Highway medians

Vehicle simulation tools are now being used to help road engineers optimize median designs for rural highways. Dr Sean N. Brennan of Pennsylvania State University's mechanical engineering department along with two research assistants – Jason S. Stine and Bridget C. Hamblin – have been working with the National Cooperative Highway Research Program to understand how median cross-section geometry can be optimized to reduce vehicle rollovers and head-on collisions.

There are more high-center-of-gravity SUVs and minivans today, and it is important to understand whether changes in median geometry can reduce the number of life-threatening accidents that occur when an automobile drifts off the road. Common sense suggests that wide and shallow medians provide the maximum safety. However, the economics of road construction and land use make wide medians prohibitively expensive.

To ensure that his work was applicable to existing highways, Brennan started with existing highway standards – medians that are 18.3m wide with 2.4m shoulders at a 4% grade. He ran thousands of simulations to evaluate how different vehicles would behave on different median geometries.

Most previous studies analyzing median geometry assumed that the driver relinquishes control of their vehicle as soon as the incursion into the median occurs. Although this is known to be an incorrect assumption (drivers frequently over-brake and oversteer when they lose control), previous computer models could not handle the combination of 3D road geometries, high-fidelity vehicle dynamics, and complex driver behaviors.

"It was very important for us to understand how common driver responses to median incursions interacted with different median cross-section geometries," says Brennan. "We know that panicked drivers often increase the probability of a vehicle rollover. If we can design roads that counteract these reactions, we can save a great number of lives."

Brennan and his team selected CarSim from Mechanical Simulation to be the project's simulation software because of its global acceptance by the world's largest vehicle manufacturers, and because it provides a high-fidelity vehicle model that accurately describes vehicle response in extreme driving conditions. It can seamlessly interface with third party control development tools such as MATLAB/Simulink. The team planned to conduct thousands of simulation runs, so the fact that CarSim can perform simulations up to 15 times faster than real-time, and could be fully automated with MATLAB scripts, was also considered essential.

"Three other features made the selection of CarSim compelling," Stine explains. "First, Mechanical Simulation also develops TruckSim and BikeSim simulation programs that will let us extend our research to determine the effect that median geometry has on a complete range of tractor/trailer configurations and motorcycles.

"Second, CarSim includes a complete set of example vehicles, 3D roads, and driving maneuvers – by modifying a small number of parameters we could begin running simulations in a very short time.

"Third, CarSim's architecture gives us the ability to extend its vehicle, road, and driver models – if we want to run the same experiments with vehicles equipped with stability control, we could easily integrate the controls into CarSim and rerun our simulations."

The team spent a great amount of time determining the exact properties of each independent variable they wanted to evaluate, as they knew that their research would require thousands of automated simulation runs. Seven vehicles were used, ranging from small passenger

FIGURE 1: **CARSIM VISUALIZATION ILLUSTRATING HOW DIFFERENT INITIAL CONDITIONS AND DRIVER ACTIONS WILL AFFECT THE FINAL VEHICLE POSITION**

cars to large SUVs. Properties such as wheelbase, track width, sprung mass, and inertias were calculated by averaging published data from representative vehicles in each class. All vehicles were equipped with ABS.

More than 12 different median cross-section geometries were evaluated. Medians varied in overall width, shape (V or trapezoid), the angle of the adjacent and opposing slopes, and the friction coefficient of the median surface.

The researchers looked at vehicle departure speeds ranging from 8-88km/h and departure angles ranging from 2.5-32.5°. Because the research focuses on gradual departure from the road rather than emergency steering and braking, the vehicle's initial roll, pitch, and yaw were set to zero.

Using CarSim's closed-loop steering model, three driver goals were evaluated: driver attempts to steer the vehicle to the center of the median; driver attempts to steer the vehicle back to the road; and the driver does not steer the vehicle. Similarly, two braking inputs were considered: light 5MPa braking and hard 15MPa braking.

