Highway Safety Manual

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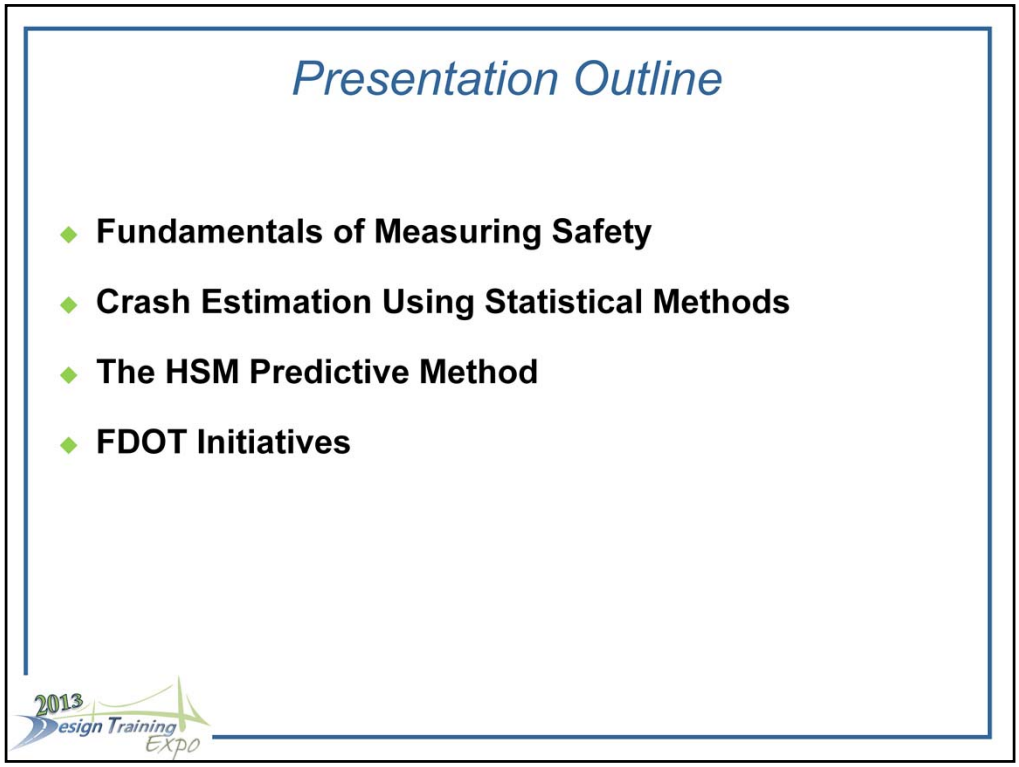
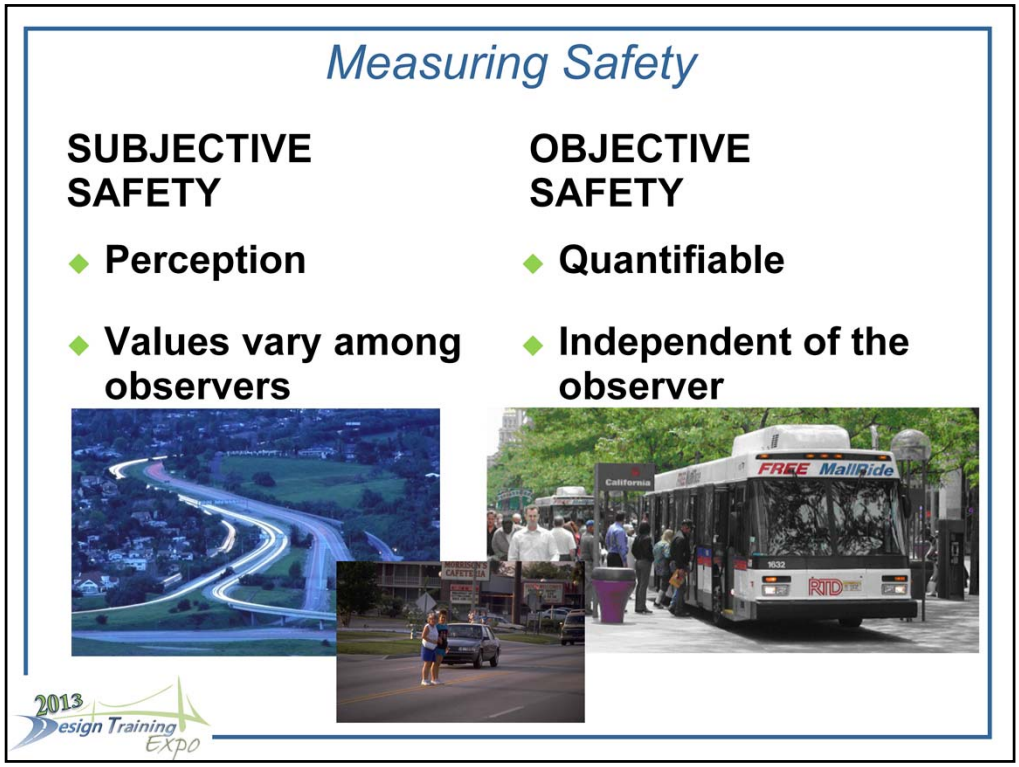


This presentation is designed for you to become familiar with fundamental terms used in the HSM and what we mean by safety as it relates to the HSM. We will discuss conventional methods for crash identification and evaluation, introduce how safety assessment has evolved, the associated techniques, and their constraints or limitations. This presentation will help you appreciate the benefits of the crash estimation methods in the HSM. It will also allow you to understand the benefits and limitations of the predictive methods of the HSM.



When we talk about measuring safety we must start by understanding subjective safety and objective safety. When we talk about objective safety, we are referring to a quantitative measure that is independent of the observer. Subjective safety, on the other hand refers to how 'safe' an individual feels when traveling. Assessments of subjective safety will vary among individuals.

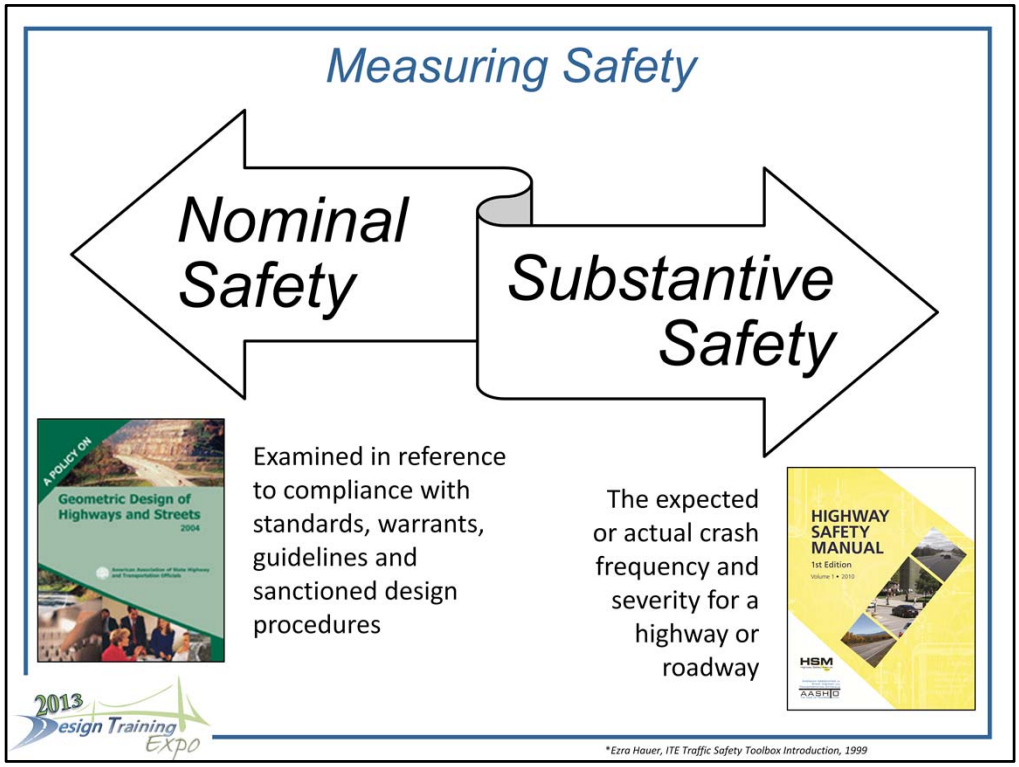
Measuring Safety

Nominal Safety (Subjective)

- Meeting standards does not necessarily make a highway safe
- Some Important features of highways are not determined by standards
  - Two-Way Left Turn Lanes
  - Interchange and intersection spacing

Nominal safety is another term for subjective safety as it relates to criteria and standards. Meeting a standard is usually understood to be a guarantee of quality. Conversely, if something is substandard it is understood to be deficient. Implied is a distinct difference between what is good and acceptable and what is bad and deficient. This meaning does not apply to highway design standards in their relationship to highway safety. Meeting the prevailing, or nominal, highway design standard does not make a highway appropriately safe.

