Multi-Resolution Visualization Tools to Aid In Conducting Road Safety Audits

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ABSTRACT:

Typical road safety audits use site investigations in addition historical data to make recommendations. Recent approaches use simulation modeling to derive surrogate measure to analyze the potential for collisions, driving simulators to analyze human behavior or other visualization tools to analyze geometric design characteristics. None of these current tools can capture the dynamics of proposed changes where traffic patterns undoubtedly change. Each proposed improvement has an influence on traffic patterns and must be captured at a regional level to determine whether vehicles choose the same path or defer to an alternate one. This research study is aimed at exploring new methods to supplement the RSA process - using visualization tools to assess the performance of each proposed improvement strategy by conducting a more thorough comprehensive safety study using multi-resolution modeling methods in situations when suggested countermeasures would almost certainly redistribute traffic to alternative routes. A case study in El Paso, Texas was selected where an audit team performed a safety audit of a diamond interchange that experiences a high number of collisions during peak hours. The visualization of the proposed improvement scenarios help the Department of Transportation better understand how mitigation strategies would influence traffic flow in and around the study area or whether the proposed changes improved safety or merely shifted the problem to alternate locations. The use of visualization tools can help convey proposed improvements to the public.
1 INTRODUCTION

Road transportation provides benefits by facilitating the movement of goods and people. It enables increased access to jobs, economic markets, education, recreation and health care, which in turn have direct and indirect positive impacts on economic growth and quality of life. However, the increase in road transportation has also placed a considerable burden on people’s health – in the form of traffic injuries and fatalities. More than 1.3 million people die on the world’s roads every year, and between 20 and 50 million others suffer non-fatal injuries. In most regions of the world this epidemic of road traffic injuries is still increasing [1]. The Federal Highway Administration (FHWA) and the United States Department of Transportation (USDOT) are strongly committed to continuous improvements in road safety. FHWA’s current efforts reflect its support for new tools such as Road Safety Audits (RSAs), which bring an improved understanding of crash cause and countermeasures to bear in a proactive manner. FHWA defines an RSA as a formal safety performance examination of an existing or future road or intersection by an independent audit team. The RSA team considers the safety of all road users, and qualitatively estimates and reports on road safety issues and opportunities for safety improvement [2]. International experience shows that effective road safety management programs should exercise an optimal balance between reactive and proactive strategies in each jurisdiction, based upon local conditions. Public agencies implementing RSAs should view them as one of an integrated range of tools intended to further the goals and objectives of a comprehensive road safety management program.

There have been well-documented experiences in Australia and Europe that show that RSAs are both cost effective and beneficial as a proactive safety improvement tool. For example, a study conducted in Surrey County, United Kingdom found that the average number of crashes causing fatalities and injuries decreased by 1.25 crashes per year (from 2.08 to 0.83 crashes per year) at project sites that were audited. The same study concluded that in comparable locations, non-audited locations had only a 0.26 reduction in crashes per year (from 2.6 to 2.34 crashes per year) [2].

The RSA concept was originally developed in the United Kingdom in 1989 and later introduced into the United States (U.S.) in 1996. Since then, the benefits of such systematic checking were soon recognized by safety professionals around the world. The basis for an RSA is the application of safety principles to new project design and improvements to the highway system to prevent crashes from occurring or to reduce their severity. Safety should be considered throughout the entire project – from planning and development, to construction and operations and maintenance. RSAs can be applied to both small as well as large projects, regardless of whether the project concerns new construction or the rebuilding of existing roads [3]. However, the RSAs conducted to date do not use integrated simulation-based modeling techniques to assist in the review process.

