JCE4600
Fundamentals of
Traffic Engineering

Safety

Types of Safety Analysis

- Infrastructure Based
  - System Planning
  - Project Implementation
- User Based (Demographics)
- Vehicle Based
BASICS:
CRASH FREQUENCY
VERSUS RATE

- Frequency: Number of Crashes
- Rate: Crashes per Exposure

Crash Rates

- Rate per Million Entering Vehicles (RMEV) (within 100’ of an intersection)

\[
RMEV = \frac{\text{crashes/ year}}{\text{approach ADT} \times \text{days/ year}} \times 10^6
\]

- Rate per Hundred Million Vehicle Miles (RHMVM) (section of roadway)

\[
RHMVM = \frac{\text{crashes/ year}}{\text{ADT} \times \text{days/ year} \times \text{miles in section}} \times 10^8
\]
Crash Rates

- A four-leg intersection, two-way ADT: 9000, 2000, 9500, 2500, 30 crashes in 2 years.

- A 6 mile roadway section, 12 crashes in two years, ADT=800.

Area Analysis – Frequency Based
Area Analysis – Rate Based

System-Wide Studies

- Crashes are Rare and Random Events
  - Rare – crashes represent a small proportion of total roadway events
  - Random – function of both controlled and unpredictable factors
- Overlapping Contributing Causes
  - Human (93%)
  - Vehicle (13%)
  - Roadway/Environment (34%)
Crashes are Random Events
Crashes are Random Events
Understanding the Numbers

Understanding the Factors

- Human Factors
  - Age
  - Sex
  - Attention
  - Alcohol/Drugs
  - Mental State (Depression/Sleepiness)
  - Seat Belt
  - Speed, Traffic Control Violation
Understanding the Factors

- **Vehicle Factors**
  - Type (truck, pickup, motorcycle, pass car)

- **Roadway Factors**
  - Type (Freeway, Arterial)
  - Rural/Urbam
  - Intersection/Traffic Control
  - Route/Location
Understanding the Factors

- Environmental Factors
  - Pavement Conditions (wet/dry)
  - Day of week, Date
  - Time of day/light conditions
  - Visibility
  - Raining/snowing/dry

Crash Types

- Head on
- Rear end
- Side swipe
- Right angle
- Out of control/off road
- Pedestrian
- Animal
Attacking a Problem

- Type of Facility
- Type of Crash
- Time of Day
- Type of Driver

System-wide Tools and Counter Measures

- Education
  - My last text video
  - [http://www.savemolives.com/distracted-driving.html](http://www.savemolives.com/distracted-driving.html)
- Engineering
  - Median Guard Cables (Video)
  - Rumble Stripes
Crashing cars to test them for safety is the main work conducted at the Insurance Institute for Highway Safety’s Vehicle Research Center (VRC). The violence of the crash tests give them an undeniable wow! factor, but the more serious side of this work is its contribution to the Institute’s mission of preventing harm from crashes by improving driver behavior and roadway design as well as vehicle crashworthiness. It’s important to improve all three, so the Institute’s research program is balanced. Yet the crash tests are the high-profile work. They grab attention worldwide.

Most VRC testing is conducted for consumer information. Vehicles are rated for safety based on performance in front, side, and rear tests. Consumers compare the results, which often differ dramatically, even among vehicles that are similar in size and price.

Auto manufacturers heed the ratings, too, and improve the designs of their vehicles to earn higher marks than the competition. Then the automakers improve on the improvements. The result is that motorists now travel in safer vehicles than they used to.

Lives are being saved because of this work, which is wholly sponsored by the nation’s auto insurers. Injuries are being prevented. This is why the VRC exists.
ENTER THE VRC

As soon as you step inside, you know the VRC is anything but ordinary. Like an automobile showroom, the lobby displays cars. But in this case the cars are crumpled and crashed. They’re from the first collision in the world involving two vehicles in which airbags inflated in both. Despite the severity of this frontal crash, the drivers walked away, in large part because of the airbags.

The VRC is a world-class center for research and testing. Except for the facilities of auto companies, few places in the world are equipped for the same range of tests. And unlike virtually anywhere else that vehicle-related research is conducted, the VRC invites visitors to view the tests. More than 1,000 people including insurers, automakers, and government officials come each year to tour the facility and see a crash test. The presence of the crashed cars in the lobby introduces visitors to the purpose of this work, which is to find and communicate ways to protect people in serious crashes.

