# COMPREHENSIVE SAFETY ANALYSIS 2010

## Carrier Safety Measurement System (CSMS) Violation Severity Weights

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# CSA 2010 Report Outline

## I. Purpose of New Violation Severity Weights

One of the core purposes of the Carrier Safety Measurement System (CSMS) is to identify poor motor carrier safety behavior through a better method than the current one, SafeStat. Once fully implemented, the CSMS will provide a more accurate and complete assessment of motor carriers' safety behaviors. These assessments will enable the Comprehensive Safety Analysis (CSA) intervention process to address safety problems in a more efficient and effective manner than before. In turn, this will lead to a reduction in Commercial Motor Vehicle (CMV) crashes and fatalities.

SafeStat uses only three groups of inspection violations to assess motor carrier safety: Vehicle Out-of-Service (OOS), Driver OOS, and select traffic enforcement violations. Collectively, these three violation groups constitute a relatively small subset (less than 20%) of all inspection violations. Moreover, SafeStat treats all violations within these groups with the same weight, or severity.

The CSMS incorporates *all* safety-related violations recorded during roadside inspections, addressing one of SafeStat's key limitations. Therefore, the roadside inspections do not just include OOS and select traffic enforcement violations. The CSMS also recognizes that roadside violations pose a wide range of crash risk. Consequently, it incorporates a severity weight for each individual violation. The severity weighting of violations allows the CSMS to capture the relative importance of each type of violation as it relates to crash risk. Hence, the stronger the relationship between a violation and crash risk, the higher the severity weight the CSMS assigns to the violation. This paper documents the approach used to derive the severity weights and their role in the CSMS. The complete list of violations and their associated severity weights are documented in the SMS Methodology Report.[1]

## II. Incorporation of Violation Severity Weights into the CSMS

The violation severity weights are a key input for the CSMS algorithm, which calculates carriers' safety measures for each of the six Behavior Analysis and Safety Improvement Categories (BASICs): Unsafe Driving, Fatigued Driving (Hours-Of-Service (HOS)), Driver Fitness, Controlled Substances and Alcohol, Vehicle Maintenance, and Cargo-Related.[2] FMCSA developed the BASICs as part of the CSA under the premise that CMV crashes can be traced to the behaviors of motor carriers and/or drivers. Each violation in the CSMS is assigned to a BASIC and given a severity weight ranging from 1 to 10, where "1" represents the lowest crash risk and "10" represents the highest risk relative to other violations in the same BASIC. This 1-to-10 scale provides sufficient differentiation among the various types of violations, without exceeding the level of precision afforded by the analysis used to derive the weights. Therefore, the structure of the violation severity weights provides both precision and simplicity, so that FMCSA's major stakeholders can understand and reproduce the calculations on their own.

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[1] *Safety Measurement System (SMS) Methodology, Version 1.2* (revised November 2009).
[2] Full descriptions of the BASICs and how CSMS assesses safety in each BASIC are found in *Safety Measurement System (SMS) Methodology, Version 1.2* (revised November 2009).

Since the severity weights reflect the relative importance of each violation within a particular BASIC, *they cannot be compared meaningfully across different BASICs*; that is, a "5" in one BASIC is not necessarily equivalent to a "5" in another. However, a severity weight of "5" does represent the midpoint between a crash risk of "1" and a risk of "10" within the same BASIC. Appendix A of FMCSA's SMS Methodology Report includes the severity weight assigned to each violation in the CSMS.

## III. Violation Severity Weight Derivation: Conceptual Approach

In the past, FMCSA relied on analysis based solely on expert opinion when it needed to quantify the crash risk associated with a spectrum of violations. For example, FMCSA has estimated the effectiveness of the roadside inspection and traffic enforcement program in terms of crashes avoided through its Intervention Model.[3] A major input to this model is the risk weight class of roadside violations based exclusively on qualitative derivation.[4]

In contrast, the CSMS severity weights are risk-based. This means that they are derived by applying quantitative analysis to historical crash and roadside violation data to the extent possible. FMCSA incorporated the input of subject matter experts prior to finalizing the severity weights in order to account for limitations in the data-driven analysis. By encompassing both quantitative and qualitative analysis, the CSMS severity weights represent a more rigorously substantiated and balanced risk assessment than the prior, strictly qualitative approach.

