VIRTUAL ROAD SAFETY AUDITS USING DRIVING SIMULATORS: A FRAMEWORK

Kelvin R. Santiago-Chaparro, M.S.
Research Assistant, Traffic Operations and Safety (TOPS) Laboratory
Department of Civil and Environmental Engineering, University of Wisconsin-Madison
Madison, WI, USA, email: ksantiago@wisc.edu

Michael DeAmico
Research Assistant, Traffic Operations and Safety (TOPS) Laboratory
Department of Civil and Environmental Engineering, University of Wisconsin-Madison
Madison, WI, USA, email: deamico@wisc.edu

Andrea Bill, M.S.
Traffic Safety Engineering Research Program Manager, Traffic Operations and Safety (TOPS) Laboratory, Department of Civil and Environmental Engineering, University of Wisconsin-Madison, Madison, USA, email: bill@wisc.edu

Madhav Chitturi, Ph.D
Assistant Researcher, Traffic Operations and Safety (TOPS) Laboratory, Department of Civil and Environmental Engineering, University of Wisconsin-Madison
Madison, WI, USA, email: mchitturi@wisc.edu

David A. Noyce, Ph.D, P.E.
Associate Professor, Traffic Operations and Safety (TOPS) Laboratory, Department of Civil and Environmental Engineering, University of Wisconsin-Madison
Madison, WI, USA, email: noyce@engr.wisc.edu

Submitted to the 3rd International Conference on Road Safety and Simulation,
September 14-16, 2011, Indianapolis, US

ABSTRACT

Driving simulators have been growing in popularity over the past years. As these research tools become widespread available throughout the country and the world an opportunity is presented to introduce the technology into the road design process as opposed to only using the technology for pure research purposes. Introduction into the design process does not mean using driving simulators for visualization purposes; instead, the concept presented in this paper is the use of driving simulator to perform what is described here as a virtual road safety audit. A virtual road safety audit, as described in this paper, involves the evaluation of a design by exposing real users to the design using a driving simulator and obtaining performance measures that reflect how different elements of the design support the driving tasks.

Road design is an already well-defined process as well as traditional road safety audits which are used to evaluate and make recommendations to a design. Hence, proposing the idea of a new process intended to provide recommendations to designers based on a newly-available technology is guaranteed to face resistance from the practitioner community. To account for this situation this paper proposes a virtual road safety audit framework whose processes run parallel to existing practices for road safety audits as well as design procedures. Processes described in the framework are intended to be used when traditional safety evaluation approaches are not appropriate or, when given the availability and feasibility of performing a simulator-based evaluation, the marginal benefits, in terms of quality, are worth the process. Instead of focusing on providing detailed recommendations about how to perform a simulator-based road safety audit this paper is focused on providing a discussion about the conceptual process that needs to be followed. Expected challenges with the adoption of the framework ideas are also presented as part of the discussion. The paper also presents a group of procedures used by the authors to speed up the scenario creation process through the use of programming and other pieces of software beyond the typical scenario creation tools provided by driving simulator manufacturers. Minimal delays in the project or result –delivery process are key to the adoption of evolving ideas such as virtual road safety audits. Due to the scenario creation process presented, which involves automating the creation of 3D models from already existing data sources significant time reductions are expected which makes feasible the adoption of the virtual road safety audit concept.

Keywords: Road Safety Audit, Driving Simulation, Framework, 3D Modeling, Photographic Logs, Sketchup, Blender, Ruby, Python, Civil 3D, Programming

INTRODUCTION

One of the characteristics of transportation engineering is how strong the field relies on standards when making design decisions. Such as reliance is not necessarily a bad idea; after all, most branches of engineering rely on standard measurements and guidelines when developing products. Hence, the existence of standards and guidelines is not the problem; instead, the problem arises when standards become a hard truth and don't face any additional scrutiny during the design process nor undergo any updates to reflect the constant and rapid growing body of knowledge of the driving process.

With road standards that are based on knowledge gained over a half a century ago, transportation engineering is particularly susceptible to reliance on standards which don't necessarily take into consideration knowledge gained recently. Although changes are made on what could be considered a periodic basis, the reality is that most of the changes do not restructure the way design features are selected, the constructs remain static and instead, new values are added or modified in existing equations and/or tables. Such an improvement process can sometimes be seen as the reduction of the existing knowledge about an extremely complicated process such as driving to a simple selection of required values from a table.

Reducing knowledge to simple values and tables, if not recognized, can lead to risk-abundant designs due to the selection of standard values without recognizing the nature of the driving task. However, an experienced designer, along with checks in the process has proven to work generally well for the system. One of the checks built, although not entirely, into the design process is known as a road safety audit.

Road Safety Audits and Driving Simulators

Road safety audits (RSA) are a systematic procedure that evaluates the expected safety performance of a design. An audit can be performed either as a reactive approach or as a proactive one. When audits are reactive the safety review of a design is probably performed because of an event that captured the attention of the media or because an abnormal number of crashes are being observed at a location. On the other hand, a proactive audit means that a prospective design is evaluated and reviewed to improve safety. The boundaries of the road safety audit process are typically defined by the selection of a multidisciplinary team which evaluates a design and by the production of a safety audit report in which findings are documented. A multidisciplinary team is a crucial aspect of the road safety audit (RSA) process because the composition of the team allows the evaluation of designs from a perspective other than the engineering one which is the perspective typically used in the design of road projects.