Important features of the highway are not determined by standards, yet they affect its future safety, such as distance between interchanges and intersections.



Nominal Safety literally means “Safety” in name only. That is, for a certain width of traffic lane or shoulder, meeting that value had the meaning of being a “safe” design which is far too simplistic a way to think of safety performance. There are many roads that have lane width and shoulders less than minimum values that have fewer crashes than the average. We highway engineers are used to thinking about safety in terms of adherence to design criteria such as those published in the AASHTO Green Book.

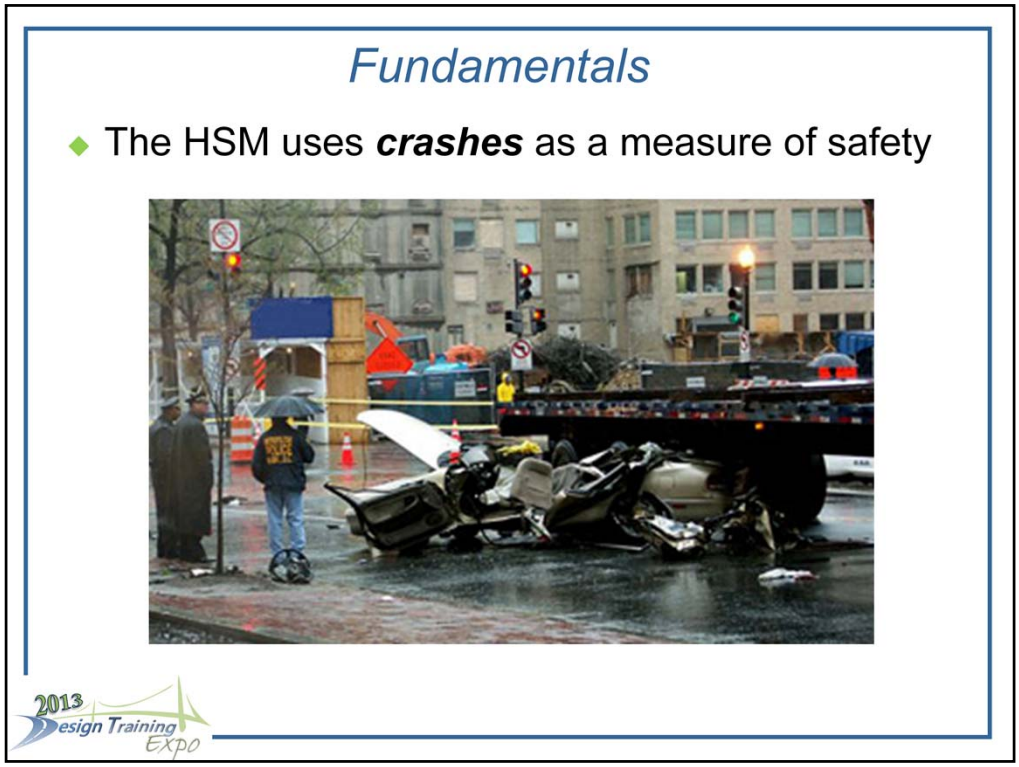
On the other hand, substantive safety is the actual crash frequency and severity of a highway or intersection. In the HSM, the safety performance of a highway (either existing or expected), is based on estimating and evaluating the crash frequency and crash severity for a particular roadway network, facility or site. Therefore, the HSM provides the added

dimension of quantitative safety to the knowledge base for highway designers.

Example of Nominal requirements and Substantive Safety.

(click, click, click)

When talking about substantive safety, crashes are the basis for safety analysis. So, for the Highway Safety Manual, safety is measured in crashes. This is called substantive safety because it is objective, dealing with actual crash numbers. Many conflicts occur between road users, but only a small portion of these conflicts result in crashes. It is then important to keep in mind that we only focus on crashes when we are analyzing and evaluating safety.



In the HSM a crash is a set of events that result in injury or property damage involving at least one motorized vehicle. A crash may involve a collision with another motorized vehicle such as a motorcycle or another road user, such as a pedestrian or bicyclist.

Fundamentals – Observed Crash Data Methods

- Crash Frequency = $\frac{\text{Number of Crashes}}{\text{Number of Years}}$
- Crash Rate = $\frac{\text{Average Crash Frequency in a Period}}{\text{Exposure in the Same Period}}$

See HSM, Appendix A.3 for examples.

There are two popular methods of using observed crash data, crash frequency and crash rate. The observed crash frequency refers to the number of recorded crashes per year.

Crash rate refers to the number of crashes that occurred at a site during a time period, to a particular measure of exposure. Statistically, we can interpret crash rates as the probability, based on past events, of being involved in a crash per instance of the exposure measure. For example, if the crash rate for a segment is 1 crash per million VMT, then the vehicle has a one in a million chance of being in a crash for every mile it travels across the segment.

Observed crash frequency and crash rates are often used as a tool to identify and prioritize sites in need of modifications and for evaluation of the effectiveness of treatments. Sites with the

highest crash rate or rates higher than a particular crash rate are further analyzed for potential modifications to reduce crashes. Appendix A.3 for Chapter 3 of the HSM provides examples of this method.

Fundamentals – Limitations of Observed Crash Data Methods

- **Advantages**
  - ✓ Intuitive
  - ✓ Acceptance
  - ✓ Limited alternatives
- **Limitations**
  - ✓ Assumes a linear relationship between crash frequency and exposure
  - ✓ Inability to account for changes in geometric design and volumes and cannot compare design alternatives

The use of the crash frequency and crash rate methods historically has been widely used for safety assessments. As a result they are generally accepted methods that are straightforward and intuitive. They can also be used, on a limited basis, to evaluate certain alternative configurations based on cross-sectional comparisons of existing features. In addition, the results are easy to understand by most members of the public, so this method is acceptable to the public if we assume observed trends will continue to occur in the future.

(click)

Unfortunately, there are some basic limitations associated with the crash frequency and crash rate methods. For example, often a linear relationship between crash frequency and exposure is incorrectly assumed. As we will see later, the relationship between traffic volumes and numbers of crashes is typically non-linear.

Crash rates can also be misleading. For example, a two-lane rural road with low traffic volumes may have very low crash frequency. A new development is planned, and with the increase in traffic, an increase in crashes is expected. However, if traffic increases threefold and the observed crashes only double, then the crash rate will be reduced by a third. One may then wrongly assume the development made the road safer.

The observed crash data methods also preclude the ability to estimate the expected average crash frequency for the existing system under different traffic flows or geometric designs.

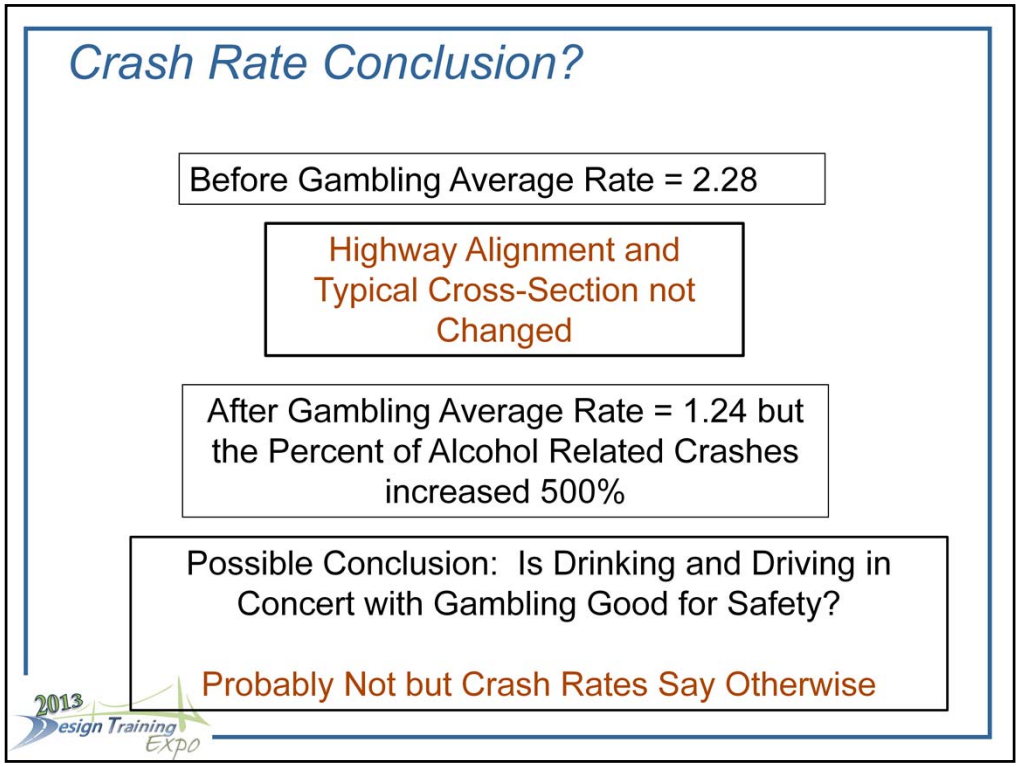
Example for Crash Rates

Before				After			
Year	No. Crashes	AADT	Rate	Year	No. Crashes	AADT	Rate
1988	13	2,900	2.11	1992	30	10,618	1.33
1989	11	2,900	1.79	1993	30	13,200	1.07
1990	13	3,050	2.01	1994	36	14,300	1.19
1991	23	3,400	3.19	1995	40	13,900	1.36
Average Rate = 2.28				Average Rate = 1.24			

Gambling Introduced in 1992

This is an example of how a crash rate analysis may provide incorrect information. In this example, a 2-lane rural corridor experiences a considerable growth in traffic and crashes, but the physical road geometry did not change. The average crash rate decreased from 2.28 crashes per MVT prior to 1992, to 1.24 crashes per MVT, but this change is rate was primarily due to the dramatic increase in traffic volume.