DISPLAY HALL

Prominent displays inform visitors to the VRC about the principles of vehicle safety such as crumple zones and safety cages. These principles are illustrated and explained using vehicles that have undergone crash tests. Advanced systems like innovative seat/head restraints also are displayed. So are front and side airbags. Other displays focus on child protection, vehicle bumpers, and the array of dummies used in VRC tests.
CRASH HALL

Described by a newspaper reporter as “a cross between a Hollywood sound stage and a NASA clean room,” the VRC’s huge crash hall with its three runways accommodates a range of test configurations including not only single-vehicle but also head-on and front-to-side tests in which both vehicles are moving. A pair of balconies overlooking the hall’s crash area provide safe vantages from which VRC visitors and staff view test vehicles as they’re propelled toward impact and then as they crash in a shatter of metal and glass. The system that propels the vehicles to impact can accelerate full-size pickup trucks to 50 mph on the VRC’s two 600-foot runways or to 25 mph on a 200-foot runway situated perpendicular to the longer ones.

This propulsion system, the first of its type in North America, uses compressed nitrogen to run hydraulic motors that, in turn, drive the cables that tow the vehicles to their designated impact speeds. A unique VRC feature is the system that provides up to 750,000 watts of illumination without glare to film crash tests at multiple angles. The resulting pictures are so clear and dramatic that video of VRC tests attracts wide coverage on television news. So extensive is the media coverage that the tests, captured in both real time and slow-motion, have become familiar images in millions of households. This is how most people identify the Institute and its contribution to highway safety.
SLED simulates a crash

Tests don’t always involve crashing entire cars. Components like head restraints and car-related gear including child restraints can be tested on a sled that runs on fixed rails to simulate a crash. The components are attached to the sled, and for most tests dummies are positioned in or on the components. Then the sled is programmed to create accelerations or decelerations mimicking those in a vehicle’s occupant compartment during the fraction of a second of a real-world crash. The sled can be programmed to simulate a range of crash types at both high and low speeds. This method is useful to study components whose performance in a crash wouldn’t be influenced by the deformation of the vehicle itself. When crash forces alone are sufficient to evaluate a component, sled tests make sense because they’re faster and less expensive than full-scale vehicle tests.
Biofidelic dummies are calibrated and then positioned in vehicles for crash tests. The dummies mimic the movement of humans in real crashes and record the forces that would be inflicted on the body.

There’s not just one dummy for VRC testing. There’s a whole family of Hybrid III dummies for frontal crash tests, from one representing a large man to another that’s like a three-month-old child. BioSID and its smaller cousin, SID-IIs, are the dummies designed specifically for side testing. For the VRC’s rear tests, there’s BioRID with its complex spinal column.

Each dummy includes 25 to 40 sensors to record forces on the head, chest, abdomen, legs, and other body parts. Careful dummy calibration ensures that the measurement of the forces can be compared with what’s measured in crash tests conducted at other facilities worldwide.

Photos

Still photos of vehicles after crash tests aren’t as dramatic as motion pictures recorded during the tests, but the photos provide important documentation. The studio in which these photos are snapped features a turntable that floats on a cushion of air to display vehicles from various angles. Specially designed lights permit high-quality images of vehicle details.

Test Track

The VRC’s outdoor track, at 1,000 feet in length, accommodates both vehicle research and demonstrations. When wet, part of the track simulates an icy road. It was on this venue that VRC researchers demonstrated the effects of antilock brakes and, more recently, electronic stability control.
Even before the opening of the VRC in 1992, the Institute conducted crash tests to demonstrate safety differences among vehicles. This work expanded with the opening of the VRC, where tests produce vehicle crashworthiness ratings of good, acceptable, marginal, or poor. Such tests wouldn’t provide car buyers with much useful information if they didn’t reflect what actually happens in real collisions. This is why all VRC test programs are preceded by study of crash and injury patterns in the real world, followed by recreation of on-the-road crashes in tests. The result is a protocol ensuring that the tests reflect real collisions.

The VRC’s front, side, and rear tests conducted for consumer information are the most familiar, but they’re not the only crash tests conducted at this facility. Others are run for research and investigative purposes. For example, one test mimicked a real-world crash in which an unbelted driver in an airbag-equipped van died of chest injuries. When investigators of the crash couldn’t establish why the driver died, a VRC test suggested that upward rotation of the van’s steering wheel left the driver’s chest unprotected.

