for application of guardrail, median barrier, etc. in conjunction with proposed improvements.	Identify the specific applications of traffic safety systems, particularly in light of numerous bridge support and sign structures, grading limits, etc.
Capacity and operational concerns Close interchange spacing (less than one mile) along I-215 combined with high entering/exiting volumes and expected extensive weaving maneuvers.	Consider revisiting the traffic analysis by applying detailed assumptions regarding the lane selection and merge/ diverge behavior among drivers within the study corridor to ensure there will be adequate capacity in peak hours.

Table 8: Summary of select safety issues and suggested actions (continued).	
Selected Safety Issue	**Suggested Action**
Wayfinding Development of in-depth signing and pavement marking plans are critical to overall project and should commence as soon as possible. Close interchange spacing combined with high speeds and projected high volumes will require drivers to process information and make decisions very quickly; therefore, application and placement of guide signs will have huge impact on safety and operations within the corridor.	Develop detailed signing and marking plans. Consider incorporating diagrammatic and lane-assigning overhead signs to encourage drivers to change lanes in advance of the merge/diverge conditions.

Benefits of the 3-D Visualization

The review of the 3-D model supported a comprehensive approach to the planning and design of the project—one that included consideration of key components of the roadway environment, such as wayfinding signs, pavement markings, and roadside barriers. Because of the scale of the Mid County Parkway project, it was not feasible to build a 3-D model that would incorporate all of the proposed roadway improvements. Based on conversations between the project team, FHWA, the project owners, and others, it was decided that the model would focus primarily on northbound movements along I-215 at Mid County Parkway, Placentia Avenue, and Cajalco Expressway/Ramona Expressway. The area selected for 3-D visualization was considered critical to the RSA in large part because of the proximity among interchange ramps, which is characterized by the following:

- Approximately 1,000 ft (0 2 mi) between the northbound exit ramps at Mid County Parkway and Placentia Avenue;
- Approximately 1,200 ft (0 2 mi) between the northbound entrance ramps from Placentia Avenue and Mid County Parkway; and
- Approximately 3,700 ft (0 7 mi) between the northbound entrance ramp from Mid County Parkway and the northbound exit ramp at Cajalco Expressway/Ramona Expressway

This close ramp spacing creates an environment in which a multitude of merging and weaving maneuvers can be expected over a short distance. Figure 29 illustrates the proposed lane configurations and key projected peak hour volumes along northbound I-215 within the study area.

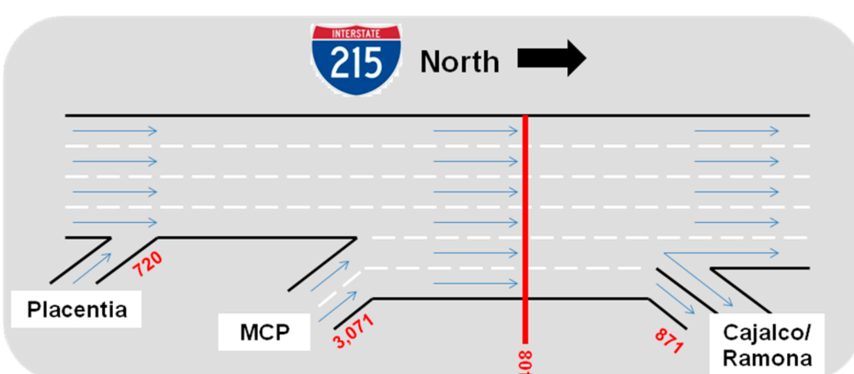


Figure 29: Illustration of proposed lane configurations and key 2040 AM peak hour volumes for NB I-215

Vehicles entering I-215 from Placentia Avenue must merge into the four mainline lanes, while the two lanes coming from Mid County Parkway will join I-215 to create a six-lane cross section (see Figure 30). The rightmost lane will become an exit-only lane onto Cajalco Expressway/Ramona Expressway, with the adjacent lane allowing vehicles to either exit or continue north along I-215.