Why did the traffic volume increase so dramatically? (click) In 1992 a casino was constructed in a remote location along this road and the increase in traffic was primarily due to that new development.



Review: before gambling the crash rate was 2.28. The road alignment and cross-section did not change.

(click) After the introduction of gambling the crash rate was 1.24, but impaired driving crashes increased by 500%. As expected, the construction of a casino introduces more at risk personalities, many of who tend to drink and drive.

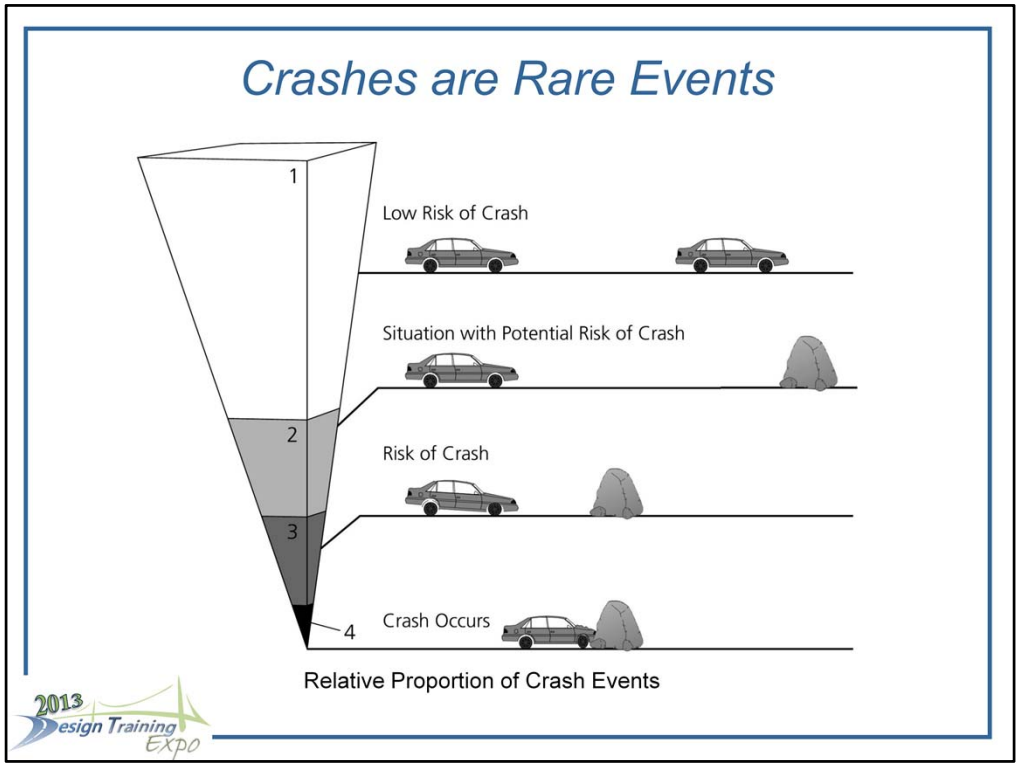
(click) If crash rate is used as an indicator, one possible conclusion would be that drinking and driving when combined with gambling is good for safety. We know this is probably not true, but if only crash rates are used to evaluate safety then this would be the conclusion derived from this evaluation.

Fundamentals – Limitations of Observed Crash Data Methods

Other Important Considerations

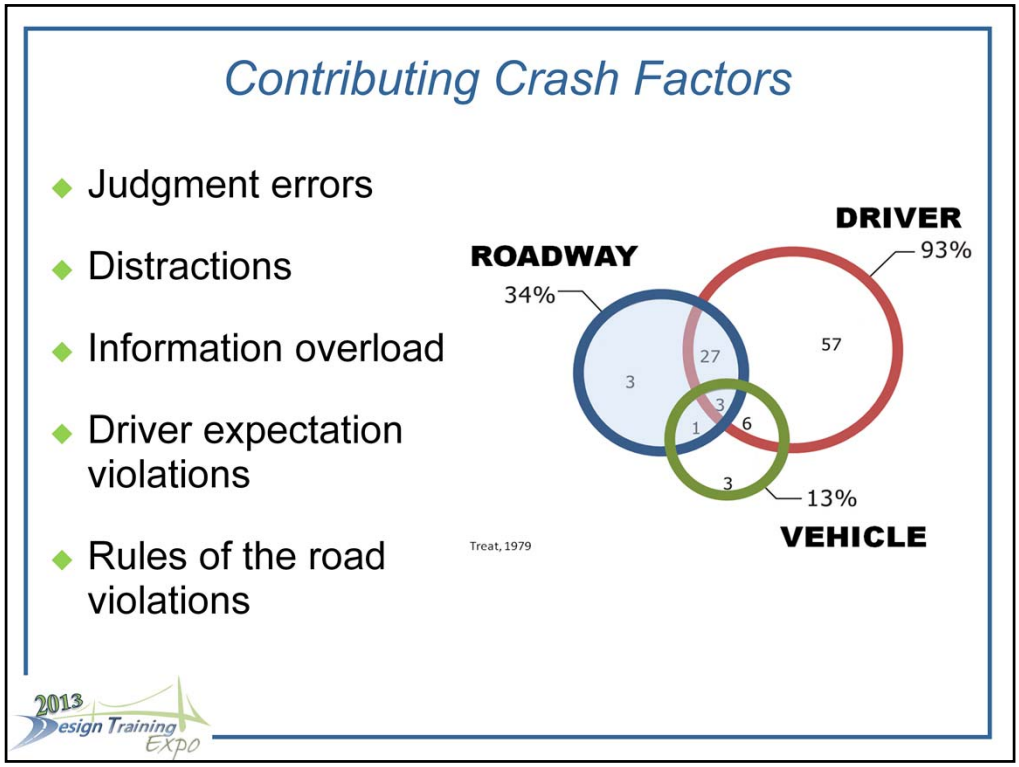
- Crashes are rare and random events
- **93%** of all crashes involve human error
- Limitations in crash data reporting

Read slide.



This diagram represents the relative proportion of crash events.

Crashes are random events. If we stand at an intersection, we cannot say that a crash will happen at a particular time at this intersection. A crash occurs as a function of a set of events that are influenced by several factors. Some of these factors can be controlled and others are random and unpredictable.



The human, or driver factors refer to aspects such as judgment, driver skill, attention, fatigue, experience, vision, and sobriety. The vehicle factors include aspects of design, manufacture, and maintenance. The roadway environment could include geometric alignment, cross-section, traffic control devices, surface friction, grade, signage, weather, and visibility. Research has shown that the roadway, on average, contributes to about 34% of crashes, but drivers contribute to 93% of crashes. This is from a research study, however, other research shows similar results.

