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Development of a Naturalistic Observer-Based Rating of Near-Crash Severity in Naturalistic Driving Data

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EXECUTIVE SUMMARY

The analysis of safety-critical events, including crashes and near-crashes, from naturalistic driving studies has proven extraordinarily useful in guiding transportation safety policies, transportation technology, and transportation infrastructure. Near-crashes, which are much more common than crashes, have the potential to answer many research questions. However, they are difficult to define, and their severity is difficult to rate. By definition, there is no impact to measure in a near-crash and therefore no injury or property damage to assess. Near-crashes cover a range of scenarios, and perceptions of severity can vary greatly depending on the person experiencing or perceiving them. From a research perspective, this variability makes near-crashes challenging. Severe near-crashes may be considered most similar to crashes and serve as better surrogates than less severe near-crashes, but less severe near-crashes are still very different from "normal" driving and are still relevant to policy, technology, and infrastructure development research.

In this effort, an observer-based, naturalistic near-crash severity rating protocol was developed and tested to help researchers produce near-crash event data effectively and reduce associated variability. Goals included producing a protocol that can (1) produce consistent and meaningful ratings, (2) be incorporated effectively and efficiently into the standard primary event assessment, (3) be implemented by trained data reductionists with access to video and basic kinematic data charts, (4) be applied without complex models, calculations, or statistical modeling, and (5) mirror the existing crash severity scale in implementation and conceptualization.

A key concept in this work was that of conflict urgency. There is no clear answer about how urgency can or should be observed or measured in naturalistic data, especially in non-crash scenarios. It is clear, however, that the concepts of collision imminence (a sense of conflict timing) and potential crash severity (related to possible damage and injury) are important factors. Thus, an additional goal was to achieve a balance between actual kinematics, predictive outcomes, and perceived subjective risks.

Operational definitions, associated research protocols, and reference guides were developed for four levels of near-crash severity ranging from Critical Severity to Lower Severity. These are documented in the appendices. At their core, the definitions are based on objective metrics such as relative speed, time-to-collision, and type of conflict, but with room for subjective assessments. An iterative approach was used in the development of these definitions, and this included assessments to evaluate interrater reliability. Results indicated that reference materials and training improve interrater reliability.

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LIST OF ABBREVIATIONS AND SYMBOLS

ISO	International Organization for Standardization
NDS	naturalistic driving study
SCE	safety-critical event
SHRP 2	Second Strategic Highway Research Program
SV	subject vehicle
V2	second vehicle
TA	time to accident
TTC	time to collision
VRU	vulnerable road user
VTTI	Virginia Tech Transportation Institute

CHAPTER 1. INTRODUCTION AND JUSTIFICATION

The analysis of safety-critical driving events in naturalistic data is fundamental to transportation safety research and the overarching goal of eradicating crashes. The analysis of safety-critical events (SCEs), including crashes and near-crashes and less urgent crash relevant conflicts, from naturalistic driving studies (NDSs) has proven to be extraordinarily useful in guiding transportation safety policies, transportation technology, and transportation infrastructure. Defining and characterizing those SCEs prior to such analyses, however, is a complicated process whereby (1) parametric data are algorithmically scanned for potential SCEs using a variety of kinematic variables, including hard decelerations, evasive steering maneuvers, and close time-to-collisions (i.e. triggers); (2) valid SCEs are identified through manual review of those triggered events; and (3) confirmed SCEs then undergo various programmatic analyses (manual and/or algorithmic) to annotate context, classification, and sequencing information. This process, as implemented by the Virginia Tech Transportation Institute (VTTI) for the Second Strategic Highway Research Program (SHRP 2) NDS dataset, was outlined by Hankey et al. (2016).

EVENT OUTCOME DEFINITION

For research involving SCEs from naturalistic driving data, one key event classification concept is a measurement or characterization of event outcome (e.g., crash or near-crash) and event severity (e.g., more versus less critical) in terms of actual harm done or risk posed to road users and property. These two types of classification facilitate robust and targeted analyses, allowing researchers to (1) select and focus on events of a certain outcome or level of severity, and 2) use outcome and severity ratings as an input into research design and analysis. However, there are key differences between events of different outcomes (crashes versus near-crashes) that preclude assessing them in the same way to assign levels of severity (or criticality) within a given outcome. To illustrate these differences, the definitions for the crash versus near-crash SCE outcome, as used by VTTI (2015), are summarized in Table 1.

Table 1. Summary of crash and near-crash outcome definitions.