Other VRC tests have helped researchers assess what could happen to people, especially children, riding very close to frontal airbags at the onset of inflation. Results led the Institute to recommend that drivers sit away from steering wheels and buckle children into back seats. At the request of the Institute and others, the government also agreed to allow automakers to use airbags that inflate with less power. These steps have all but erased the formerly serious problem of injuries from airbags.
FRONTAL crash testing

The VRC’s frontal test program, underway since the mid-1990s, was preceded by studies of real-world crashes and tests involving various degrees of overlap between colliding vehicles in front-to-front crashes.

Additional studies helped researchers design a barrier that allows simulation of a front-to-front crash between two vehicles in a single-vehicle test. The outcome is the VRC’s 40 mph/40 percent overlap frontal test into a deformable barrier. It’s the first use of this test to supply consumers with crashworthiness comparisons among vehicles. Automakers also pay attention to the results of these tests. As a Ford executive said, the tests “provide information we have to address. Our customers are paying attention.” In fact, automakers have paid so much attention that there has been a turnaround since this program began. Most cars in recent years have earned good frontal crashworthiness ratings, which were rare in the 1990s. So consistent are these ratings that the VRC has virtually declared victory, allowing automakers who have earned good ratings for their vehicles in previous years to conduct the tests on which the VRC bases ratings of new designs of the same vehicles.
Next to frontal crashes, side impacts are the most serious, so the VRC launched consumer information tests in 2002 to rate and compare passenger vehicles’ side crashworthiness. The research underlying this program of tests included analyses of real-world crashes and injury data that revealed the risks when high-riding vehicles like SUVs hit cars. Another finding was that women in side-struck vehicles are at higher risk than men. From this research, VRC staff developed a moving barrier with a front end like a pickup truck or SUV. During tests, this barrier is propelled into vehicles’ sides.

The protocol is the first in the world to use such a barrier and to use side impact dummies representing small women. The vehicle ratings based on performance in the test attract the same widespread media attention as the VRC’s frontal offset test results.
WINNERS

Top Safety Pick

Every year the Institute recognizes the safest cars, minivans, and SUVs with TOP SAFETY PICK awards. Qualifications include good front, side, and rear crashworthiness ratings plus electronic stability control. The idea is to give consumers a short-cut to finding the safest vehicles overall. The award also puts pressure on automakers, who are so keen to earn TOP SAFETY PICK that they have improved the designs of many vehicles specifically to win. The Institute toughened the qualifications for this award after the first year and will continue doing so to spur further crashworthiness improvements.
Seats and head restraints are intended to reduce neck injuries in rear crashes.

In 1995 VRC researchers began measuring the geometry of the restraints, rating them according to how well they could be positioned to prevent injury. Since then restraint geometry has been improved, but this was only the first step. Seatback characteristics also influence neck injury likelihood, so VRC researchers worked with insurer-sponsored groups worldwide on a dynamic test to assess seat as well as restraint performance in crashes. Automakers have responded with more design changes that improve neck protection in rear impacts.
tests at slow speeds

For more than 30 years, the Institute has conducted low-speed crash tests to assess and compare how well vehicle bumpers resist (or fail to resist) damage in the kinds of minor impacts that frequently occur in commuter traffic and parking lots. Attention to these tests prompted some automakers to equip their vehicles with stronger bumpers, and after the government rolled back federal bumper requirements in the early 1980s these tests provided virtually the only pressure on automakers to use stronger bumpers.

Now VRC researchers have revised this program, working with international partners on tests that better reflect what happens in real impacts. In particular, the new tests produce the patterns of damage to sheet metal and other expensive-to-repair parts that occur when vehicles over- and underride each other.