Limitations of Crash Data Reporting

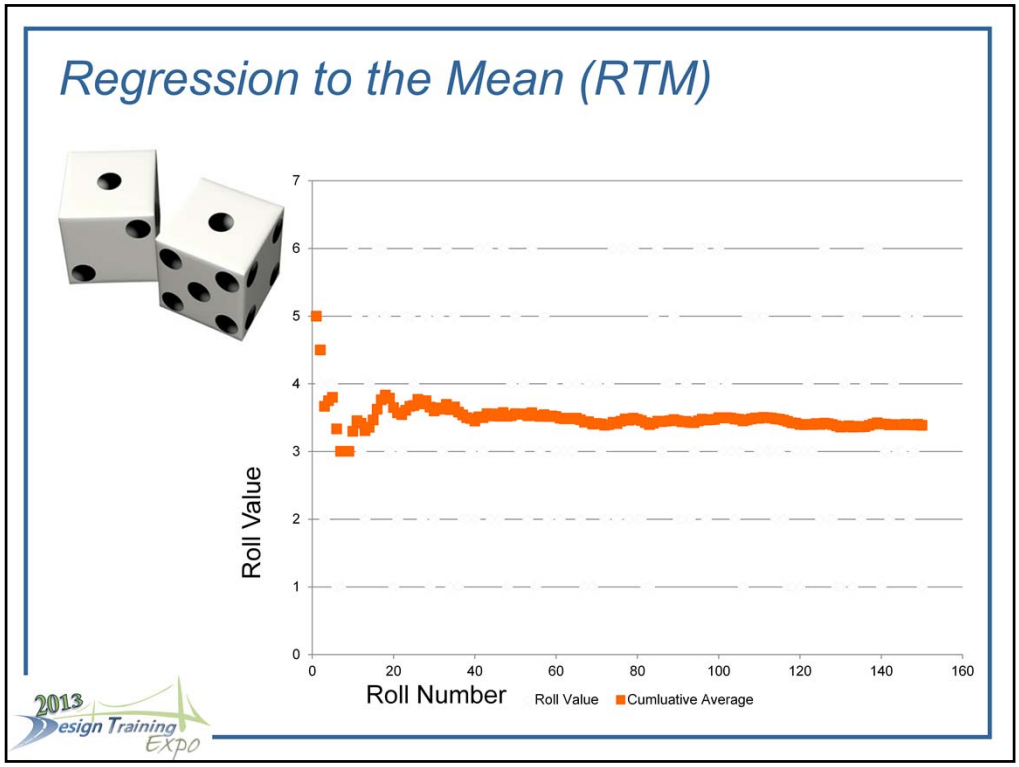
- Not all crashes are reported
- Differences in crash reporting thresholds
- Judgment of observer preparing crash report
- Subsequent injury or fatality
- Data entry can introduce typographical errors, imprecise location data, incorrect entries, lack of training, subjectivity

-Not all crashes are reported: Crash reports not forwarded to DMV. Fender benders not written up in the field.
- Long form/ short form.

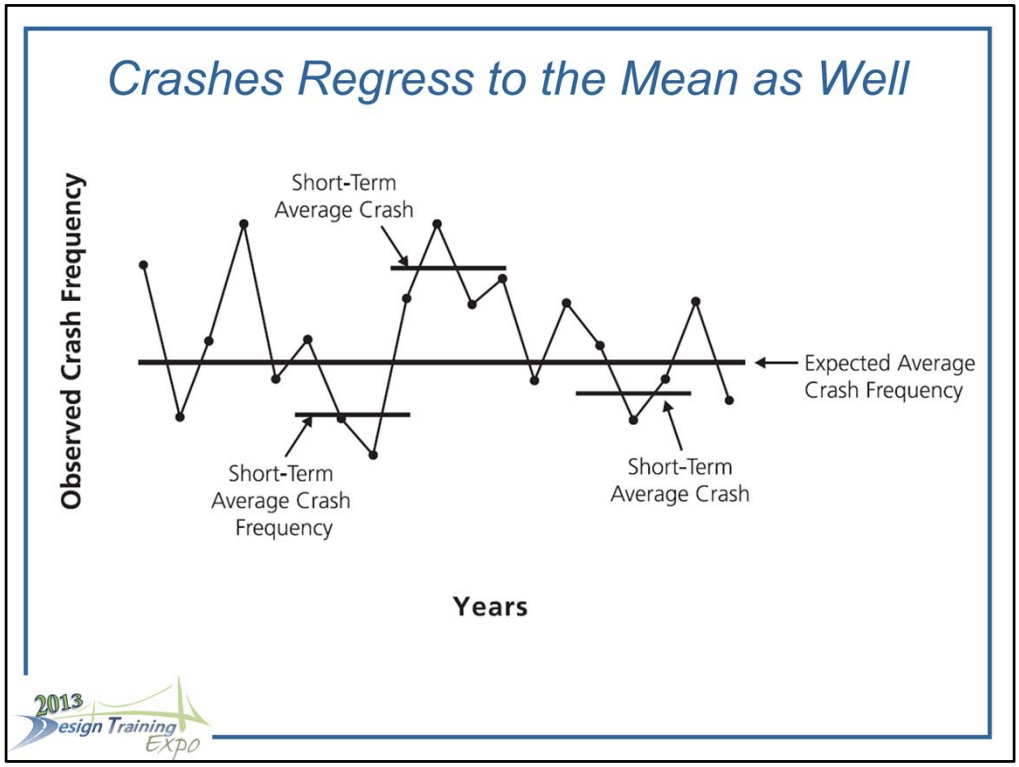
Data Randomness and Change

- Natural variability in crash frequency
- Regression-to-the-mean
- Variations in roadway characteristics
- Changing site conditions

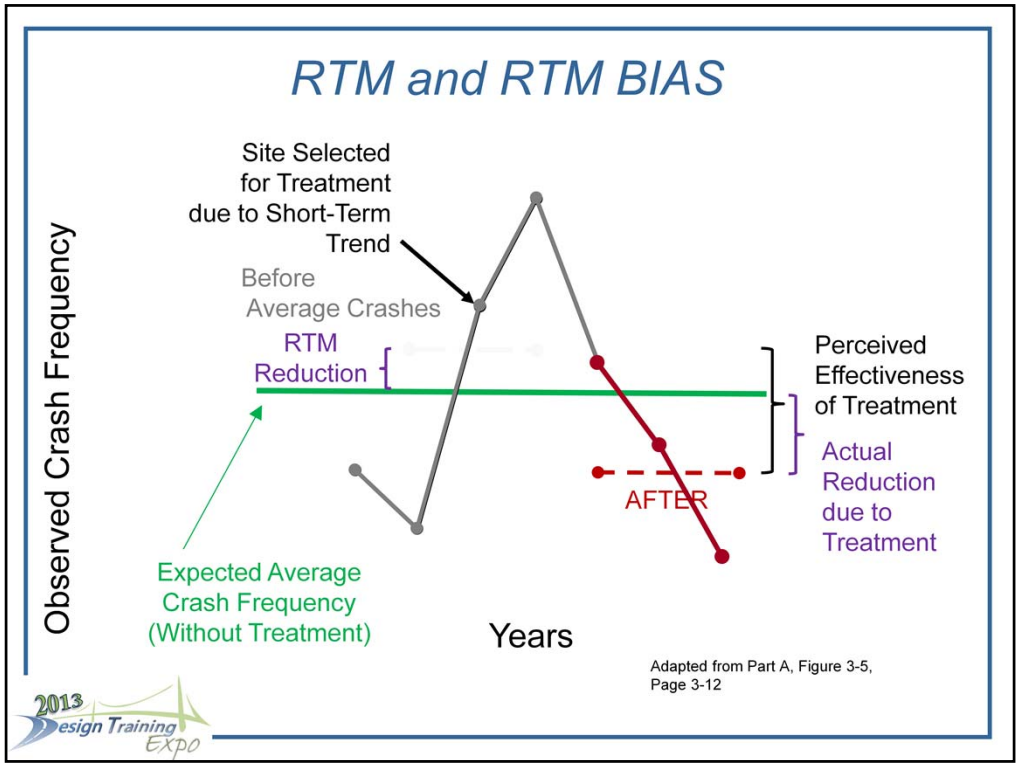
As we noted earlier, crashes are random and relatively rare. Because of this there are issues with just looking at the short term crash history. In addition, projects continue to be constructed and as a result, roadway characteristics and site conditions change.



If you roll a die twice what is the average number you expect to see? Would you expect to see 3.5 in just two rolls? Probably not. But the more rolls of the dice the more likely that the cumulative average of results will be equal to 3.5. The phenomena of the average of the dice converging to the long-term average as you roll the dice more is called regression to the mean.



Crash frequency at a site, any site, naturally varies up and down. But, over the long term, assuming nothing else changes, regresses to a long term average just as the dice roll does. So short term crash analysis, say 3 to 5 years, may not accurately represent the safety performance of a roadway site or segment. How does this impact our safety analysis?



Another issue associated with Regression to the Mean relates to selecting sites for improvement, and measuring the effectiveness of a particular treatment.