Event Outcome	Summary of Outcome Definition
Crash	Any circumstance that includes contact between the subject vehicle and another object, either moving or fixed, at any speed. This includes contact with other vehicles, roadside barriers (including curbs), objects on or off the roadway, pedestrians, cyclists, or animals. The Crash category also encompasses non-premeditated departures of the roadway where at least one tire leaves the paved or intended travel surface of the road.
Near-crash	Any circumstance that requires a rapid evasive maneuver by the subject vehicle or any other conflict partner (e.g., vehicle, pedestrian, cyclist) to avoid a crash and where a Crash (as defined above) is successfully avoided. Near-crashes must meet four criteria: 1. Not a crash. The event does not meet the “Crash” definition above. 2. Not pre-meditated. The maneuver causing the conflict must not be planned, unless an unexpected conflict occurs as a result (e.g., an aggressive lane change results in conflict with an unseen vehicle).

Event Outcome	Summary of Outcome Definition
	3. Evasion required. An evasive maneuver to avoid a crash was required by at least one conflict partner. An evasive maneuver may be steering, braking, accelerating, or a combination to avoid a potential crash. 4. Rapidity required. The evasive maneuver must require rapidity. Near-crashes often have an available response time (from the beginning of the reaction to the potential impact) of 2 seconds or less, though this is not an absolute threshold.

SEVERITY RATING WITHIN OUTCOME CATEGORIES

As seen in Table 1, the kinematic properties of crashes render them relatively easy to identify and define; either two conflict partners (a vehicle plus another vehicle, pedestrian, animal or object) collide or a road departure occurs. Similarly, degrees of severity within the crash outcome category can also be classified relatively simply and objectively using actual outcome metrics such as the level/extent of injuries, the value of property damage, and the magnitude of impact forces. VTTI (2015) has developed and exercised extensively such a crash severity rating scale that places crashes into one of four severity levels. These levels have allowed many researchers to identify and narrow down the types of crashes that best fit their research needs. Those crash severity levels and the objective criteria that are used to classify them are summarized in Table 2.

Table 2. Summary of severity levels for crash event outcome.

Crash Severity Level	Summary of Crash Severity Level Definition
1 - Most Severe	Any crash that includes at least one of the following: an airbag deployment, any injury to person, a vehicle rollover, a high Delta V, or that requires vehicle towing. Injury, if present, should be sufficient to require a doctor's visit, including those self-reported and those apparent from video. A high Delta V is defined as a change in speed of a conflict partner in any direction during impact greater than 20 mph (excluding curb strikes) or acceleration on any axis greater than ±2 g (excluding curb strikes).
2 - Police-reportable Crash	A police-reportable crash that does not meet the requirements for a Level 1 crash. Includes sufficient property damage to be police reportable (minimum of ~$1,500 worth of damage, as estimated from video). Also includes crashes that reach an acceleration on any axis greater than ±1.3 g (excluding curb strikes), as well as most large animal strikes and sign strikes.
3 - Minor Crash	Most crashes not included above are Level 3 crashes. Includes physical contact with another object but with minimal or no damage. Includes most road departures (unless criteria for a more severe crash are met), small object and animal strikes, all curb and tire strikes that are potentially in conflict with oncoming traffic, and other curb/tire strikes with an increased risk element that was mitigated by the presence of the curb/struck object.
4 - Low-risk Tire Strike	These crashes involve a tire strike only with little/no risk element (e.g., clipping a curb during a tight turn). Distraction may or may not also be present.

THE NEAR-CRASH SEVERITY RATING CHALLENGE

Naturalistic crash data are a valuable part of addressing many research questions, and they are often considered to be much easier to work with than other event outcomes, such as near-crashes, because of the simple and objective defining criteria discussed above. However, crashes are also rare (a good thing in other contexts), and this results in analytical challenges and limited statistical power that are difficult to overcome.

Near-crashes are much more frequent, giving them great potential for increasing the scope and power of transportation safety research. Research has shown that near-crashes can serve as surrogates for crashes and be analyzed in conjunction with crashes to improve statistical precision and power. Guo et al. (2010) came to four main conclusions: (1) the causal mechanisms for crashes and near-crashes appear to be similar, (2) there is a strong frequency relationship between crashes and near-crashes, (3) any bias introduced by including near-crashes will be consistent (and can therefore be controlled), and (4) using near-crashes as surrogates can significantly improve the precision of the estimation.