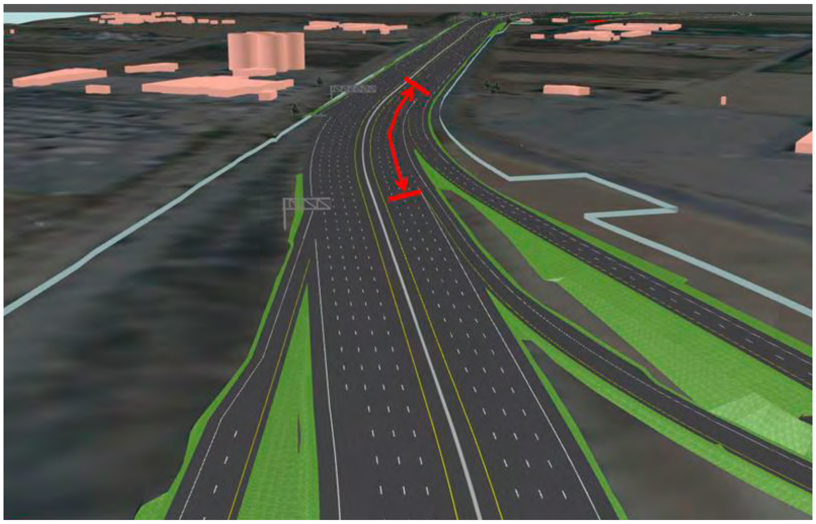


Figure 30: Image from 3-D model showing proximity of northbound I-215 entrance ramps from Placentia Ave and Mid County Pkwy

By traveling along the northbound paths within the model, the RSA team gained a realistic sense of what the proximate ramp connections would look like upon construction. It was noted that Caltrans has been known to use 2,200 vehicles per lane per hour as an upper limit of "stop-and-go" capacity along its freeways. Evenly dividing the total projected I-215 volume across the lanes resulted in per-lane volumes below capacity; however, if the projected volumes were assigned to the proposed cross section based on consideration of expected driver behavior and interactions and not through an even distribution, then the potential for certain lanes to become over-saturated may be realized. From this discussion, the RSA team made three recommendations:

1. The development of detailed signing and pavement marking plans should commence early in the design process and not be left as a final step.
2. Diagrammatic and lane-assigning signs should be included in the signing plan to encourage drivers to maneuver into the appropriate lanes well before they encounter the merge/diverge conditions. (Some examples of such signs are provided in Figure 31 and Figure 32).
3. Consider the reassessment of per-lane capacity by applying human factors considerations to the lane selection and merging/diverging behavior in this segment of I-215.

Figure 31: Mock up of freeway guide signs on Mid-County Parkway

Figure 32: Mock up of exit sign along I-215

Another concern highlighted by the 3-D model was that the sign types currently in use along I-215 (see Figure 33) may be obscured by heavy vehicles and, therefore, largely ineffective in delivering information to drivers in the leftmost lanes. The rendering of the driver's vantage emphasized the vastness of the cross section and supported the notion of diminished value of roadside signs to left-lane drivers due to the distance from their vehicles to the right side of the road (see Figure 34). Therefore, it was recommended that the designers consider the installation of sign bridge structures to allow all critical guide signing to be placed above the Interstate through lanes, which will promote sign visibility to drivers in all of the travel lanes.

Figure 33: Photo of existing freeway guide sign in use along I-215

Figure 34: 3-D image showing wide cross section of I-215 and distance from left lanes to the right edge of the roadway

The 3-D model also helped identify the potential for nighttime confusion among northbound drivers on the I-215 east frontage road. Drivers here will be looking almost directly at the proposed traffic signal at the realigned northbound I-215 exit ramp at Ramona Expressway. Figure 35 and Figure 36 show the vantage of the northbound driver in plan view and in 3-D, respectively. This perspective could lead drivers to expect that they will be following a path toward the ramp signal and not curving toward the right, as per the proposed designs. The concern became much more apparent to the RSA team by virtually "driving" the frontage road in the 3-D model than it would have by only conducting a review of the 2-D roadway design plans.