Results from a RSA process are typically desirable as soon as possible. Time consumed in the process can result in two things. When the RSA is being performed on an already existing project every day that a result is not being produced by the safety audit teams means that road users are exposed, on a daily basis, to potentially unsafe conditions. On the other hand, when the RSA is being performed on a proposed design every day that decisions are not made in terms of "approving" the project from a safety point of view means that time and money are being wasted on aspects of the design which could later face significant changes. Based on the aforementioned considerations there is clearly a need to streamline the RSA as much as possible when performing the RSA using already established methods as well as newly proposed virtual RSA methods which involve the use of a driving simulator.

The road safety audit process described above certainly takes design to a higher level by introducing expert knowledge in the selection and evaluation of the design characteristics. However, a fundamental limitation of the process is that knowledge about the performance of users at the project being evaluated as part of the RSA is limited to the expert evaluation which, although based on advanced knowledge, does not take into account the actual reaction users experience while navigating through the design. Using a driving simulator can take RSA to the next level by combining the feasibility of measuring the reaction of drivers and understanding their performance as they navigate through a virtual world with expert knowledge about how these factors should be accounted for in design or in making changes to existing/already built designs.

In theory, using driving simulator engineers should be able to understand every individual aspect of a design and determine whether or not the design supports driver performance in a positive way or if, at least, the design does not have a negative impact on the performance of drivers. A virtual RSA approach, although feasible, is bound to introduce delays into the process given the tasks of bringing proposed and/or existing designs into a scenario that can be evaluated in a driving simulator. Therefore, this paper presents a proposed framework for the introduction of driving simulators for the completion of RSA. Significant attention is devoted in the framework on streamlining the process of bringing existing and/or proposed designs into a model that can run on a driving simulator environment given that the scenario modeling process is extremely time consuming in general. The framework looks at how the process of importing existing 3D

CAD drawings, as well as data collected for existing roads using photographic logs which contain accurate geographic points collected at a constant interval, can be streamlined to reduce the scenario creation process and therefore allow completing RSA evaluations faster.

Framework Overview

The framework presented as part of this paper is based on the idea that minimal disruption/delay of the traditional RSA process is a key factor for the adoption of the framework concepts. Furthermore, the framework should be presented in a way similar to existing methodologies such as RSA with which design teams already feel comfortable applying. The framework also needs to contain proper guidance in terms of how to streamline the procedures for 3D scenario creation which is crucial for performing a RSA for an existing or proposed facility. Guidance is provided for the aforementioned process by documenting the procedures which have been followed by the authors in being able to go from raw data for a road into a preliminary 3D model in a day's work.

SUPPORTING LITERATURE

Performing a comprehensive literature review for a newly proposed subject is a difficult task since specific literature in the area is not available. However, there are always sources of information from which ideas used in the development of the proposed framework come from. For example, there is plenty of literature available on the subject of traditional road safety audits. Some of the most important sources in the subject include reports from the National Cooperative Highway Research Program (Wilson, 2000) as well as reports produced by the Federal Highway Administration (FHWA, 2007). These reports described the processes that agencies go through in order to perform road safety audits as well as provide a description of the experiences.

The feasibility of using different types of driving simulators to evaluate specific road design characteristics has also been extensively discussed in the literature along with the idea that research and design issues need to be handled appropriately (Lee, 2011). However, the problem with existing research is that the topics discussed, even when focused on the design characteristics of the road, are presented from a high-level scientific point of view which difficult its understanding by those involved in the design of roads on a day-to-day basis. While from a state of the research point of view the community is at a point where those involved in the driving simulator field can understand the measurements that need to be taken in order to report findings of interest to the design community there is no guidance on how these two communities will interact. Until the existing gap in the literature regarding the establishment of procedures to communicate and evaluate designs in a way consistent with current design practices is filled, the research on driving simulators will kept moving forward; however, the disconnect between the research and practitioners world will stay untouched. This type of disconnect is not something that only occurs in the field of transportation; in fact, other fields such as healthcare have identified the need to remove the gap in order to have better patient care (Bero, 1998).

Even with concerns about the procedures and gaps that need to be filled driving simulators continue to make progress in the types of evaluations that can be performed with them. Among the examples of research are the use of simulator to evaluate the effectiveness of technologies such as rumble strips (Noyce, 2004), driver fatigue (Young, 2007), the understanding of variable message signs (Dutta, 2004), among many other examples. Pages of can be filled with examples of how driving simulators have been used; however, for purposes of this paper the important aspect to consider is that driving simulators are a proven and flexible research tool.