Including near-crash event outcomes in many research analyses presents a new set of challenges. Most notable is that near-crashes have a broad range of severities, and those severity levels are much more complicated to define objectively. By definition, there is no impact to be measured and therefore no injury or property damage to be assessed. Second, evasive maneuvers can occur with varying degrees of severity, and the magnitude of the evasive maneuver performed does not always align with (i.e., is often greater than) what is required to avoid a collision. Third, a near-crash can cover a wide range of scenarios, and the subjective perception of severity for such scenarios can vary greatly depending on the individual(s) experiencing or perceiving them. Finally, from a research perspective, near-crashes present a statistical challenge because of this variability. More severe near-crashes may be considered most similar to crashes and may serve as better surrogates than less severe near-crashes for some research questions. However, less severe near-crashes are still very different from normal (e.g., baseline) driving and are relevant to policy, technology, and infrastructure development research.

As crash and near-crash severity perception and the range of near-crash experiences differ, the same severity rating scale cannot be used for both crashes and near-crashes, and near-crashes are inherently more complicated to objectively rate. Because near-crashes are of great potential value to transportation research, the ability to scale them in a system comparable to crashes would enhance their utility. A near-crash severity rating scale would allow researchers to select and focus on events of a certain level of severity and provide a critical dependent variable in a wide range of analyses.

PROJECT OBJECTIVES

The project objective was to develop and validate an observer-based system for rating the severity of naturalistic near-crash events. This included developing a rating protocol that:

- can be applied in a consistent and meaningful manner;
- can be incorporated effectively and efficiently into the standard primary event assessment;

- can be applied by trained data reductionists with access to video and basic kinematic data charts;
- can be coded without complex models, calculations, or statistical modeling; and
- mirrors the existing crash severity scale in implementation and conceptualization.

This severity rating system will add value and power to the more readily available near-crash datasets, enhance researcher ability to target efforts by tailoring their near-crash data inputs, and provide better predictive ability for conflict cause, prevention, and countermeasure models.

PROJECT OUTPUTS: RESOURCES FOR NEAR-CRASH SEVERITY RATING

This report presents the process of developing and testing iterations of the observer-based, naturalistic near-crash severity rating protocol. Final definitions, visual aids, and references are listed below and included as Appendices A, B, and C. Together, these three elements constitute the final rating protocol.

- Appendix A: Full Definitions for Observer-Based, Naturalistic Near-Crash Severity:
  A full description of the final Near-Crash Severity variable and full definitions for each of the four severity levels.

- Appendix B: Near-Crash Severity: Quick Reference Criteria Matrix:
  A quick reference matrix of the final Near-Crash Severity level definitions for faster classification. The matrix assumes familiarity with the full definitions in Appendix A.

- Appendix C: Near-Crash Severity: Quick Reference Sheet:
  A two-page quick reference cheat sheet for applying the Near-Crash Severity variable and its four severity levels to naturalistic data. The Quick Reference Sheet includes the Criteria Matrix from Appendix B, as well as diagrams, tables, and text to help users estimate distance between conflict partners, conflict partner speeds, and times to collision (TTCs); assign relative conflict partner vulnerability using mass categories; and convert between common speed units.

CHAPTER 2. LITERATURE REVIEW

This section presents a review of existing literature pertaining to approaches to, metrics and methods for, and value added by rating the severity of naturalistic driving near-crash events.

Traffic safety research often uses crash data to identify and analyze risks to drivers on the road. Crash data can be a high-quality resource to measure driving safety, but they have limitations when it comes to availability. If our work is successful and road safety continues to improve, crash numbers will decrease and leave researchers with less crash data to analyze (Saunier & Laureshyn, 2021). Data collection can require a considerable amount of time to reach a substantial number of crashes (and that time requirement will increase as crash rates go down), which may present challenges not only with funding and resources to conduct such research but also with technology, infrastructure, and other conditions remaining constant or comparable for case comparisons over a long time span (Saunier & Laureshyn, 2021).

The necessity for other means to measure driving safety has led many to use surrogate events during analysis. The use of surrogates for crash events is "based on the premise that surrogate events happen more frequently than crashes and that better risk assessment can be achieved with an increased number of observations" (Guo et al., 2010, p. 4). According to the International Organization for Standardization (ISO, 2018), there are two classifications of non-crash trajectory conflicts that may be considered as surrogates for crash events: near-crash events and crash-relevant events. Near-crashes are conflicts "where a crash was avoided because the required urgent evasive maneuver(s) were performed successfully by at least one conflict partner" (ISO, 2018, section 5.1.1.4). Crash-relevant events are circumstances that require "an evasive maneuver on the part of the subject vehicle or any other conflict partner that is not urgent…but is still greater in magnitude than a 'normal maneuver' to avoid a crash" (ISO, 2018, section 5.1.1.5). The urgency of near-crash events is more similar to crash scenarios than crash-relevant events, and therefore near-crashes are better surrogate candidates for crash events.