This research study is aimed at exploring new methods to supplement the RSA process - using visualization tools to assess the performance of each proposed improvement strategy by conducting a more thorough comprehensive safety study using multi-resolution modeling (MRM) methods in situations when suggested countermeasures would almost certainly redistribute traffic to alternative routes. This MRM approach allows roadway agencies to visualize how proposed safety improvements affect the overall transportation system in and around the project limits. It must be noted that this research does not try to predict accidents based on simulation-based modeling.
2 LITERATURE REVIEW

2.1 Simulation Modeling for RSAs

Several studies have been conducted linking micro-simulation models to safety studies. These studies have derived several different surrogate safety measures which are then used to support evaluations of various traffic engineering alternatives for both pre and post construction locations. In a study conducted by Gettman et al., several surrogate measures were derived to analyze the interactions of two vehicles in which one vehicle must take evasive action to avoid a collision. Those defined surrogate measures included time to collision, post encroachment time, deceleration rate, maximum speed and speed differentials \[4, 5\]. Time to collision, post encroachment time and deceleration rate are used to measure the severity of a conflict while the maximum speed and speed differentials (in addition to mass of the vehicles) are used to measure the severity of potential collisions. Cunto and Saccomanno used vehicle trajectories obtained from the Next Generation Simulation (NGSIM) program as input to the VISSIM micro-simulation software to analyze the potential for rear-end crashes at signalized intersections. Three measures of safety performance were considered: crash potential index, number of vehicles in conflict and total conflict duration per vehicle \[6\]. Ozbay et al. described and validated an analytically derived new crash index; and modified time to collision index as new safety indicators by extension of well-known time to collision safety indices and applied it in a case study of a 6.67 mile section of the New Jersey Turnpike \[7\]. FHWA also sponsored research to develop the Surrogate Safety Assessment Model (SSAM) software application designed to perform statistical analysis of vehicle trajectory data output from microscopic traffic simulation models. The software computes a number of surrogate measures of safety for each conflict that is identified in the vehicle trajectory file and then computes summaries of each surrogate measure \[4\].

2.2 Current Visualization Tools Available

The use of driving simulators for road safety audits has gained popularity over the past several years. As these tools become more readily available, an opportunity is presented to introduce the technology into the road design process. These advanced technologies make it possible to investigate the role of human factors under a multidisciplinary perspective \[8\]. Utilizing simulators into the road design process does not mean using driving simulators for visualization purposes but instead using them to perform what is described as a virtual road safety audit (VRSA). A VRSA involves the evaluation of a design by exposing real users to the design using a simulator and obtaining performance measures that reflect how different elements of the design support the driving tasks. The use of VRSAs allows design engineers to understand all aspects of a design and determine whether it supports driver performance in a positive or negative way \[9\].

Researchers from Purdue University introduced a concept tool called the Road Site Investigation Tool (RSIT) which uses tree-like knowledge base where the branches form a sequence of checks leading to specific safety countermeasures and their connection with roadway conditions and crash patterns. It takes the form of an “intelligent checklist” that leads the investigator through relevant questions in an interactive process. The RSIT prototype assists less experienced investigators and saves time for more experienced ones but has been limited to basic stop-controlled intersections \[10\]. Urban Circus has developed a road safety audit visualization platform specifically designed to calculate sight distances of motorists and they
traverse through the roadway network. The software is designed to provide different perspectives of sight distances including aerial views and driver’s vantage views [11]. In addition, the software is capable of measuring 3D vertical/horizontal curves, gradient changes and can provide linear measurements and clearances [12].

Historical crash data can now be stored into Geographical Information Systems (GIS) with spatial visualization. Over a decade ago, researchers developed the Accident Information Management System (AIMS) to visually track crash locations. The AIMS software plots accidents on a GIS map with symbols that correspond to locations where accidents occurred. If a location has two or more accidents, it stacks the symbols on top of each other, creating a 3D view. Locations with a higher stack of symbols mean more accidents [13]. The Interactive Highway Safety Design Model (IHSDM) developed and maintained by the Federal Highway Administration (FHWA), is a suite of software analysis tools used to evaluate safety and operational effects of geometric design decisions on two-lane rural highways. It provides estimates of a highway design’s expected safety and operational performance and checks existing or proposed highway designs against relevant design policy values [14].