No vehicles earn commendation for performance in the VRC’s new series of four bumper tests, although some perform reasonably well in some tests. This program will continue until automakers pay more attention to bumper design. The goal is for every vehicle to perform at least as well as the best ones tested.
Passenger vehicles aren’t all alike. Some are bigger and heavier than others, and they ride higher than smaller, lighter vehicles. This mismatch can compromise safety when vehicles collide, especially when cars collide with SUVs or pickup trucks. The risks for the car occupants are elevated in both front and side crashes with the bigger, heavier vehicles. Crash tests conducted at the VRC reveal the consequences of vehicle incompatibility, and the results have been instrumental in a cooperative effort by automakers to reduce mismatch in both front and side collisions. Nearly every auto manufacturer is participating in this voluntary effort, conducted in conjunction with the Institute, so that vehicle incompatibility in crashes is diminishing faster than the federal government’s rulemaking process ever could have addressed the problem.
SHOW IT
in a demonstration

Sometimes there’s nothing like a picture to drive home a point, so the VRC conducts some crash tests specifically for demonstration purposes. This is a good way to introduce a new vehicle safety technology or warn people about a hazardous practice. Before many vehicles were equipped with side airbags, for example, VRC tests demonstrated what can happen to people’s unprotected heads in side crashes and how side airbags can prevent intruding structures from striking the head. These tests showed the importance of side airbags more clearly than a description alone ever could, and media coverage of the tests helped spur the introduction of head-protecting side airbags. A different kind of demonstration, conducted on the VRC’s test track, showed how children riding in the cargo beds of pickup trucks may be injured or killed, even in the absence of a crash. All it takes is a sudden evasive maneuver for a child to be thrown from a vehicle and hit the pavement or an object alongside the road. While it’s useful to warn people about this hazard, the warnings become far more persuasive when they’re accompanied by pictures of the dire consequences. Video of child-size dummies spilling from pickup beds on the VRC’s track attracted the interest of media nationwide.
ENHANCING public health and safety

Tucked into the foothills of central Virginia, the VRC is situated off the beaten path. However, the work that insurers sponsor at this facility attracts lots of attention and contributes directly to changes for the better in vehicle designs. The result is a major contribution to public health and safety.

VRC researchers aren’t going it alone in this work. They’re collaborating with others worldwide to improve vehicle crashworthiness. Protocols for crash testing and other research are being established cooperatively and used internationally.

Researchers at the VRC also have cooperated with automakers to identify safety improvements. As Institute President Adrian Lund points out, “We watch the manufacturers, working with them when we can and when necessary admonishing them to do a better job of protecting the people who buy their vehicles.”

The main measure of VRC success is that lives are being saved and injuries prevented. The health and safety of everyone who drives or rides in a car is thus enhanced.
The Insurance Institute for Highway Safety is a nonprofit research and communications organization funded by auto insurers.

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Project Level Analysis

- Understanding the Details

Intersection Crash Diagram
Intersection 1

Connection to Old Lemay Ferry Road

Intersection 1

Legend:
- Pedestrian
- Bike
- Truck
- Motorcycle or larger
- Fatal
- Injury
- Property Damage
- Fixed object
- Parked vehicle
- Speeding
- Out of control

OLD LEMAY FERRY

No. of Accidents: 21
Hit-and-run Accidents: 10
Intersection 2

Moss Hollow Road

Legend:
- Car
- Bus
- Other
- Motorcycle or bicycle
- Pedestrian
- Fixed object
- Parked vehicle
- Backing
- Out of control

No. of Accidents: 18
Planted Accidents: 17
Counter Measures

- Lighting
- Traffic Control (traffic signals and timing, signage, pavement markings, message boards)
- Traffic Calming
- Enforcement (User behavior)
- Geometric Design Fixes (barriers, improve sight distance, wider shoulders, medians….)
- Maintenance (snow removal, drainage)

Highway Safety Manual

- http://www.highwaysafetymanual.org/
Introduction to the HSM

Outline

• What is the HSM?
• Why should we use the HSM?
**What is the HSM?**

An AASHTO Publication that…

- Provides information and tools to conduct quantitative safety analyses.
- Facilitates explicit consideration of safety throughout the project development process.

**What is the HSM?**

A compilation of:

- Methods for developing an effective roadway safety management program and evaluating its benefits.
- Predictive methods to estimate crash frequency and severity to support project level decision making.
- Catalog of crash modification factors for estimating the effect of a variety of geometric and operational treatments.
What is the HSM?

Akin to the HCM, but for safety…

1. Definitive; represents quantitative ‘state-of-the-art’ information
2. Widely accepted within professional practice of transportation engineering
3. Science-based; updated regularly to reflect research

What is the HSM?