A dataset representing each independent variable was designed using CarSim's vehicle definition, driver control, and 3D road-building tools. After each dataset was tested, the research team developed a MATLAB test script that automatically generated a test for every combination of the experimental parameters. With each component of the test validated, the researchers started the batch processing using the automated MATLAB script. Using its tight integration with CarSim, the MATLAB script ran each test with a two millisecond time step until the vehicle came to a complete stop or experienced a rollover. A complete record of each vehicle run was archived after MATLAB logged the most important data of the run, such as the vehicle's lateral and longitudinal stopping point, and whether the vehicle became airborne or its bumper came into contact with the median surface. "Considering
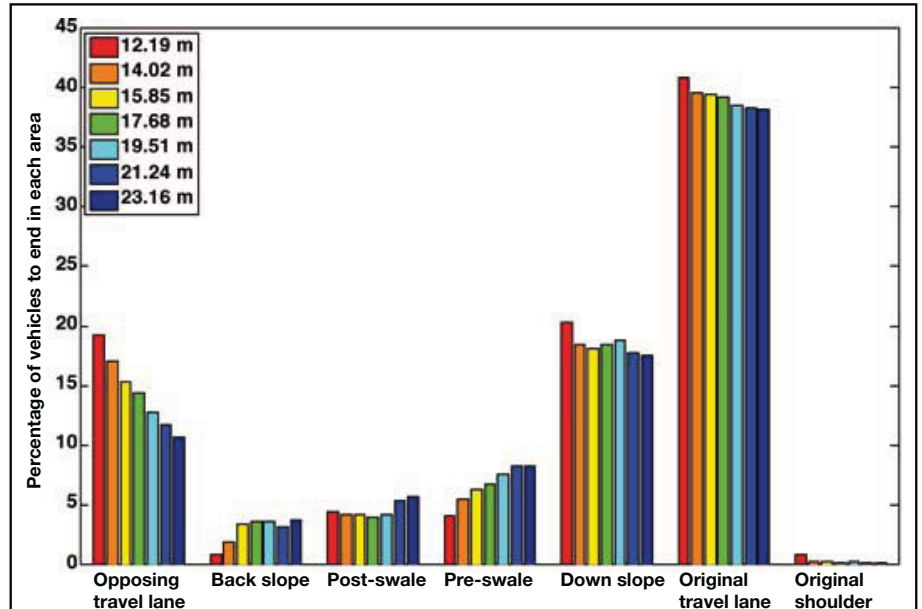
the great number of calculations required, the entire set of 2,058 runs for each median design only took a couple of days to run on our computers," explained Jason Stine.

After analyzing and distilling data for more than 50,000 test runs, Brennan and his team propose that their research has several theoretical and practical applications. On the practical side, the research confirms that driver reaction plays a major role in determining if road departures will result in a rollover or head-on collision.

The data also conclusively shows that the median's width and cross-section geometry greatly affects the outcome of an automobile drifting off the road (Figure 2). Finally, the project helps engineers design each highway according to the parameters they prioritize. The research did not pinpoint an ideal design for every situation because of the extent of the project and the multiple independent variables.

"We show that highway engineers must make trade-offs and carefully consider driving and technology trends as they strive to design safer highways," says Brennan.

"If the ratio of SUVs to passenger cars decreases in future, engineers will take that into consideration as the ideal median geometry is not the same for cars and SUVs. And as a higher percentage of cars and SUVs are equipped with active safety and crash mitigation technologies, highway engineers will need to understand how features such as side airbags, torque vectoring stability control, and active lane departure systems perform in emergencies."

Brennan is now taking the research to the next level, running simulations using road, shoulder, and median data measured on thousands of miles of US highways. By adding median undulations and grade variances of the shoulder and median into the simulation, the team is confident they will obtain a higher level of simulation than was possible with ideal road geometries.

FIGURE 2: **RESULTS SHOWING HOW DIFFERENT V-SHAPED MEDIAN WIDTHS WITH THE SAME SLOPE AFFECT FINAL VEHICLE POSITIONS**