Modern 3D modeling capabilities have evolved from traditional 2D based computer aided design software into comprehensive highway engineering methodologies that include highway design modeling, design visualization, and animation. Data from 3D highway design models can be output to interface with more specialized 3D software applications [15]. Four-dimensional visualization techniques are similar to 3D visualization techniques, but with the added dimension of time to make the image dynamic. Four-dimensional models use simulation-based motion and incorporate a wide range of dynamic imagery in a series of 3D images that are sequentially related in space and time [16].

While each researched simulation modeling and visualization tool has unique properties, perspectives and characteristics, none of them address how proposed mitigation strategies affect traffic in and around the study area. For example, one mitigation strategy might be to increase capacity on a section of roadway to reduce congestion where stop and go conditions routinely occur. However, this added capacity has influence on drivers and will uncertainly redistribute traffic flow in and around this section of roadway. Does the added capacity on this section of roadway create a bottleneck location further downstream? This research is aimed at addressing these types of questions by utilizing MRM techniques that can capture the dynamics of proposed changes at both the localized and regional levels simultaneously and whether those safety recommendations have adverse effects on the roadway system.

3 ROAD SAFETY AUDIT CASE STUDY

An RSA was performed at the Loop 375/SH 20 Alameda interchange and surrounding areas (El Paso, Texas) to identify any potential safety hazards that would increase the frequency or severity of crashes. Project limits stretched from North Loop Dr to the Zaragoza Port-of-Entry (POE) on Loop 375 to approximately a half mile east and west on Alameda Ave as shown in Figure 1. The RSA composed of several site investigations in May and June of 2010 to observe the existing traffic flow, driver behavior and lighting conditions. The RSA team collected video recordings at the interchange to determine incoming approach volumes and turning movements during peak hours. Speed profiles were collected upstream of exit ramps on Loop 375 using a radar gun. TxDOT also provided crash data and existing signal timing plans for the three sequential diamond interchanges within the project limits. Once the RSA team processed and documented all findings, a stakeholder’s meeting was held at the TxDOT El Paso district...
headquarters to present findings. The RSA team provided documentation that summarized all discoveries and possible short, mid and long-term mitigation strategies in a technical memorandum [17]. The stakeholder’s meeting provided feedback to the audit team when each mitigation strategy was proposed and whether any of the proposed strategies were feasible (e.g. costs, right-of-way constraints, political, etc.). Several short and mid-term solutions that did not require simulation modeling are not outlined in this research paper.

Figure 1: Loop 375/SH 20 Alameda Project Limits

3.1 Site Investigation

One of the most important aspects of the RSA involves a field review which is conducted to observe conditions “on the ground” that created safety hazards. The audit team used the opportunity to observe all traffic flow conditions and patterns during peak and off-peak hours. Night-time observations were conducted to document lighting conditions and sight distances. The site investigation provided an opportunity to analyze pavement conditions, the amount of signage used at each signal approach, drainage conditions, driveway access locations and typical pedestrian movements around the many stores and restaurants that sit adjacent to the interchange. During the site investigation, the team collected traffic data which is outlined below.

3.2 Data Collection

Data collection is also a significant and necessary part of the RSA process. It provides critical information about the study area and allows auditors to better understand the causes and
locations of many traffic accidents. Data collection comes in the form of historic crash data, traffic volumes and turning movements at intersections and abutting driveways, pedestrian volumes, existing design schematics, and signal timings. Data collection also includes all planned/proposed roadway improvements in the form of operational strategies and routing (new roadway infrastructure) strategies along with right-of-way constraints.

3.2.1 Crash Analysis

Crash analysis data was provided by roadway agencies and law enforcement. The crash data identified hot spot locations and allowed emphasis on sites that experienced high frequency and severity of crashes. Traffic accident data was analyzed and hot spots were prioritized based on several parameters including the relationships of accident trends with adjacent streets, parking lots, time-of-day, relationships between accident’s peak periods, patterns and location, visibility conditions and transportation mode. The top contributing factors for crashes are listed below in descending order.