Constructing a new violation severity weighting scheme was a complex undertaking. Thousands of potential violations of the Federal Motor Carrier Safety Regulations (FMCSRs) and Hazardous Materials Regulations (HMRs) may be found during roadside inspections. The associations between these regulations and crash risk are multifaceted. Some regulations lead directly to crash reduction whereas other regulations encourage management practices that reduce crash risk indirectly. Yet, other regulations are meant to mitigate damage after a crash has occurred without impacting the likelihood of such occurrence. FMCSA followed a multi-pronged, six-step process in order to capture the various factors associated with roadside violations' crash risk. The process addressed the issue from the perspective of CMV drivers, crash outcomes, motor carriers, and enforcement personnel. This six-step approach can be summarized as follows:

1. **BASIC Mapping—**Map all safety-related roadside violations to the appropriate BASIC, depending on the nature of the violation. Following this mapping, each BASIC represented an exclusive set of violations related to its behavior area. This allocation of violations to the BASICs made it possible to conduct the severity weight analysis on each individual BASIC one at a time.

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[3] *Intervention Model Technical Documentation*, June 2007, Volpe National Transportation Systems Center.
[4] *Risk-based Evaluation of Commercial Motor Vehicle Roadside Violations: Process and Results*, July 1998, Cycla Corporation.

2. **Violation Grouping—**Place the violations in each BASIC into groups of similar violations based on the judgment of subject matter experts from the enforcement community. The violation groups ensured that similar types of violations received the same severity weight. In addition, this approach allowed the incorporation of rarely-cited violations into the statistical analysis used to derive the severity weights. These rarely-cited violations would otherwise be unusable.
3. **Crash Occurrence Analysis—**Conduct statistical analysis within each BASIC in order to quantify the extent of the relationship between crash involvement and the violation rates in each violation group. The analysis used a driver-based approach because of the demonstrated relationship between driver violations and crashes (described below in Section IV and documented in Volpe Center research for FMCSA's Compliance Review Work Group (CRWG), the predecessor to CSA 2010).[5]
4. **Crash Consequence Analysis—**Adjust the results of the Crash Occurrence Analysis to account for Crash Consequences, partly by incorporating findings from the Violation Severity Assessment Study (VSAS).[6] Together, the statistical analysis (Step 3) and the VSAS findings made it possible to address total crash risk in terms of both crash occurrence and crash consequence.
5. **CSMS Effectiveness Test—**Evaluate the various severity weighting schemes developed in prior steps using a CSMS Effectiveness Test modeled after the SafeStat Effectiveness Test.[7] This test measured the ability of the CSMS to identify carriers that pose a high crash risk.
6. **Subject Matter Expert Review—**Modify the severity weights to compensate for the limitations of a purely quantitative analysis. Base this modification on input from Safety Investigators (SIs), FMCSA's CSA Team, and individuals with expertise related to hazardous materials violations.

This multiple-step process made it possible to enhance the outcome of each individual step based on the information obtained during other steps. For example, the Effectiveness Test's (Step 5) results were used to guide the execution of earlier steps. This comprehensive approach yielded incremental improvements to the severity weights. The following section elaborates on the phases and results of the severity-weighting process.

## IV. Violation Severity Weight Derivation: Technical Approach

As described above in Section III, the first step of the analysis was to map all violations to a BASIC (Step 1). For this reason, the analysis-derived severity weights reflect the

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[5] Appendix G, *Compliance Review Work Group Phase II Final Report: Proposed Operational Model for FMCSA Compliance and Safety Programs*, February 2005, Volpe National Transportation Systems Center. This research provided the basis for developing a Driver Information Resource (DIR) that uses individual crash and inspection reports from all states to construct multi-year safety histories for individual CMV drivers.