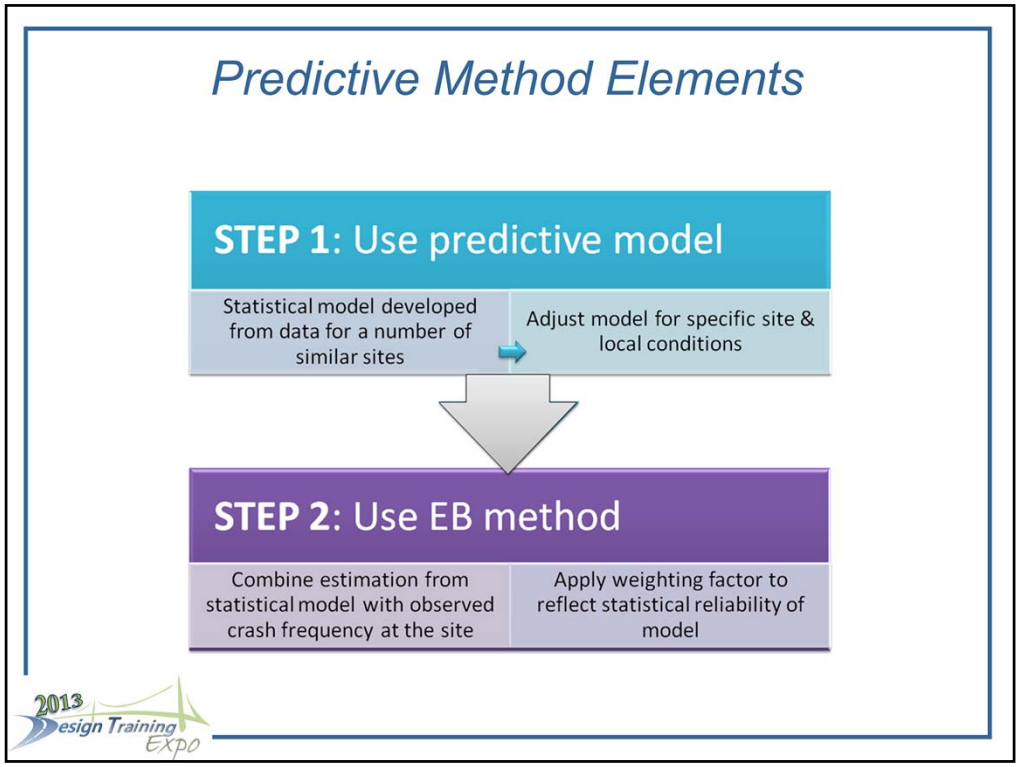
In years 2 to 4 our crash frequencies are increasing every year. As a result, the particular site is selected because of the short term upward trend. Because of RTM it is probable that the crashes will, without treatment, decrease during the following years. If we applied a treatment at the site that in reality reduced the number of crashes because of the treatment, we cannot attribute the entire reduction in observed crashes to the treatment alone. Some of the reduction is attributable to RTM. So we overestimate the effectiveness of the treatment.

The HSM Predictive Method

- Safety Performance Functions
- Crash Modification Factors
- Calibration
- Weighting with Empirical Bayes
- Limitations

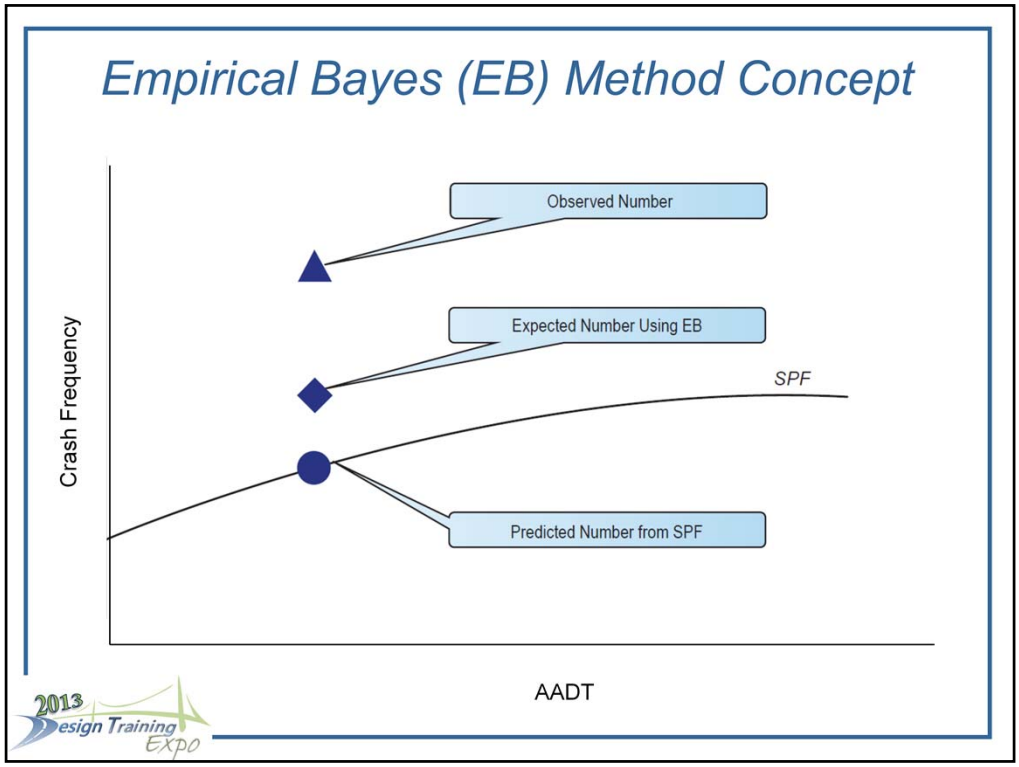
Our attention now shifts to the HSM predictive method, a more reliable way of estimating crashes and measuring safety. Due to improvements in the statistical sophistication of our methods, but also reflect changes in our thinking about safety. In this section, we will also discuss the benefits and limitations of the different methods, and focus on three crash estimation methods:

Statistical analysis techniques and statistical methodologies to incorporate observed crash data to improve the reliability of crash estimation models.



The predictive method consists of two basic elements:
First, a predictive model is used to predict the average crash frequency for a specific type of facility.
Second, the EB method is applied to determine the expected number of crashes at a specific site.

The predictive model is developed using data from a number of similar sites. The model is then adjusted for specific site and local conditions. The EB method allows us to combine estimation from the statistical model (we refer to these as "predicted crashes") with the observed crash frequency at the specific site to determine "expected crashes."



This graph shows one way of conceptualizing the EB method. The circle on the curve shows the predicted average number of crashes based on the SPF. The triangle is the observed number of crashes at the site and the diamond represents the expected average number of crashes per year calculated by using the EB method. The observed crash frequency and predicted average crash frequency are combined using a weighted average equation and a weighting factor “w”.

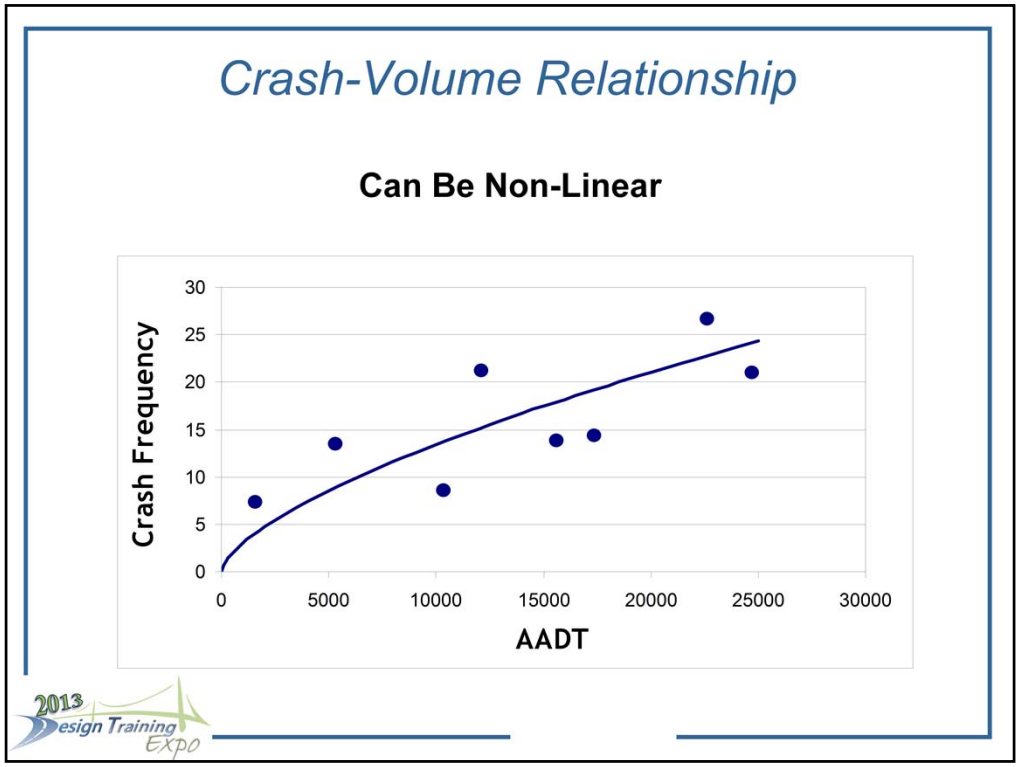
Note that the observed number of crashes and the resulting expected average crash frequency won’t always be higher then predicted by the SPF.