- Failure to control speed
- Driver inattention
- Not applicable
- Unsafe lane change
- Following too closely
- Other factors

Traffic accidents are normally recorded by law enforcement and cataloged into a central database hosted by the roadway agency – in this case the TxDOT Crash Recording Information System [18]. Note that sometimes the contributing factor was not readily apparent by law enforcement and therefore was listed as not applicable when entered into the database. Plotting all crash locations into GIS helps auditors in identifying the main contributing factors of accidents. Non-intersection location where drivers failed to control speed likely means that drivers were more than likely inattentive to the spillback of traffic from the off-ramp onto the freeway main lanes which routinely occurs at this particular location (Figure 2).

![FIGURE 2: GIS Figure showing accident location and frequency](image.png)
3.2.2 Traffic Data

Traffic counts and turning movements were obtained by using video camera recordings and loop detectors. This allowed researchers not only to determine what the highest movements were at each approach at the intersection, but also determine the vehicle class distribution (i.e. number of cars versus trucks). Data was collected during several periods of the day including morning peak, mid-day and afternoon peak. Pedestrian counts were also collected at each of the four approaches at the interchange. In addition, signal timing data was collected and used as part the simulation model development and calibration.

Table 1: Americas Southbound Traffic Counts & Vehicle Class Distribution

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<th>Thru</th>
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Data collection results showed that during all periods of the day, left turn movements on the southbound approach to the intersection were the highest yet the current lane assignment had only one left turning lane (no bays) as shown in Figure 3 below. Researchers showed the DOT actual traffic counts during peak hours which routinely reached saturation levels. Turning percentages were also shown simultaneously with video recordings of the actual peak period traffic where traffic continuously queued back onto freeway main lanes. Presenting the traffic counts and turning movements while showing video recordings of traffic flow helped convey the message that the intersection was not functioning at an optimal level. There were too many vehicles making left turns and not enough storage capacity to keep the queue from spilling back onto the freeway main lanes.
3.3 Multi-Resolution Modeling

MRM methods were used to analyze the project limits at both the corridor and localized levels simultaneously. MRM refers to the integration of various software platforms at different levels of resolution (macroscopic, mesoscopic, microscopic) to achieve a specific goal. In the case of an RSA, MRM was used to analyze how existing traffic patterns shift when safety mitigation strategies are implemented. For example, a diamond interchange experiences a high frequency of rear-end collisions from vehicles queuing back onto freeway main lanes. The simulation models can analyze various strategies including signal timing optimization, reconfiguration of lane assignments, access management strategies and proposed new off ramps. The MRM process can determine whether the proposed strategies improve traffic flow, reduce queue spillback and determine whether congestion problems are shifted to alternate locations [19].

The MRM begins with a regional travel demand model which is the foundation for all subsequent modeling platforms. The travel demand model, usually owned by metropolitan planning organizations (MPOs), provides the blueprint for all existing roadway infrastructure. In addition, it provides the origins and destinations of all trips encountered on a typical day. The regional travel demand model is converted to a regional simulation-based mesoscopic model. The purpose of using a mesoscopic model is to utilize the dynamic traffic assignment (DTA) algorithm embedded within the software. DTA is a time-dependent methodology which captures traveler’s route choice behavior as they traverse from origin to destination. The objective function (DUE) is based on the idea of drivers choosing their routes through the network according to their generalized travel cost experienced during the simulation. A generalized cost includes both travel time and any monetary costs (e.g. tolls) or other relevant attributes associated (preference) with a roadway. An iterative algorithmic procedure attempts to establish DUE conditions by assignment of vehicles departing at the same time between the same OD pair to different paths. At any given point and after much iteration, travelers learn and adapt to the transportation network conditions. Simulation-based DTA models allow users to analyze traffic conditions both spatially and temporally (i.e. analyze traffic congestion at any specific time period). Regional travel demand models only show the total traffic traveling on any specific roadway for the entire day or hourly sections and cannot show traffic dynamics (e.g. queuing). In addition, travel demand models are capacity constrained and can typically have a volume-to-
capacity (V/C) ratio >1 which is not realistic. DTA models are capacity constrained so at location of oversaturation – the model routes traffic to alternate paths just like reality.