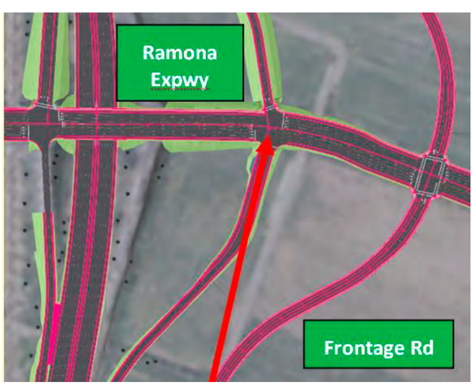


Figure 35: Vantage of NB driver on frontage road as seen in plan view

Figure 36: 3-D Image from 3-D model showing vantage of NB driver on frontage road

Just as the 3-D model proved valuable in its ability to illustrate the vertical qualities of the traffic signal, it also helped the RSA team to visualize the impacts of other 3-D features in the roadway environment. The proximity of the southbound I-215 exit ramps to the bridge overpasses at Cajalco Expressway/Ramona Expressway and Placentia Avenue was noted as a safety concern. This closeness gives the bridge structures the potential to obstruct sight distance for drivers looking to turn right on a red signal indication. (See Figure 37, Figure 38 and Figure 39 for supporting images from the 3-D model.) This example also highlights the benefits of including as much detail in the model as possible, as the more accurate information that can be input into the model, the more accurate assessment that can be made of it on the total design—in this case, the impacts of the bridge design on various users of the roadway.

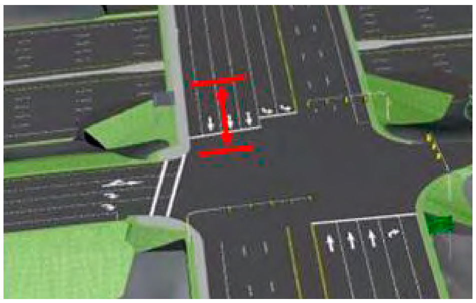


Figure 37: Image from 3-D model showing proximity of bridge structure to ramp terminus

Figure 38: Image from 3-D model showing potential for overpass structure to obstruct sight distance of drivers at SB exit ramp

In the end, 3-D visualization was instrumental in the RSA of the western terminus of Mid County Parkway. By bringing the planned complex interchange to life, the multidisciplinary RSA team was able to travel the conceptual roadway segments and view them from the vantage of prospective users. The model played an integral role in both the discussions among team members and those between the team and the stakeholders by providing a visual representation to the abstract design. Additionally, 3-D visualization helped bring to light issues that may have otherwise gone unnoticed from a review of only the 2-D plans, such as the concern about the traffic signal vantage for drivers on the east frontage road.

Figure 39: Image from 3-D model showing closeness of interchange ramps and multilane cross section

APPENDIX B: CREATION OF 3-D PDF

APPENDIX B

Creation of 3-D PDF

This appendix presents an outline of the procedure used to create the 3-D PDFs used for the RSAs in this study.

Software used:

- Bentley Microstation (v8)
  Version 08 05 02 70
- Bentley Microstation (v8i)
  Version 08 11 07 443
- Bentley InRoads
  Version 08 09 03 06
- Adobe Acrobat Pro
  Version 9 4 0

Base Information:

- Existing feature DTM or 3–D Contours
- Proposed feature DTM or 3–D Contours
- 2–D or 3–D survey
  (3–D preferred)
- 2–D or 3–D proposed design
  (3–D preferred)
- 2–D or 3–D pavement markings
  (3–D preferred)

Displaying and Breaking-out Base Information:

- Open InRoads > open existing and proposed DTMs.
- If only 3–D contours exist, import each as a separate surface.
- Display Proposed perimeter.
- Select and Import Proposed perimeter as external boundary for the existing surface.
- Display existing and proposed surface triangles on separate layers.
- Breakout the triangles into separate layers/colors based on the feature as needed:
  > Existing roadway, existing sidewalk, existing ground, existing water, etc.
  > Proposed roadway, proposed sidewalk, proposed ground, proposed wall, etc.
- Create pavement markings by offsetting the line string of the pavement marking to the correct width. Line thickness cannot be read by the 3–D PDF.
- Import the pavement markings shapes/lines and drape on the proposed/existing surface.
- Display triangles and modify and delete triangles where necessary.
- Check the model and modify, add, or remove points as necessary to create desired result.