FRAMEWORK DEFINITION

When looking at a framework for the use of driving simulators in road safety audits the reader must understand the typical reaction designers have when presented with the idea of testing their designs prior to construction and completion. While the reaction is always a positive one, the reaction itself brings the economic principle of scarcity to the discussion table. Scarcity, in economic theory, is the principle that indicates that the wishes and/or needs of society are always greater than the resources available. In terms of evaluating designs using driving simulators the scarcity principle idea applies because designers usually do not understand the limitations of these research tools; therefore, their ideas of what can be tested differs from the ideas of those involved in the field of driving simulation. Furthermore, the time involved in scenario development can significantly slow down the evaluation process and therefore delay the time-to-delivery.

Based on the aforementioned principles the first step in a framework for the use of driving simulators for performing road safety audits is determining whether or not the safety effects of a particular aspect of a design can be tested using driving simulators. At this point in the framework, which shown in Figure 1, elements of the design are split into two subgroups: those elements that can be tested in a driving simulator and those that are more appropriate for a traditional road safety audit. Being able to test a design feature in the simulator is not a guarantee that a simulator-based safety audit can be performed. As with any other experiments, performing a driving simulation experiment requires having test subjects, the creation of scenarios, data analysis, among others; hence, even when a design feature can be tested the question that needs to be asked at this stage of the process is whether or not a simulator based evaluation is a feasible one.

The feasibility of an evaluation from an experimental design point of view is related primarily to time and cost constraints. An evaluation that will take too long to complete and that will delay the design process by an unacceptable amount of time would probably be deemed as not feasible. Considerations of costs are always an important factor in the decision making process and performing simulator-based road safety audit is not an exception to the rule. Furthermore, during the feasibility consideration stage, expert knowledge should be used to assess how feasible is the creation of the scenario required for the virtual RSA. The scenario creation part of the framework, which proposes methods to significantly speed up the process through the use of scripting language and multiple software tools, is discussed on a separate section of this paper and assumed to be independent of all the other processes.

Feasibility Considerations

Cost feasibility of the evaluation is an aspect of the framework that requires a significant amount of attention by those involved in the evaluation process as well as those involved in the project delivery. Making a decision of whether or not to proceed with a simulator-based road safety audit for a design is a decision that should be made by taking into consideration a cost-benefit evaluation. The question that needs to be asked during this process is whether or not the marginal costs of performing a simulator-based evaluation can be justified by possible safety improvements that could result from the identification of possible user performance issues caused by the design in question. As the previous statement suggests, the cost-benefit evaluation process is not a straight forward one given the uncertainty involved in the process. Therefore, from a policy maker point of view a crucial task is the identification of those projects with costs and complexity that, when technically feasible, warrant undergoing a simulator-based road safety audit.

The reader must understand that simply because a road safety audit evaluation is not feasible in a driving simulator that should not be counted as an argument against the use of driving simulators for conducting road safety audits. Feasibility of the evaluation, as previously pointed out, can be a result of experimental design constraints as well as limitations of the simulator to test certain aspects of the design. Furthermore, not being able to evaluate certain aspects of a design is something that can occur in other scenarios that do not involve the use of driving simulators. A clear example of why road safety audits can benefit from the use of driving simulators is that there are aspects of the evaluation which can be analyzed in more depth using simulators hence traditional road safety audits are often deemed not appropriate for an evaluation themselves.

When an experiment in a simulator is not a feasible option or when the characteristics of the simulator used are not adequate to test certain design elements then the safety evaluation continues in the form of an expert-knowledge based evaluation. On the other hand, if a road safety audit using a driving simulator is a feasible option, the experiment is conducted, data is collected from drives and expert knowledge is used to identify those performance measures that can be used as safety indicators of interest are set apart for analysis. A review of the actual value of variables of interest is performed by the team in charge of performing the simulator-based road safety audit. At this stage of the process the team looks for indications in the data that the design undergoing the evaluation does not provide adequate support for the performance of road users or in the worst case scenario identify aspects of the design that can have a detrimental effect in the performance of the road user.

Performance Measures of Concern

Experience at this stage of the process is critical mostly because the team needs to decide whether or not performance measures values for the design are of concern. A concerning measure does not necessarily means one that does not indicate optimal performance. Hence the experience aspect at this stage of the process involves selecting the threshold values for different performance measures that indicates a safety concern for the road users. As expected, the selection of these values is a process with no fixed answer, dynamic in nature, and which relies significantly on expert knowledge. A value considered not significant indicates that the design element producing the value will not get an improvement recommendation from the evaluation team.

Design elements which produce performance measurements that are of concern to the evaluation team essentially leaves the team with two scenarios. In the first scenario the concerns of the evaluation team are not a critical ones and a "canned" alternative to the design element producing the performance measure of concern can be included in the recommendations report to the designers. A secondary scenario involves a more complicated situation in which performance measures of concern were identified in the evaluation process and for the corresponding concerns there are no known solutions.