All proposed routing (mid and long range) strategies that include new infrastructure, intelligent transportation systems (ITS) improvements, or changes to existing infrastructure (added/reduced capacity) were examined for current, as well as future, congestion levels. Once all routing strategies had been examined, more detailed operational strategies were analyzed at the microscopic level. Microscopic models are derived from sub-area cuts of the regional mesoscopic DTA model where all paths and flows are truncated and retained in the microscopic model. The microscopic models allowed auditors to evaluate whether operational (short-term) strategies improved or adversely affected congestion and ultimately safety by comparing queue lengths, speed differentials and density patterns. Figure 4 below outlines the entire MRM framework. Once mitigation strategies are implemented, the regional DTA model must be rerun to equilibrium conditions to analyze how proposed improvements impact traffic flow and ultimately safety.

![Figure 4: Multi-Resolution Modeling Framework](image-url)
4 RESULTS

4.1 Signal Timing Optimization

One of the main contributing causes of traffic accidents on the Loop 375 corridor was queue spillback onto the main lanes. The southbound exit ramp at SH 20/Alameda is the first most viable option for commuters destined for the lower valley. During the afternoon peak hour, traffic regularly spills back onto highway main lanes creating a potential traffic safety hazard. Traffic volume counts and turn volumes showed that the highest movement of traffic at this approach was left-turning onto Alameda eastbound. However, there is only one left-turning lane. The first mitigation strategy proposed was to determine whether or not the traffic signals were operating at an optimized level. Current traffic approach volumes and signal timings were input into Synchro to determine existing level-of-service (LOS). Simulation results showed that the intersection was operating at an overall LOS of “F”. The southbound exit experiences the highest control delay, queue delay, and volume-to-capacity (v/c) ratio. The software was then run to optimize the signal timings to see if there would be any benefit to the intersection LOS. Dual left turns were added to increase throughput on the southbound approach. Simulation results showed an improvement to LOS “D” at the interchange. Optimization showed slight improvements at the downstream Socorro and Pan American diamond interchanges as well.

![3D Synchro model – Signal Optimization](image-url)
4.2 Auxiliary Lane

An additional strategy was to provide an auxiliary lane on Loop 375 southbound at the Alameda exit ramp. Current freeway main lane configuration has two travel lanes plus left and right shoulders. Recommendations were to utilize the right shoulder as an auxiliary lane which exits on the southbound frontage road. The regional DTA model with the added capacity was run to equilibrium conditions where a sub-area of the diamond interchange was extracted and converted to a microscopic counterpart. Simulation results showed that the additional storage capacity reduced the queue spillback on the main lanes. Queue spillback was not completely eliminated but reduced enough to provide some relief and possibly a reduction in the number of rear-end collisions. Figure 6 shows the VISSIM simulation model used to produce 4D video files used in final the final presentation to TxDOT.

![Figure 6: Proposed Auxiliary Storage Lane – Loop 375 (Southbound)](image)

4.3 Turning Bays

There is only one approach (Americas Ave northbound) at the Loop 375/SH 20 Alameda interchange that accommodates a right-turn bay. The remaining three approaches all experience substantial queuing caused by peak hour congestion. A VISSIM 4D model was developed (again derived from the regional DTA model) to analyze the impact of additional right-turn bays. The Alameda Ave westbound approach experiences the longest delays where queuing sometimes reach more than ½ mile long. The turning movements were pretty evenly split between through and right turns. Two right turning bays were modeled including the Alameda Ave westbound and
the Americas Ave frontage road southbound. Both turning bays provided additional relief with reduced queuing and delay during peak periods.