[6] *Violations Severity Assessment Study Final Report*, October 2007 (Phase 1), Volpe National Transportation Systems Center.

[7] Chapter 7: SafeStat Evaluation, SafeStat *Motor Carrier Safety Status Measurement System Methodology: Version 8.6*, January 2004, Volpe National Transportation Systems Center.

relative severity of violations within their corresponding BASIC only; they are not comparable across BASICs.

**Step 1: BASIC Mapping**

Map all safety-related roadside violations to an appropriate BASIC in order to conduct the severity weight analysis on each individual BASIC.

This analysis compiled all of the FMCSR and HMR violations included in SAFETYNET, ASPEN, and MCMIS into a violation data set. The violations were examined for their potential to be cited during roadside inspections as opposed to other procedures (e.g., Compliance Reviews (CRs)). Roadside violations cited during the three-year period 2004 to 2006 were used as a basis for violations considered for the CSMS. All violations cited during that period, or otherwise determined to be relevant to roadside inspections, were then mapped to a BASIC in consultation with the subject matter experts. Overall, roughly 2,000 violations were placed into the six BASICs. A team of subject matter experts (SMEs) assisted with finalizing the BASIC mapping.[8]

**Step 2: Violation Grouping**

Place the violations in each BASIC into groups of similar violations within that BASIC.

The starting point for the "sub-BASIC" groups was the violation category scheme used in SAFETYNET. This scheme categorized violations as of February 2007. Based on input from the group of SMEs that assisted with the initial mapping of violations to the BASICs, the analysis revised the SAFETYNET categories to more accurately reflect the enforcement and hazardous materials perspectives. The resulting violation groups are defined in the "Violation Group Description" column in the table for each BASIC in Appendix A of the SMS Methodology Report.

**Step 3: Crash Occurrence Analysis**

Within each BASIC, conduct statistical analysis to quantify the extent of the relationship between crash involvement and the violation rates in each violation group.

As discussed above, prior Volpe Center research for FMCSA revealed a strong relationship between CMV crashes and driver violations for a wide spectrum of the FMCSRs. The analysis therefore used driver crash and violation data as the basis for deriving the CSMS violation severity weights.

*Initial Statistical Analysis*

[8] This SME team consisted of the entire CSA 2010 Team, comprised of approximately fifteen members from FMCSA headquarters and field offices and state law enforcement.

The analysis used a five-year driver history data set composed of driver crashes and violations for the period June 22, 2002 through June 21, 2007. The data set was generated using the same complex matching algorithm used to derive the DIR.[9] The DIR algorithm uses multiple driver fields from inspection reports (last name, date of birth, state, commercial driver's license number) to match inspection records and create individual driver histories. The analysis did not include post-crash inspections because of the potential to bias the analysis. Sensitivity analysis focusing on driver activity level was measured via proxy as the number of inspections attributed to each driver. This analysis revealed the strongest statistical results for drivers with seven-plus to ten-plus inspections.

The analysis calculated violation rates in each of the BASICs for the drivers comprising the analysis data set. This calculation involved dividing the number of violations cited by the number of relevant inspections. Additionally, violation rates were calculated for all sub-BASIC violation groups. Finally, the drivers were grouped by the number of crashes with which they were associated during the five-year analysis period. Initial analysis involved comparison of these driver crash rates by violation group, for drivers with zero, one, and two or more crashes. The analysis used standard statistical tests to ascertain whether the differences found in violation rates for drivers with different levels of crash involvement held any significance. These initial measures provided preliminary indicators of the relative relevance of the violation groups. Later, they were used in the analysis to validate further findings.