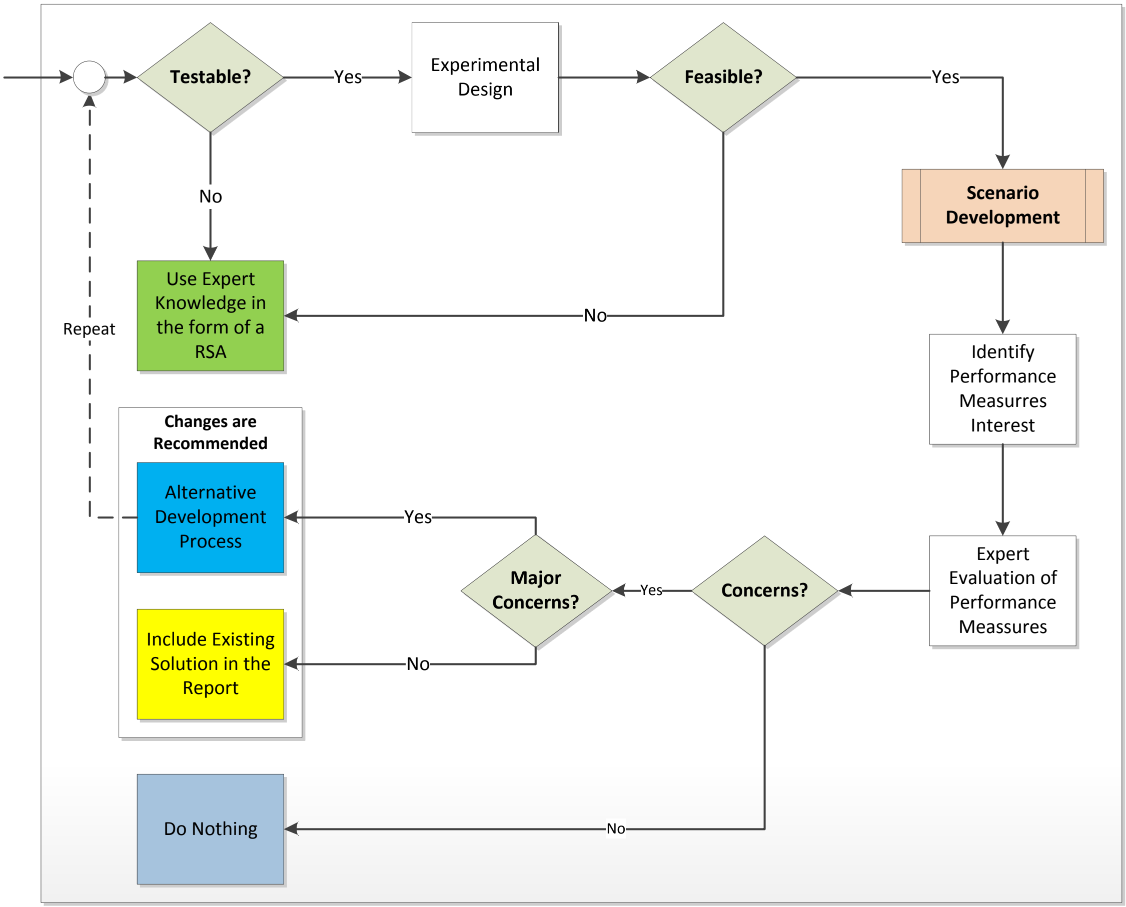

Figure 1 Conceptual Framework

Development of Non-Standard Alternative Designs

An alternative development process starts as a result of the aforementioned situation. The development of alternatives to improve user performance while navigating through a road is not a single step process as portrayed in the framework for simplification purposes. Instead, the process will definitely involve an internal loop in which the evaluation team will go back and forth between the proposed alternatives. Furthermore, alternatives resulting from this process will undergo additional evaluations under the driving simulator to guarantee that performance measures actually meet the threshold value of no performance concern. Also important, the additional evaluations allow the evaluation team to have scientific grounds for making the recommendations to the design team.

Communication of Findings

No matter how well the findings from a simulator-based road safety audit are those findings need to be communicated properly to the design team. In the traditional road safety audit report findings the safety audit team will write a report which is provided to the design team and comments are made. Since designers are used to this type of process for the communication of issues found in their designs, the team in charge of the simulator-based evaluation should follow this style of communication as much as possible. The opportunity for comments from the design team should be welcomed as an opportunity to start a process of conflict resolution and to even maybe discuss the introduction of new alternatives that none of the two teams developed initially.

SCENARIO CREATION PROCESS

As previously mentioned, the scenario creation process which makes virtual RSA a feasible option is a time consuming one that needs to be streamlined. Two situations are possible for a virtual RSA. First, a road which is already built, and for which no 3D CAD drawings are available, needs to undergo a virtual RSA. Second, a road which is being proposed needs to undergo a virtual RSA. For the first situation, the ideal condition is that for the road there are photographic logs available which contain latitude, longitude, and elevation points collected every certain distance. A typical text view representation of the aforementioned log is shown in Figure 3. For the second scenario, i.e., a newly proposed road, the ideal condition involves having a CAD model capable of producing a 3D view of the proposed road environment. These aforementioned situations, as clearly stated, are ideal conditions which allow engineers to streamline the process for importing data into 3D modeling software which could then export a file compatible with the scenario creation tools used by the driving simulator on which the virtual RSA will be performed. The process used for streamlining the creation of scenarios is presented in Figure 2.