The ISO standard (ISO, 2018) for classifying different event outcomes into crash, near-crash, etc., relies on kinematic criteria and can be defined conceptually by comparing the conflict partners' maximum possible deceleration, the deceleration actually required to avoid a crash, and how that ratio changes over time as the conflict partners approach each other (Figure 1). The required deceleration increases as proximity decreases (assuming a constant relative speed) and eventually approaches the maximum possible deceleration. Once that threshold is crossed, a crash becomes unavoidable. In this way, not only is a continuum of outcome urgency defined, but a visualization of increasing severity within a given outcome is also understood. This finer scale of severity levels within outcome categories requires additional input.

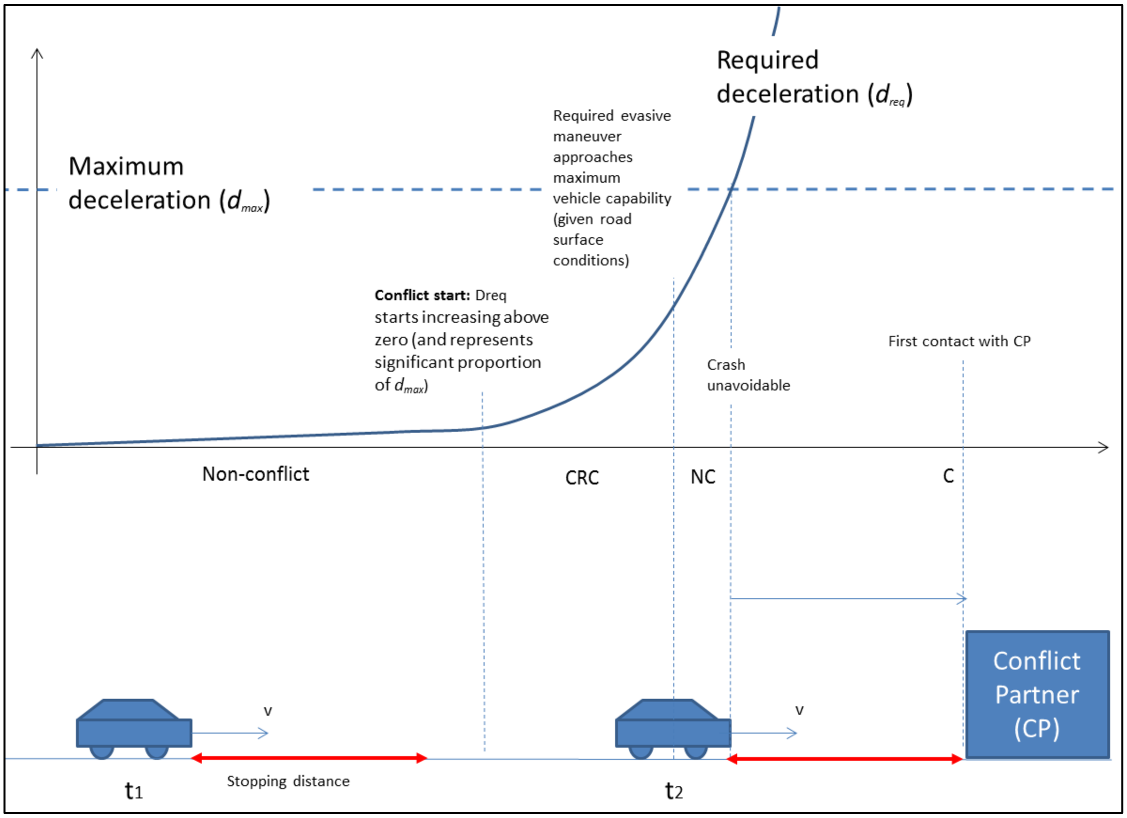

Figure 1. Diagram. Conceptualization of a trajectory conflict in terms of the minimum deceleration required to avoid a crash (d_{req}) relative to the maximum possible deceleration (d_{max}) (as appears in ISO, 2018).