*Multivariate Regression Analysis*

The analysis explored a number of regression approaches in order to examine the relative relationships between driver violation groups and crash occurrence. Each regression approach addressed one BASIC at a time. Regressions were estimated with driver crash involvement as the dependent variable. Driver violation rates in each of the sub-BASIC violation groups comprised the set of explanatory (independent) variables.

A negative binomial regression approach was chosen based on initial comparisons with Poisson and Ordinary-Least-Squares regressions. Negative binomial regression is often used when the dependent variable—in this case, crash occurrence—takes low, positive and discrete values but does not meet the stringent assumptions that a Poisson distribution imposes.[10] In particular, the negative binomial has one more parameter than a Poisson. With the additional parameter, a negative binomial regression treats a distribution's mean as a random variable rather than as a dependent of the variance. This allows for a better model fit in cases of overdispersed data.

The regression analysis was conducted for each BASIC, and separately for drivers with seven-plus and ten-plus inspections to allow for later comparison. The vast majority of

[9] The DIR algorithm uses multiple driver fields on inspection reports (last name, date of birth, state, commercial driver's license number) to "match" inspection records and create individual driver histories.
[10] In a Poisson distribution, the mean and standard deviation must be equal. Often, real-world data sets defy this condition.

sub-BASIC violation groupings yielded statistically significant relationships with crash occurrence. The statistically significant regression coefficients were used to generate preliminary violation severity weights of 1 to 10. This was done separately for one BASIC at a time as follows: First, each coefficient estimate was used to calculate the corresponding Incidence-Rate Ratio (IRR).[11] In general, an IRR greater than 1.0 represents a positive association between the dependent and independent variables. On the other hand, an IRR less than 1.0 represents a negative association. Values close to 1.0 indicate a weak association. Second, within each BASIC, the violation group with the lowest IRR was given a weight of 1 and the group with the highest IRR was given a weight of 10. The remaining groups were assigned severity weights between 1 and 10, corresponding to their proportional difference from the values assigned to the lowest, and highest, coefficient groups.

After consideration of crash consequences in Step 4 below, the preliminary violation severity weights were used as inputs in the CSMS Effectiveness Test (Step 5).

***Step 4: Crash Consequences Analysis***

Adjust the results of the Crash Occurrence Analysis to account for Crash Consequences, partly by incorporating findings from the VSAS.

The analysis in Step 3 focused on the relationship between violations and crash occurrence. However, once a crash occurs, consequences can range from minor property damage to injuries and fatalities, and particular aspects of the FMCSRs and HMRs are in place to reduce such consequences. This analysis examined and incorporated early findings from the VSAS in order to produce a more holistic measure of carrier crash risk. Using this more robust measure of crash risk at the carrier level, it was possible to produce violation severity weights that reflect both crash occurrence and crash consequences.

The VSAS, conducted at the Volpe Center, has produced preliminary estimates of the relationship between violations and crash consequences. The study initially began at the individual violation level. For the purposes of the CSMS, this analysis aggregated the violation-level VSAS results at the level closest to the CSMS sub-BASIC violation groups. These aggregated VSAS results were then incorporated into the CSMS severity weights developed in Step 3 by increasing the initial severity weights to reflect the additional importance of regulations aimed at reducing crash consequences. The predictive value of these combined weights, in terms of carrier crash risk, was examined using the CSMS Effectiveness Test described below.