Safety Performance Functions

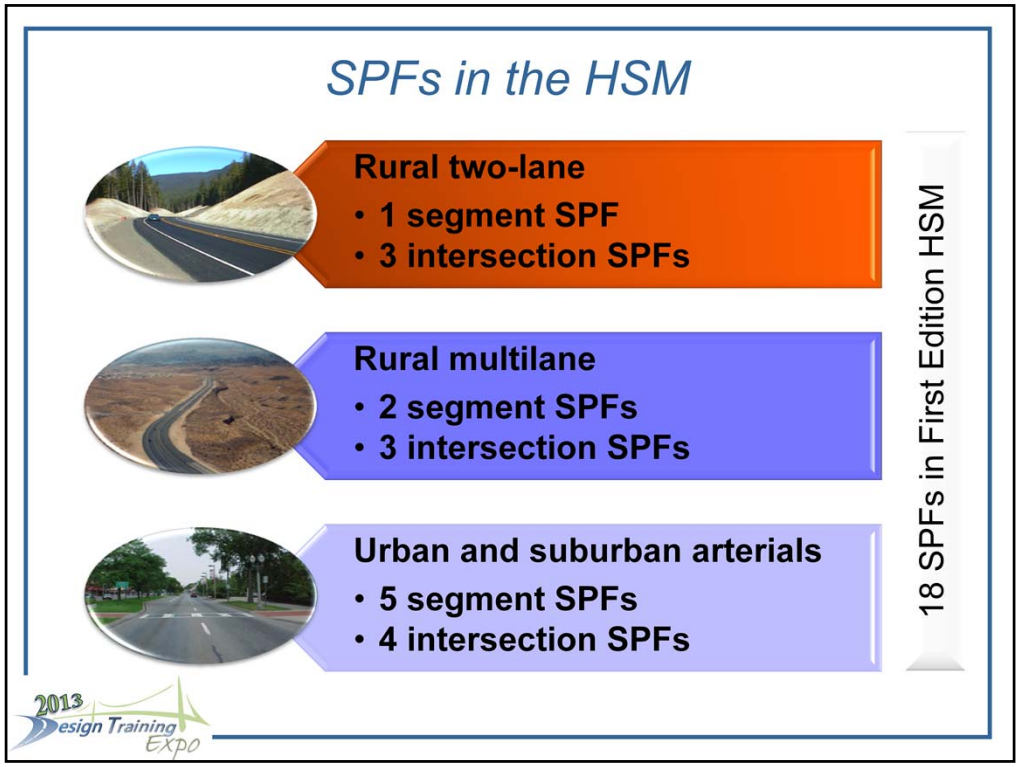
$$N_{SPFrs} = (AADT) \times (L) \times 365 \times 10^{-6} \times e^{(-0.4865)}$$

- N_{SPFrs} = Predicted crash frequency for base conditions for a rural 2-lane, 2-way roadway segment
- *AADT* = Average Annual Daily Traffic
- *L* = Length of Roadway Segment (Miles)

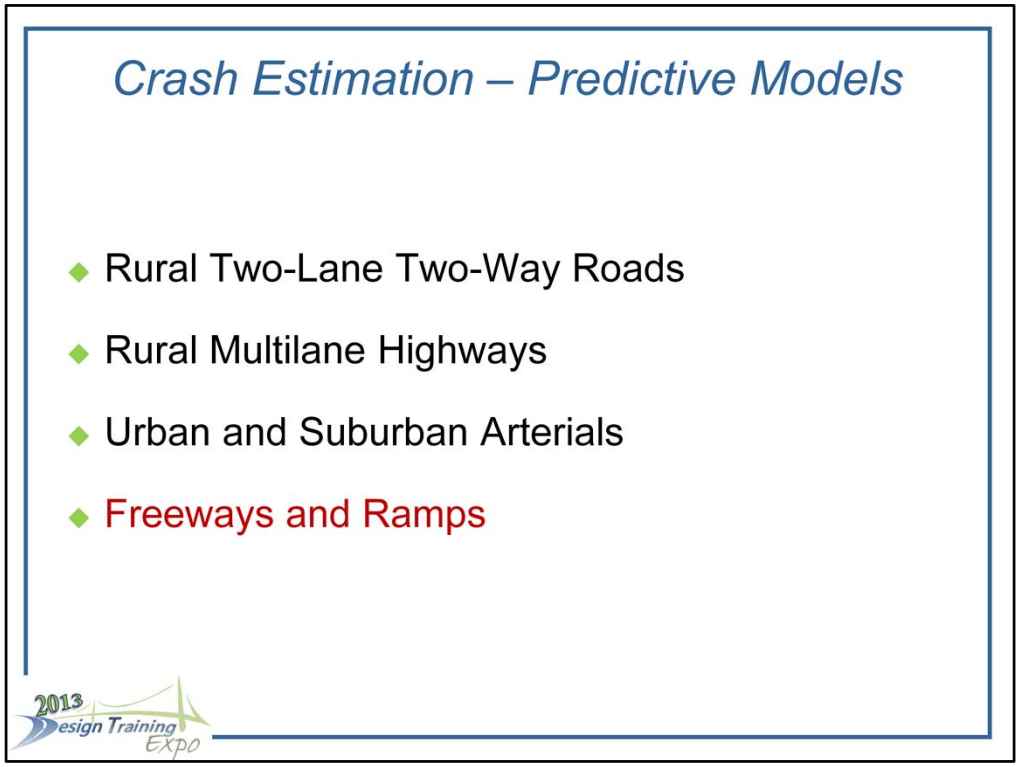
SPFs are mathematical functions developed through regression and that serve as our base models. We use the SPF to estimate the average crash frequency for a facility type with specified base conditions. Since the number of crashes are directly related to AADT and the length of the roadway segment, these variables are direct inputs to the SPF.



Though some of the SPFs may follow a linear format, it is also just as likely that a SPF may be non-linear. Since the SPF represents the general distribution of crashes it is important that the SPF reflect actual patterns as they relate to traffic volume and crash frequency.



Currently Volume 2 (Part C) offers the predictive method for three different highway types: two-lane rural highways, rural multi-lane highways, and urban and suburban arterials. For each of these facilities there are different segments and intersection SPFs available.



In addition to the three roadway types just mentioned, the Freeway and Ramp research was recently completed and adopted into the HSM.

Predicted Crashes Adjusted for Base Conditions and Local Factors

$$N_{SPFrs} = (AADT) \times (L) \times 365 \times 10^{-6} \times e^{(-0.4865)}$$

$$N_{\text{predicted}} = N_{SPF\,x} \times (CMF_{1x} \times CMF_{2x} \times \ldots \times CMF_{yx}) \times C_x$$

Where:

N_{SPFx} = Base condition crash frequency from SPF for site type x

CMF_{yx} = Crash Modification Factors

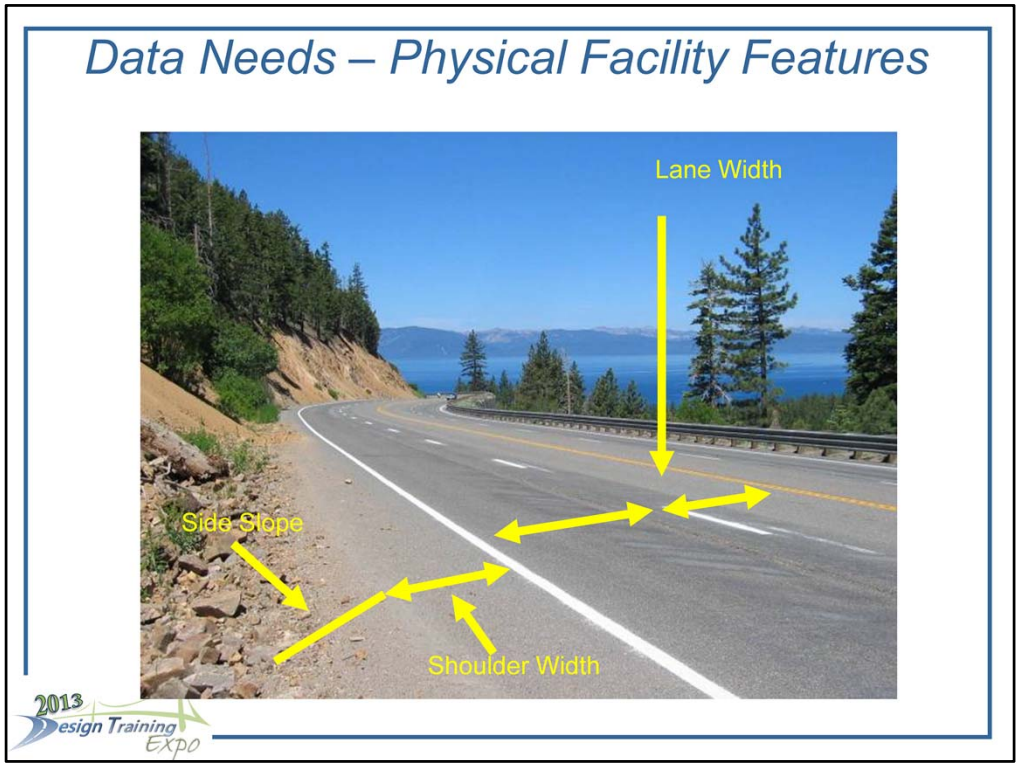
C_x = Calibration factor for site type x

Here we show the fundamental equation of the predictive method again. This equation predicts the number of crashes per year assuming that all the base conditions are met.
(click)
This equation is used to adjust the result for local and site conditions. Note the CMFs in the parenthesis and the Calibration Factor at the end. These CMFs relate to the base conditions. Examples of base conditions for a 2-lane rural highway are 12’ lanes and 6’ shoulders, level terrain, and clear, traversable roadside conditions. If you have an 11’ wide lane and 4’ wide shoulders there would be CMFs for each of these included in the equation.