It’s the product of:

• $7 million, 10-year research program funded by NCHRP, AASHTO & FHWA
• Thousands of hours of effort in reviewing the research results:
  • TRB Task Force on Development of the HSM
  • AASHTO Joint Task Force on the HSM, with members from Safety, Design, and Traffic Engineering
Why should we use the HSM?

• We need quantitative estimates of safety performance for many planning and project development decisions.
• More reliable estimates lead to more safety cost-effective decision making.
• The estimation methods in the HSM are based upon good science/research and improve upon much of current practice.

Why should we use the HSM?

Decisions requiring quantitative safety estimates:

• Identifying sites with the most potential for crash frequency or severity reduction
• Identifying crash patterns and treatments to address those patterns
• Conducting economic appraisals of projects
• Evaluating the crash reduction benefits of implemented treatments
• Estimating the effects of design decisions on crash frequency and severity
Why should we use the HSM?

Quantifying safety facilitates tradeoff analysis…

Why should we use the HSM?

HSM methods complement design guidelines…

Nominal Safety

Examined in reference to compliance with standards, warrants, guidelines and sanctioned design procedures

*Ezra Hauer, ITE Traffic Safety Toolbox Introduction, 1999

Substantive Safety

The expected or actual crash frequency and severity for a highway or roadway

HSM Application to Rural Two-Lane Intersections
Why should we use the HSM?

HSM estimates the safety effects of design decisions…

Why should we use the HSM?

Better methods improve the “bottom line”

- Better safety analysis tools to support decision making
- More safety cost-effective investments
- More lives saved and injuries avoided per dollar invested
Why should we use the HSM?

HSM methods improve upon current practice:

• Safety is measured in terms of expected (long-term) average crash frequency
• Alternative ways to estimate:
  • Crash counts
  • Statistical (predictive) methods
  • Combination of crash counts and predictive methods (Empirical Bayes method)

Why should we use the HSM?

HSM predictive methods:

• Apply appropriate statistical methods to:
  • Model the variability in crash data
  • Compensate for regression to the mean
  • Account for changes in traffic volumes
• Include the following components:
  • Safety performance functions (SPFs)
  • Crash modification factors (CMFs)
  • State/local calibration factors
  • Empirical Bayes weightings
Introduction and Background

June 2010

Why should we use the HSM?
Short-term crash counts do not reliably estimate expected average crash frequency

1983-1985

Number of Crashes

Number of Crashes

1986-1988

Number of Crashes
Introduction and Background

HSM Application to Rural Two-Lane Intersections

Why should we use the HSM?
Short-term crash counts do not reliably estimate expected average crash frequency

1989-1991

1992-1994

Why should we use the HSM?
Short-term crash counts do not reliably estimate expected average crash frequency

HSM Application to Rural Two-Lane Intersections
HSM predictive methods help us estimate expected (long-term average) crash frequency.

Why should we use the HSM?

Short-term crash counts are subject to regression to the mean bias.

Data Source: Virginia Tech Center for Injury Biomechanics
Why should we use the HSM?

Short-term crash counts are subject to regression to the mean bias

For the same pole locations, the change in the # of occupants exposed to impact, 2006-2008

Data Source: Virginia Tech Center for Injury Biomechanics

Why should we use the HSM?

HSM predictive methods account for regression to the mean bias

Probability

Number of Exposed Occupants

All Utility Poles
"Hot Spots" 2003-2005
"Hot Spots" 2006-2008
In summary:

- We need quantitative estimates of safety performance for many planning and project development decisions.
- More reliable estimates lead to more safety cost-effective decision making.
- The estimation methods in the HSM are based upon good science/research and improve upon much of current practice.
Home work – Due next class

- Calculate the crash rate for a four-leg intersection with the following characteristics:
  - Two-way ADT per leg: 10,000, 3000, 5000, 15,000
  - 2005 (8 crashes), 2006 (7 crashes), 2007 (1 crash), 2008 (15 crashes), 2009 (4 crashes), 2010 (10 crashes).

- Calculate the crash rate for a 15 mile roadway section
  - 2007 (12 crash), 2008 (18 crashes), 2009 (22 crashes), 2010 (10 crashes).
  - ADT= 18,500 vpd

- Chose the most correct answer. The HSM
  - Automates the process of calculating historical crash rates
  - Is driver education program
  - Provides a predictive safety tool for roadway planning and design.
  - Is used widely by law enforcement professionals to improve roadway safety

- Create an intersection crash diagram for the data emailed to you after class.