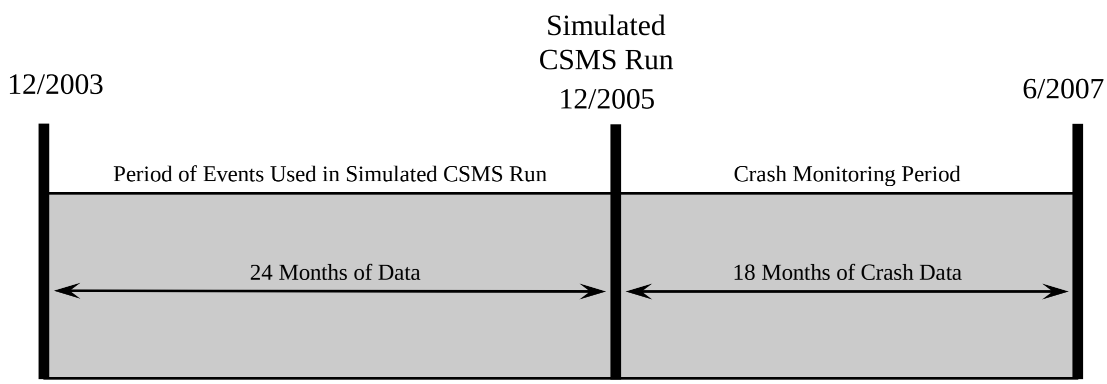
***Step 5: CSMS Effectiveness Test***

[11] The IRR is calculated by raising the base of the natural logarithm *e* to the power of the original regression coefficients *b*.

Evaluate the various severity weighting schemes developed in prior steps using a CSMS Effectiveness Test modeled after the SafeStat Effectiveness Test.

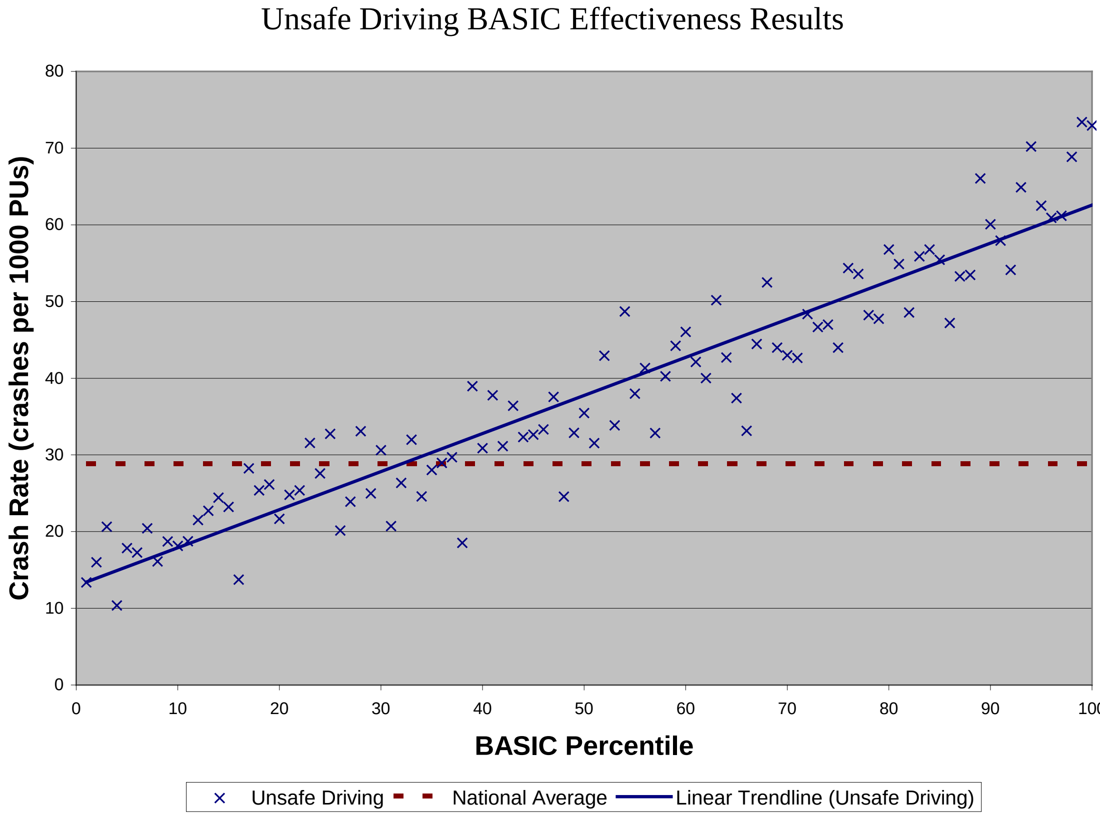
The CSMS Effectiveness Test measures the ability of the CSMS to identify high crash-risk carriers. The test was accomplished through three actions: (1) performing a simulated CSMS run that calculates carrier percentile ranks for each BASIC using historical data (December 24, 2003 through December 22, 2005); (2) monitoring each carrier's crash involvement over the 18-month period immediately following the simulated CSMS timeframe (December 23, 2005 through June 22, 2007); and (3) observing the relationship between the percentile ranks (from 0 to 100) in each BASIC and subsequent post-CSMS carrier crash rates. The Effectiveness Test framework is illustrated in the figure below.