Creating 3-D objects

- Building Objects:

  > Objects like buildings, non standard signs, and other unique items are best if built on their own level/color using the tools in the 3–D main toolbar.

- Importing Objects:

  > Microstation can import or reference a large number of formats including skp (Sketchup) and 3–Ds (3–D studio).

- Use the snap buttons to snap to the 3–D surface when placing objects so they will show up at the correct elevation.
- Quick Check: View the model from the front or side and locate any rogue objects or triangles and modify them to the correct elevation.

Creating Materials

- Using the material editor, create a material for each surface class.
- Place that material by color/layer.
- In some instances, buildings for example, it may be preferable to place a material on the face.
- Using an aerial photo for the existing ground material can be a good way to provide extra contrast in the model without additional 3–D objects.

Setting View Locations

- In Microstation, create a vehicle path by snapping 50 ft (or other predetermined spacing) line segments on the proposed surface.
- Select the vehicle path level and increase the z elevation by 6 ft This simulates the view from the eyes of the driver.
- Turn on the camera in View 1.
- Using two windows, View 1 as the camera and View 2 as top, manipulate the camera so the view is from the first point of your vehicle path and the target point about 100 ft from the view point.
- Use the define camera tool to help keep consistency in each view.
- Preferred settings: Projection > two point, reference point > eye, focal distance > 100’.
- Once the camera view is established, create a new saved view, using the station/road name and direction as a view name (for example, Sta 100+00 EB or Main St EB).

- Move the camera using View 2 to the next point.
- Continue moving the camera and saving the view for each of the vehicle paths.
- Include a plan, elevation, and isometric as saved views, as well.

Rendering

- The final rendering should be done in v8i or higher.
- Open the print dialogue box.
- Select the pdf pltcfg that comes with Microstation v8i.
- Select the print to 3–D check box.
- Settings > 3–D plotting options.
- These settings will need to be modified depending on how complex the model that has been developed is Enabling the “Place Walk on PDF Toolbar” will assist the end user.
- Print to desired location.

PDF Modifications

- Open the model tree Here the views that have been saved in Microstation can be seen using the arrows in the views box, you can toggle quickly through the created views.
- In the model tree dialogue box, one can also modify the levels and references and save new views, but note that any modifications here will not be reflected if a new PDF is printed from Microstation.

Viewing Tips

- The model is best viewed in the latest release of Acrobat Pro, Standard or Reader.
- Change the following setting to optimize the appearance of the PDF:

  > Edit > Preferences > 3–D & multimedia.

  > Optimization scheme for a low frame rate: NONE.

  > Make sure “Enable View Transitions” is checked.
- Advance the model through the preset views in two ways:

  > Manually selecting the view from the views tab.

  > Clicking the model tree button to the right of the views tab, in the middle window there is the option to move forward or backward through the preset views.

- At each view, the “walk” tool can be used to look around, move forward or backwards Use this tool by selecting it from the tool bar, clicking a point on the screen, and—keeping the mouse button depressed—moving the mouse in the direction that you want to look (left or right) or move (top or bottom).

Internet Resources

- 3–D Google Warehouse: http://sketchup.google.com/3–Dwarehouse/
- Federal Lands Highway Division Design Visualization Guide: http://www.efl.fhwa.dot.gov/manuals/dv/
- Bing Birds-Eye Maps: http://www.bing.com/maps/
- Google Maps: http://maps.google.com/
- Bentley Communities: http://communities.bentley.com/
- Adobe PDF Reader: http://get.adobe.com/reader/