A discussion on the export data process is a technical issue dependent on different types of software. However, an example of the types of procedures used by the authors to streamline the scenario creation process is presented. Scenario creation for the driving simulator used by the authors (which is manufactured by Realtime Technologies) takes places using a 3D modeling software called *Internet Scene Assembler (ISA)*. ISA utilizes the Virtual Reality Modeling Language file format. Therefore, the challenge faced by the authors involved automating, to the highest degree of practicality, the process of creating VRML files that represent roads which will undergo a virtual RSA process. Besides ISA, three other software tools were used by the authors to bring existing road designs, as well as proposed ones, into the scenario creation tool provided by the manufacturer of the driving simulator. The three software tools used were Autodesk Civil 3D, Google Sketchup Pro, and Blender. Autodesk Civil 3D was selected because of the capability of exporting 3D surfaces of proposed roads which can then be opened in Blender for texturing and conversion into the VRML file format. Google Sketchup was selected because of the application programming interface (API) which allows automating the process of creating a road alignment given that a dataset such as the one shown in Figure 3 is available.

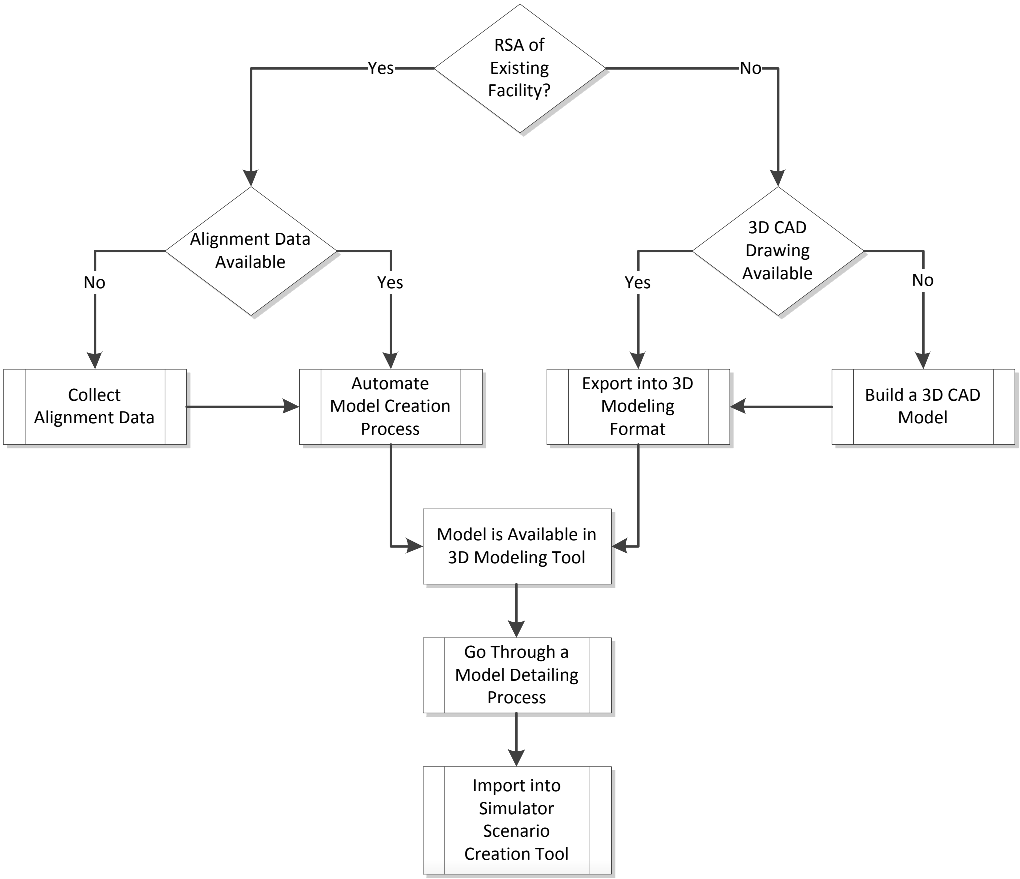

Figure 2 Scenario Creation Sub Process

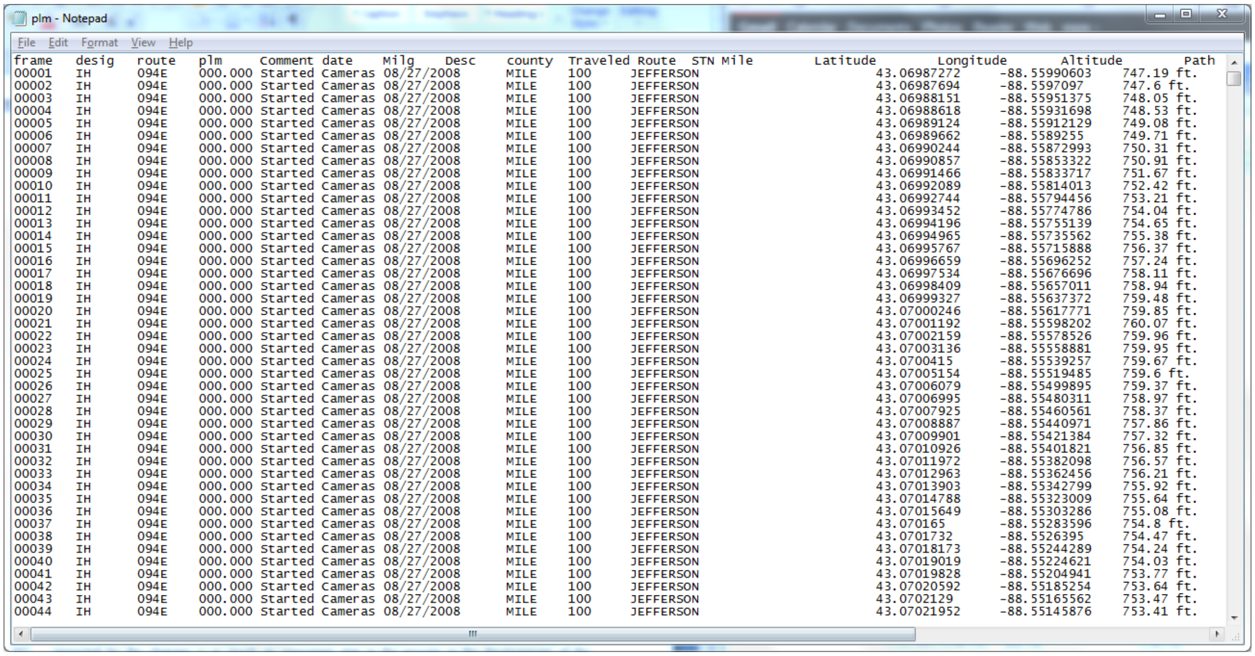

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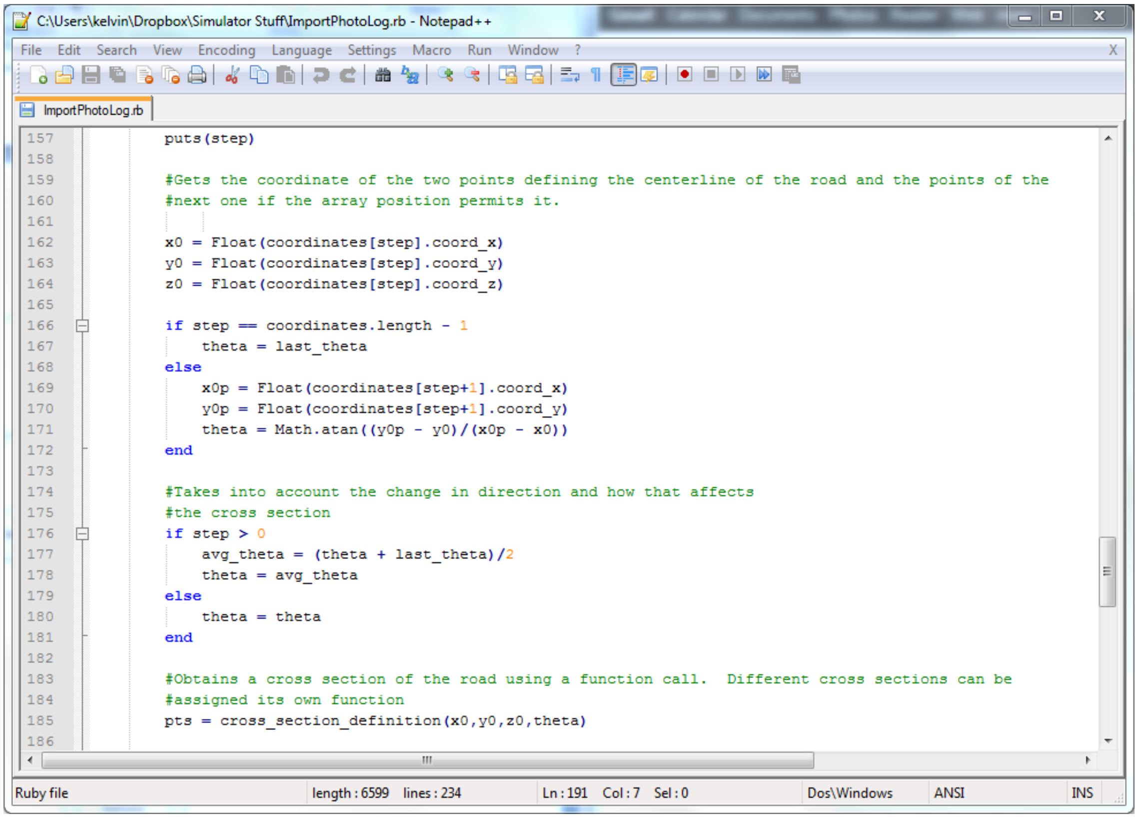
Figure 3 Typical Data Contained in Photographic Load of Highways

Automating the process of creating a 3D model of the alignment allows engineers to avoid a significant portion of the time typically involved in the model creation process. A detailed description of the algorithm used is outside the scope of this paper. However, for illustration purposes a portion of the Ruby code used to automate the process is shown in Figure 4. Ruby is the programming language used by Google Sketchup to automate processes within the software. Furthermore a summary of what the code does is as follows:

- Process the file containing the road alignment information and convert it into an object usable inside the Ruby code;
- Create an object which defines the centerline of the alignment contained in the aforementioned text file;
- Define a function within the code which mathematically calculates the points associated with a specific cross section given the points which define the centerline of the alignment; and,
- Create model faces using the points returned by the functioned mentioned above.