CSMS Effectiveness Test Timeline




This simulation approach provided the ability to conduct a "what-if" analysis. This analysis applied various severity weighting schemes to the CSMS and observed changes in the relationship between carrier BASIC percentiles and subsequent crash rates. The analysis was accomplished through the following process:

1. Apply the severity weighting schemes to each violation when calculating the carriers' BASIC measures.
2. Convert the BASIC measures into percentile rankings ranging from 0 to 100; 100 represents the highest, or "worst," BASIC measure and "0" denotes the lowest, or "best," measure.
3. Group all carriers with a percentile rank in a particular BASIC into one-percentile increments (carriers with percentile ranks from 0 to 1, 1 to 2…99 to 100).
4. Calculate the post-CSMS crash rate for each percentile group.
5. Plot the results of the post-CSMS crash rates for each BASIC percentile group and develop trendlines that demonstrate the crash-risk relationship. An example of such a plot for the Unsafe Driving BASIC is shown below.




6. Test and compare the various severity weighting schemes by observing changes to the trendline. Particularly focus on the impact at the high-end (above 50th) percentiles, where carriers could be flagged for the CSA intervention process. This comparison of trendlines among the tested severity weighting schemes was used to ascertain which scheme provided the most improvement in identifying high crash-risk carriers.

***Step 6: Subject Matter Expert Review***

Modify the severity weights based on input from safety investigators, FMCSA's CSA Team, and individuals with expertise related to hazardous materials violations.

The first five steps of the severity weight derivation process were highly data-driven. All results were computed and tested using statistical techniques. The results, however, do not necessarily reflect all of the relevant information on which carrier safety measures should be based. Roadside data and measures of recordable crash involvement simply do not capture some information. Subject matter experts with years of experience in the field of CMV safety have technical and institutional knowledge that can augment a statistically-based analysis. To compensate for the limitations of a purely quantitative approach, the analysis team shared the weighting scheme developed through Steps 1 through 5 with SIs, members of the CSA Team, and hazardous materials experts.[12] These subject matter experts reviewed the integrity of the weighting scheme and identified any instances that might lead to biased carrier safety measures. The final violation severity weights incorporate this expert feedback.

## V. Next Steps

This report documents the initial derivation of the new CSMS violation severity weights. These weights are currently being used in the CSA Operational Model (OM) Test that began in February 2008. Along with the present CSMS methodology, the severity weights are part of a continuous improvement process in support of the CSA initiative and OM Test. FMCSA will base future improvements to the weights on feedback from stakeholders, such as enforcement personnel, industry, and the public, as well as on findings from the OM Test. In addition, FMCSA will continue to analyze new data sources for possible enhancements to the severity weights. Finally, FMCSA periodically will enhance the CSMS, including the severity weights, as future research reveals new and useful knowledge about crash causation and about the relationship between crash risk and regulatory compliance.

[12] This SME team consisted of (1) a FMCSA Division Administrator with HM-related experience, (2) a current FMCSA SI who is a former MCSAP-trained State trooper, and (3) a FMCSA Enforcement team member who is a former SI.