4.4 Socorro Road off Ramp (Southbound)

The highest potential for collisions occurs at the Loop 375/Alameda exit ramp southbound. An additional exit ramp was proposed at the downstream Socorro Rd interchange with the intention of alleviating congestion at the upstream ramp by redistributing traffic. The premise was to shift some of the Americas southbound through traffic to the new exit ramp and prevent queue spillback onto the Loop 375 main lanes.
Mesoscopic DTA model was used to analyze the project limits at a system-wide level. Simulation results showed that traffic was redistributed between the two ramps with the Socorro exit attracting more than 3 times the volume than the existing Alameda off ramp resulting in queue spillback onto Loop 375 main lanes (Figure 9). However, since there is only one “left-turning” lane onto Socorro Rd eastbound at the downstream diamond interchange, queuing began to form on the new exit ramp (i.e. shifted the problem from the Alameda exit to proposed Socorro exit). In order to eliminate this new problem, Socorro Rd would have to be widened to accommodate two lanes of eastbound traffic. This would require TxDOT to purchase additional ROW. An additional scenario was run where there were two turning lanes onto a widened Socorro Rd. Simulation results showed that the additional left-turning lane onto Socorro Rd east would alleviate the queue spillback onto the freeway.
CONCLUSIONS

The use of integrated MRM tools helped analyze multiple proposed improvements. The signal timing optimization (Synchro) helped alleviate queuing on the southbound approach to the interchange. The southbound approach is the location that experienced the highest number of rear end collisions due to the queue spillback onto the freeway main lanes. In addition, the Synchro model showed that the addition of a second left turning lane also provided some relief to the southbound approach. However, the additional green time did have a negative impact on the remaining three approaches in terms of approach LOS. The addition of a right turning bay on the westbound approach alleviated some queuing to offset the green time reduction due to signal optimization. When simulating both the signal optimization and turn bay strategies together, significant improvement to traffic flow was realized. Converting the freeway shoulder to an auxiliary lane provided additional capacity for exiting vehicles but more importantly allowed the interchange queuing to be confined to the auxiliary lane. TxDOT converted the shoulder to an auxiliary lane in the summer of 2010.

TxDOT had originally proposed the construction of an additional off-ramp downstream at the next diamond interchange (Socorro Rd). The DTA model accounted for the shift in traffic from regional perspective, but it is not detailed enough to account for extended green times at actuated signals nor can it account for pedestrian flow crossing the street. Therefore the regional DTA model was converted to a microscopic counterpart in VISSIM format which could accommodate complex signal timings and pedestrian flow. This MRM methodology showed that the limited capacity of the Socorro/Americas Ave intersection constrained the flow of vehicles traveling through the signal resulting in vehicles queuing back onto the freeway main lanes. The simulation modeling was able to show that the proposed off-ramp merely shifted the queue
spillback problem to a downstream location. As a result, TxDOT did not pursue the possibility of constructing an additional off-ramp (i.e. TxDOT Advanced Project Development section did not begin initial design of proposed off-ramp).

Through extensive literature review, researchers were not unable to find case studies that utilized integrated modeling techniques to aid in conducting RSAs nor could they address key issues including the diversion of vehicles, the impact of vehicles that opt to take alternate routes outside the project limits, or the time-dependency of traffic variations throughout the day. This innovative and unique modeling methodology helped to address safety issues and provided a more comprehensive and robust approach to traditional methods. Incorporating MRM into an RSA gives roadway agencies a better understanding of how short, mid and long-term strategies affect the transportation system and the regional and localized levels simultaneously. The use of visualization tools helped convey results to TxDOT, especially when the proposed improvements had adverse effects on the transportation system and ultimately safety.

5 REFERENCES


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