Although simplistic in nature, the algorithm described above allows obtaining a 3D model of an existing alignment with a single click in approximately five minutes which is the time required for the algorithm to run. While the algorithm does not automate the process of texturing the API used by Sketchup does allow that automation process therefore reducing the amount of time that required to model an existing road.



```ruby
        puts(step)

        #Gets the coordinate of the two points defining the centerline of the road and the points of the
        #next one if the array position permits it.

        x0 = Float(coordinates[step].coord_x)
        y0 = Float(coordinates[step].coord_y)
        z0 = Float(coordinates[step].coord_z)

        if step == coordinates.length - 1
            theta = last_theta
        else
            x0p = Float(coordinates[step+1].coord_x)
            y0p = Float(coordinates[step+1].coord_y)
            theta = Math.atan((y0p - y0)/(x0p - x0))
        end

        #Takes into account the change in direction and how that affects
        #the cross section
        if step > 0
            avg_theta = (theta + last_theta)/2
            theta = avg_theta
        else
            theta = theta
        end

        #Obtains a cross section of the road using a function call.  Different cross sections can be
        #assigned its own function
        pts = cross_section_definition(x0,y0,z0,theta)
```

Figure 4 Screenshot of Code for Importing Alignment into Sketchup

Although the algorithm discussed above focus on the use of Google Sketchup and the Ruby programming language that is not the only option available. Another option is using Blender and automating the 3D modeling creation process through the use of the Python programming language. Blender is a robust 3D modeling tool which is open source and available free of charge. Blender is also a key part of the framework because of the features which allow manipulation of *dxf* files which contain a surface of a project created from 3D CAD drawings using design software such as Civil 3D.

Once a road surface is exported into a dxf format that surface can be imported into Blender and using several manipulation techniques available within the software which allow the selection of individual elements within the surface in an efficient way the time required to create a model is significantly reduced. Among the processes involved is converting the surface to Quads and using loop selection to being able to manipulate and texture groups of road elements such as the traveling surface, terrain, and curbs, among others. Figure 5 shows a screenshot of how a road created in Civil 3D can be imported into blender in a format compatible with the driving simulator scenario creation tool.