Also, note the Calibration factor.

Crash Modification Factors

Crash Modification Factors represent the relative change in crash frequency due to a change in one specific condition, when all other conditions and characteristics remain constant



Besides traffic and crash data, we need physical data from the site in order to make adjustments to the base conditions.

(click) For a 2-lane undivided roadway this includes lanes (click) and shoulders, (click) as well as the roadside.

Calibration Factors

- Account For Differences In Geographical Areas
  - ✓ Driver Characteristics
  - ✓ Terrain
  - ✓ Climate
  - ✓ Animal Population
  - ✓ Crash Reporting Threshold
  - ✓ Crash Reporting Practices

Calibrations must be performed because regions differ in climate, animal population, driver populations, crash reporting threshold, crash reporting practices, etc. The method of calibration is covered in the HSM. A calibration factor is really just an adjustment factor to adjust crashes upward or downward so that the estimate better represents what is happening locally.

Florida Segment Calibration Procedure

- Identify facility types
- Collect Road Characteristic Data (RCI Database)
- Collect Crash Data (CARS Database)
- Apply SPF for crash prediction
- Apply CMFs
- Compute calibration factor

$$C = \frac{\sum_{\text{all selected sites}} \text{observed crashes}}{\sum_{\text{all selected sites}} N_{\text{predicted(uncalibrated)}}}$$

The Department conducted a research study with the University of Florida a few years ago to calibrate the segment equations in Part 'C'. Looking at the calibration equation, you can see that the calibration factor is the sum of all the observed crashes for all the sites selected, divided by the predicted crashes using the equation for all the same sites.

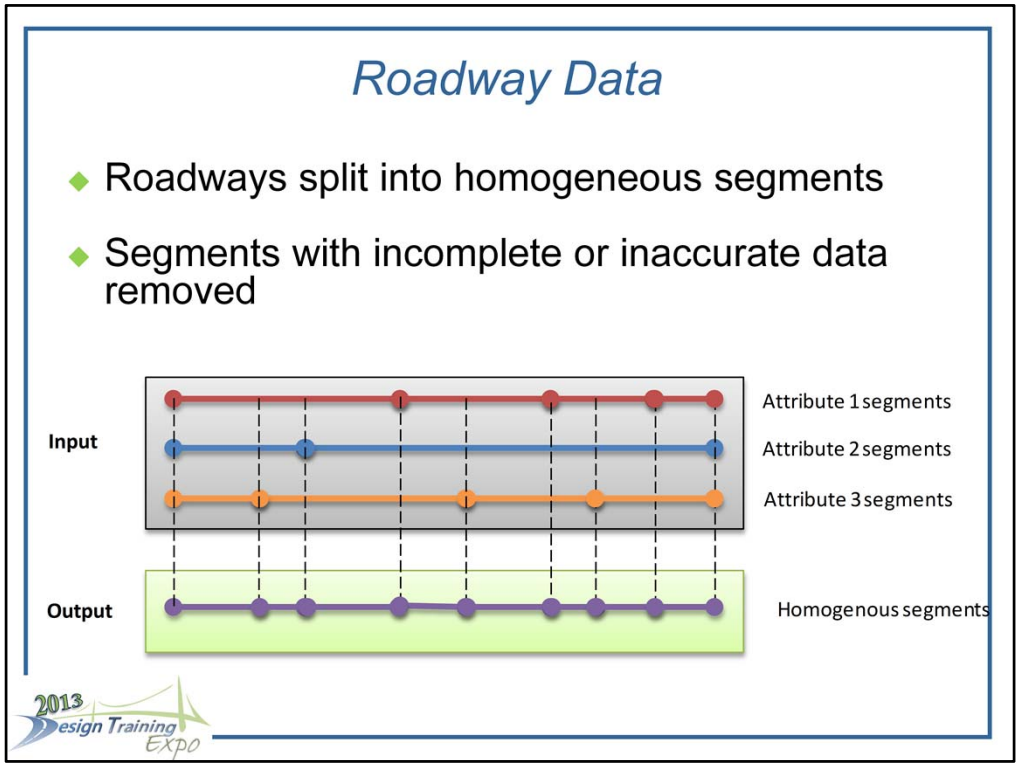
In order to accomplish this, in the true spirit of a research study, we made the effort as complicated as possible. The process we followed was: (click…).

Florida Facility Types for Calibration

- FDOT Prioritized Segments
  - ✓ Rural two-lane roads
  - ✓ Rural multilane divided roads
  - ✓ Urban multilane divided arterials
- Additional segments
  - ✓ Urban two-lane undivided arterials
  - ✓ Urban two-lane with TWLTL
  - ✓ Urban four-lane undivided arterials
  - ✓ Urban four-lane with TWLTL

The priority roadway segments are the most common type segments on the State Highway System.

(click) The additional segments types that were calibrated are these.



So lets consider as two lane undivided segment of roadway that would be represented by the total length of the line. Attribute 1 might represent lane width. Every place you see a node would represent a change in lane width. Likewise, Attribute 2 might represent shoulder width, and so on. The output is a series of subdivided segments that are homogenous. The appropriate CMFs are then applied to each homogenous segment.

Facility Types for Calibration

	Rural			Urban				
	Two-Lane Undivided	Four-Lane		Two-Lane Undivided	Three-Lane with TWLTL	Four-Lane		Five-Lane with TWLTL
		Undivided	Divided			Undivided	Divided	
Number of Segments	4788	25	1330	4664	620	1009	6634	2416
Mileage	2117.40	4.64	541.71	589.61	59.21	85.52	881.52	217.13
Fatal and Injury Crashes								
2005	949	0	584	1002	94	256	2681	926
2006	982	2	587	951	123	306	2560	936
2007	947	4	582	1066	115	320	2635	889
2008	906	4	544	901	109	278	2487	850
Fatal and Injury Crashes*								
2005	662	0	385	560	46	137	1503	480
2006	691	2	389	506	67	158	1450	485
2007	629	3	376	554	52	163	1432	446
2008	617	3	346	460	60	140	1359	445

*Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

Take a look at the priority segments in yellow. / #of homogenous segments/ total miles/ all that had geometric changes over the last four years were dropped/ all that were less than one-tenth of a mile were dropped/

Statewide Segment Calibration Results

Calibration Factor Time Frame		Calibration Factors by Facility Type						
		Rural Two-Lane Two-Way Roads	Rural Multilane Highways	Urban and Suburban Arterials				
		R2U	R4D	U2U	U32LT	U4U	U4D	U52LT
HSM SPF that was Calibrated		Eq. 10-6 Page 10-15	Eq. 11-9 Page 11-18	Eq. 12-10, 12-13, 12-16, 12-19, & 12-20	Eq. 12-10, 12-13, 12-16, 12-19, & 12-20	Eq. 12-10, 12-13, 12-16, 12-19, & 12-20	Eq. 12-10, 12-13, 12-16, 12-19, & 12-20	Eq. 12-10, 12-13, 12-16, 12-19, & 12-20
Fatal and Injury Crashes (KABC)	2005	1.063	0.719	1.093	0.952	0.641	1.750	0.710
	2006	1.069	0.696	0.977	1.126	0.742	1.611	0.726
	2007	1.026	0.701	1.119	1.028	0.749	1.653	0.711
	2008	0.980	0.665	0.928	1.046	0.707	1.602	0.695
	2005-2006	1.066	0.707	1.035	1.040	0.692	1.680	0.693
	2007-2008	1.005	0.683	1.025	1.038	0.729	1.628	0.669
Fatal and Injury Crashes (KAB)[a]	2005	1.353	0.769					
	2006	1.372	0.752					
	2007	1.241	0.740					
	2008	1.217	0.688					
	2005-2006	1.362	0.760					
	2007-2008	1.232	0.714					

a: using the KABCO scale, these include only KAB crashes; crashes with severity level C (possible injury) are not included

Review R2U segment results. The roadway segments were originally calibrated to Washington State. So all the calibration factors for the segment equations are 1.0 for Washington State. Likewise, all the calibration factors for the intersection equations are 1.0 for California.