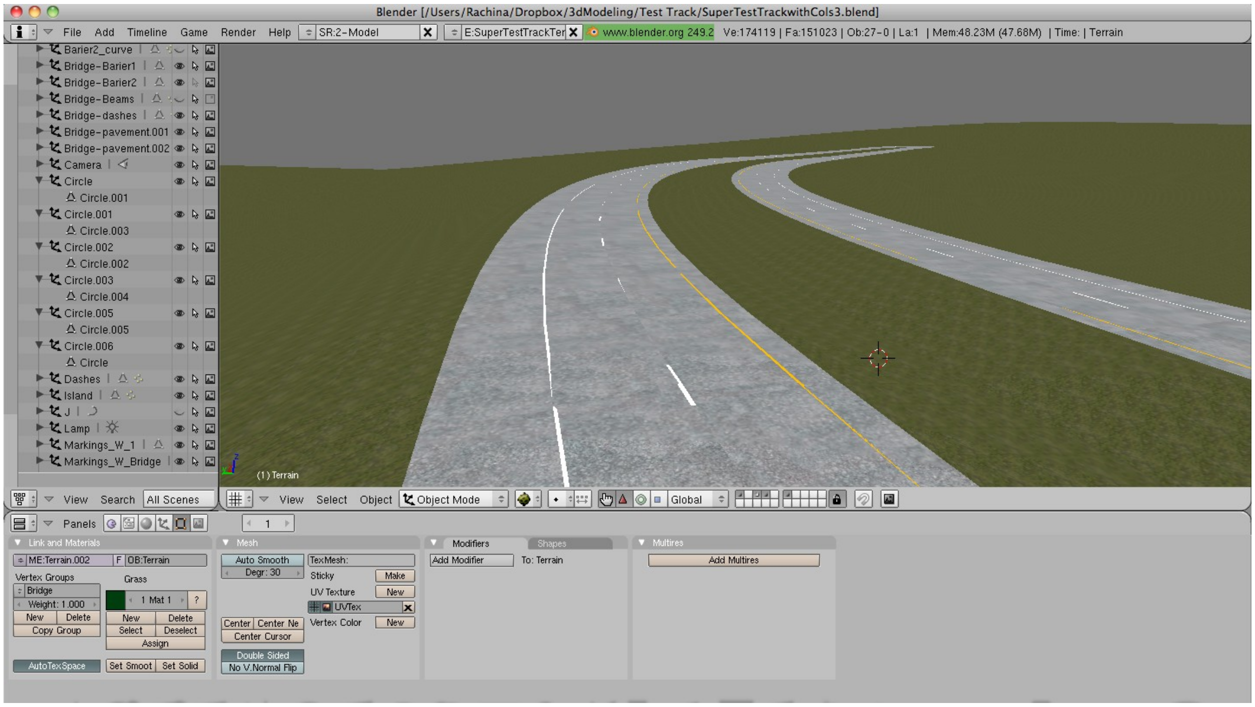


Figure 5 Screenshot of DXF Surface Imported into Blender

The discussion presented above is not intended to be a how-to manual; instead, the intention of the authors is to show the feasibility of bringing existing and proposed road designs into the simulator environment using a streamlined procedures which takes away a significant portion of the manual labor involved in the process of 3D modeling. In summary, through the use of scripting languages capable of automating 3D modeling software, by using the right conversion tools, the authors were able to come up with a methodology which is allows going from raw data into a preliminary 3D model of the road within one day. The detailing process that must be followed after the initial model is created is going to be dependent on the specifics of the study and need to be considered on a case-by-case basis.

ADOPTION CHALLENGES

Proposing changes to a process is not as simple as developing guidelines and new ways of 'doing business'. Often, proposed changes, even when beneficial, face resistance from those impacted by the new process. Factoring that resistance into the adoption process and educating those impacted by the changes is as much an important step in the process as the development of the new procedures and guidelines. Furthermore, anyone who intendeds to alter already established procedures such as the design process must take into account that although ideas might have been well-thought at a higher level there are low-level details that are almost impossible to account for in the development process unless there is a clear understanding about how every individual involved in the design process works. Not realizing the aforementioned situations can lead to a complete rejection of ideas by those who are crucial to making the process a success. Examples of novel ideas and changes in procedure that because of a poor understanding of the process the idea intended to change failed are well documented throughout the literature and range in everything from the field of healthcare to business.

Additionally, based on the recognition that the introduction of simulator-based road safety audits for designs can create friction between the team performing the design and the team involved in the driving simulator evaluation, the framework was created as a parallel process. Furthermore, some of the software used in the process of scenario creation is either simple to use or are software that are already used in the design process. The design team can focus on the design and simply produce design files with already existing options within the software they used that can be used as part of the scenario creation framework presented.

Even when everything is feasible, resistance should be expected from the team involved in the design process. This argument of expected resistance is based on the experience of how defensive a design team can be when their design is criticized by a road safety audit report. Hence, there are no reasons to believe that reactions to a recommendations report produced by a team using a driving simulator will be any different. Another naive assumption would be to think that no resistance should be expected from those who are commonly referred to as practitioners to a report which could be seen as too academic. The underlying reason for this resistance can be attributed to the fact that most driving simulators are university-based ones. Since at the practitioner level liability issues are different than at the research level of transportation engineering this issue is guaranteed to become an item capable of creating an impasse between practitioners and those focused on research. To account for such an important item communication and an understanding of the needs of both sides need is crucial by everyone involved in the process.

CONCLUSIONS

This paper presented the reader with the one problem associated with using driving simulator to perform virtual road safety audits. In principle the idea is one that no one would argue is where driving simulators are going to be moving in the future once several of the challenges associated with the process are resolved. One of the challenges presented in the process is the creation of scenarios which resemble the real world that needs to be evaluated through the virtual road safety audit process. Creating a real world, in the sense presented in this paper, refers to being able to create simulation environments which replicate existing designs as well as proposed designs. While there is no doubt that this process can be achieved with existing tools the challenge is that creating these world is usually a time consuming tasks which due to the delay that would introduce into the road safety audit process will make adoption of the process a difficult sell to those interested in the process.

A streamlined procedure for the creation of these worlds was presented in this paper. Among the benefits of the framework procedures is the reliance on tools which are widely available as well as low cost or even free of charge. Furthermore, the framework procedures for scenario creation rely on datasets which most departments of transportation already own such as photographic logs of their roads thus adding value to existing datasets. When the required data is not available, a significant portion of the data can be obtained from mapping tools as well as through the use of handheld device which keeps costs involved in the data acquisition process to a minimum. Another aspect of the virtual road safety audit process discussed in the paper is a simple approach to how to navigate the decision making process using the virtual road safety audit procedures. Flexibility and parallelism with existing process are key factors to consider in the development and application of the framework.

Besides the aspect of streamlined scenario creation that does not rely on tiles provided by the manufacturer of the driving simulator, the development of a framework for integrating state of the art technologies such as driving simulators into the already well-established practice of road safety audits is a challenging task. The task is challenging not only because of the nature of an evolving technology but also because of the delays that are introduced into the process by the experimental procedures. Hence, a plan for the integration of the new safety evaluations and in the design analysis process requires careful consideration from the time-to-project-delivery point of view by the end user and is a crucial aspect for the framework implementation.

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