Predicted Crashes Adjusted for Base Conditions and Local Factors

$$N_{\text{predicted}} = N_{SPF\,x} \times (CMF_{1x} \times CMF_{2x} \times \ldots \times CMF_{yx}) \times C_x$$

Where:

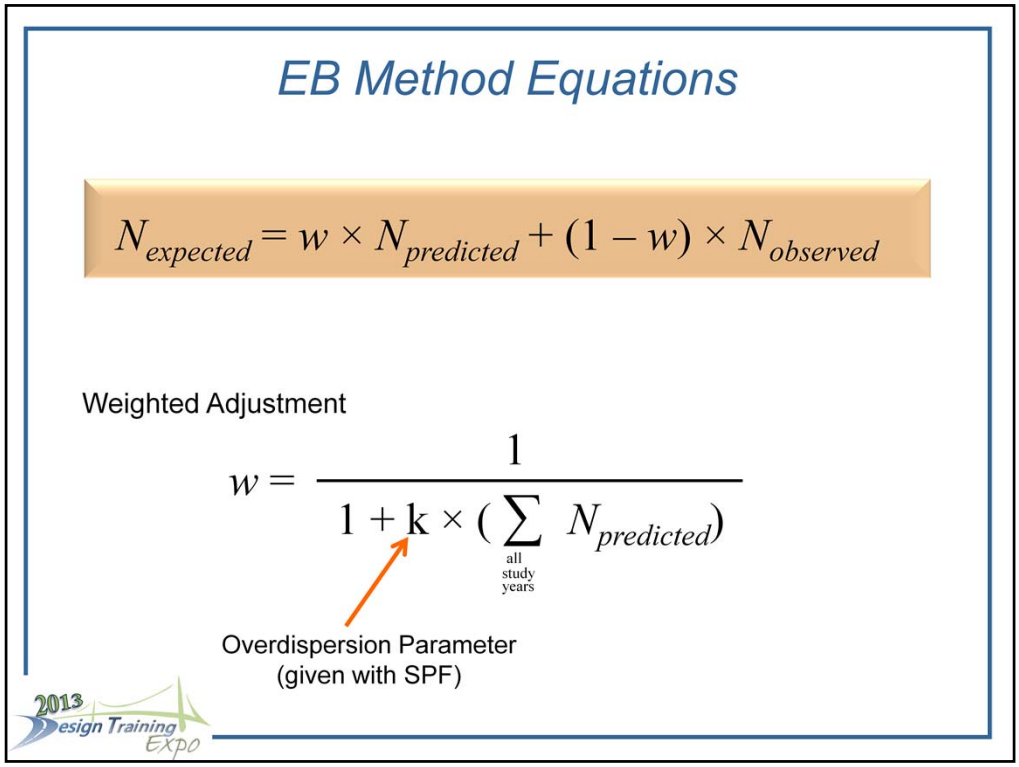
N_{SPFx} = Base condition crash frequency from SPF for site type x

CMF_{yx} = Crash Modification Factors

C_x = Calibration factor for site type x

WHAT'S NEXT?

What is the next step once you have the adjusted Predicted Crashes?



Allying the Empirical Bayes adjustment.

Numerous statistical methods are available to estimate expected average crash frequency. The HSM focuses on the Empirical Bayes Method (EB). If observed crashes are available, the EB method is used to modify the base prediction from "predicted" average crashes to "expected" average crashes. This refinement improves the estimate of crash frequency by accounting for regression to the mean.

w = weighted adjustment to be placed on the predictive model estimate.
k = over-dispersion parameter of the associated SPF used to estimate $N_{predicted}$ (from the Volume 2 (Part C) predictive methods or the jurisdiction-specific SPF). The over-dispersion parameter is provided with each SPF in the HSM, and is estimated as part of the modeling process to develop the SPFs. It is used in models where the observed data variance is greater than the variance of the

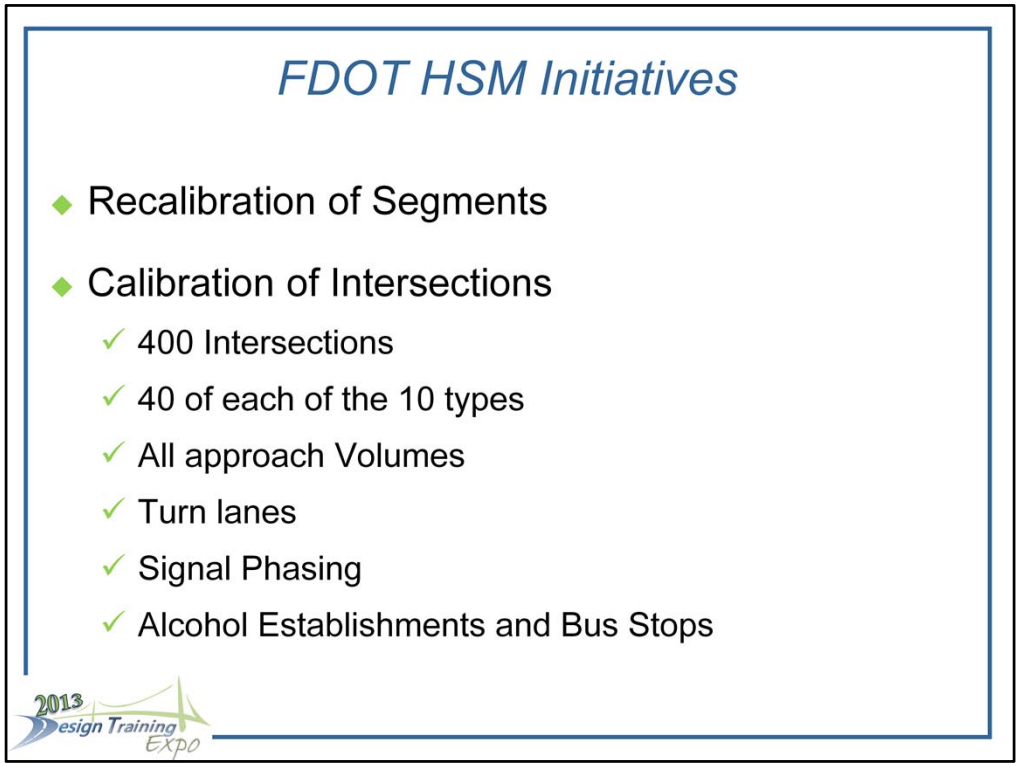
predicted data. So the greater the over-dispersion factor, the smaller W.

Predictive Method Advantages

- RTM bias
- Predictive relationships
- Non-linear relationship: crashes and exposure
- Negative binomial distribution

The predictive methods in Part C offer a number of advantages.

The predictive methods:
•Account for regression-to-the-mean bias;
•Reliance on the availability of limited crash data for any one site is reduced by incorporating predictive relationships based on data from many similar sites;
•The methods account for the nonlinear relationship between crash frequency and traffic volume; and
•The SPFs in Part C use the negative binomial distribution. This statistical distribution is better suited for modeling crash data since a typical crash data set is randomly distributed with a variance larger than its mean indicating that the data is over-dispersed.



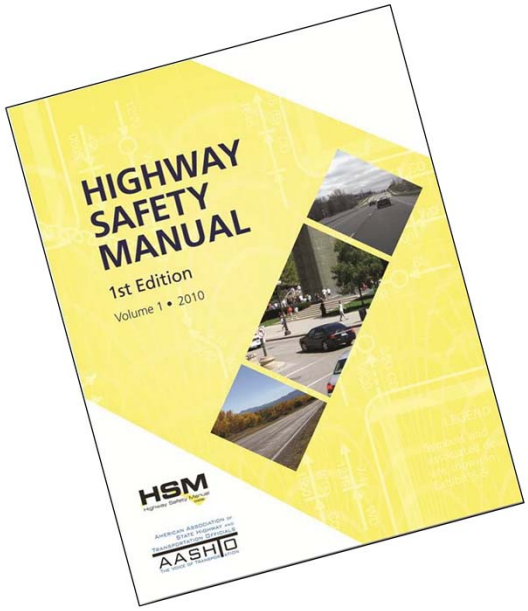
Recalibration of the Segment Equations – the equations should be recalibrated every 1 to 3 years. We are making a goal of recalibrating every two years.

The intersection equations have never been calibrated. Even though we attempted to calibrate the intersection equations with the segment equations, we found out that the RCI database had too many missing data types to accurately calibrate the intersection equations. We currently are collecting all the intersection data types at 400 intersections selected at random. These 400 intersections represent 40 intersections of each of the ten types of intersections. Therefore we hope to publish new calibration factors for both segments and intersections. Designers can then determine the safety performance of an entire project.

Safety Analysis Matrix

FDOT HSM Initiatives

- Design Exception and Design Variation Training
- Freeway and Ramps Training
- Managed Lanes Research

Design Training Expo 2013 – HSM Update

Questions?