As noted earlier, crash events have a defined scale of severity levels to provide more detail about how injurious, damaging, or risky the crash event was (ISO, 2018). Each severity level includes guidelines and instructions on how to classify each crash event. A variety of factors are considered, including personal injury, degree of damage to property, impact-related change in velocity, and type of conflict partner. By contrast, near-crashes are classified under a broad "near-crash" definition without any standardized categorization into how severe or risky (i.e., how "near a miss") the event was.

Near-crashes have been categorized in a multitude of ways using different variables. Hydén (1987) presented the concept of "serious conflicts," which consisted of two event types: accidents and near-accidents. By Hydén's definition, a serious conflict "occurs when the Time to Accident (TA) is equal to, or less, than 1.5 seconds" (section 3.5.3, page 44). TA is "the time that remains to an accident in the moment when evasive action has just been started," assuming that the road-user speed(s) and direction(s) continue unchanged (or without evasion) (section 3.5.1, page 41). TA is concept similar to TTC, which is a common variable that has appeared in surrogate safety research through 2015 (Laureshyn et al., 2016) and was first described as the time that remained before two vehicles would collide if they stayed on their current path at their current speed (Hayward, 1971).

TTC is often used at the time an evasive action is initiated when analyzing traffic conflicts. Brown (1994) used TTC in conjunction with observer subjective assessments to create a score for probability of collision. The observer would assess the risk of collision using proximity, speed, and other factors, and they would rate it on a subjective 3-point scale. TTC would be calculated based on the speed and trajectory of conflict partners and assigned a score on a separate 3-point scale. The scores were then combined into a 5-point Likert-type scale. This allowed for subjective assessments to modulate mathematical assessments and vice versa. The midpoint on the final scale was a “moderate” probability of collision, which corresponded with a TTC of 1.5 seconds or less and was presented as the definition of a critical conflict event. Importantly, this research found that inexperienced but well-trained observers can give insights into the event that were not obvious through only viewing objective measures (i.e., TTC and evasive action). Including risk of collision in the conflict definition helped offset bias associated with only using quantitative definitions for traffic conflicts.

K-clustering is another method that researchers have used to identify and categorize near-crash events. For instance, Wang et al. (2015) used peak deceleration, average deceleration from trigger point to peak deceleration point, and percentage reduction in vehicle kinetic energy as the features to cluster events into low, moderate, and high-risk categories. They found that four variables had the largest influence on driving risk level: velocity when braking, triggering factor, potential object type, and potential crash type. Naji et al. (2018) used a similar analysis method but instead used time headway, deceleration, and braking pressure to cluster near-crashes into low, moderate, and high severity categories. They found several factors to be significant to near-crashes, including near-crash type and cause, average deceleration, and vehicle kinetic energy.

Seriousness of near-crash events can be examined by exploring assessment options other than measures of time or space proximity (Zheng et al., 2014). Laureshyn et al. (2017) studied the use of “Extended Delta-V as a measure of traffic conflict severity that considers both proximity to a crash and the severity of potential consequences” (p. 55). Extended Delta-V can be used to assess potential outcomes of a conflict and to estimate the significance of injuries that would occur if the conflict progressed to a crash. It calculates the change in velocity vector a conflict partner experiences during a potential crash by using speeds at the minimum TTC, approach angle, mass of the involved road users, assumed deceleration rate, and time remaining for an evasive maneuver. The inclusion of conflict partner mass in its calculation helps Extended Delta-V acknowledge the seriousness of a potential crash for a vulnerable road user (VRU), which is an important factor that has been more often identified by subjective judgment.

Each of these methods has limitations. Wang et al. (2015) only analyzed braking variables, and Naji et al. (2018) did not include events that had steering as an evasive maneuver. Both studies focused on the subject vehicle and its actions when assigning a conflict severity but did not consider the other conflict partner in that judgment. Both also used naturalistic data and reviewed video recorded from the subject driver but ran analysis on the kinematic data and only used the video to first verify if the conflict was a true near-crash. By evaluating only objective measures, these studies excluded key factors that could change their assessment of the conflict severity. For example, “two conflicts with identical TTC, one involving a pedestrian and a truck and the second involving a pedestrian and a bike, should have different severities” (Zheng et al., 2014, section 5.4, page 639).

The Extended Delta-V method proposed by Laureshyn et al. (2017) used overhead video footage recorded at an intersection to objectively determine vehicle type and maneuver types and to calculate TTC, relative speed, approach angle, etc. However, the method did not use video to make any subjective considerations as to the conflict severity. Braking force was assumed to be 4 m/s^2 (−0.41 g) for "normal braking" and 8 m/s^2 (−0.82 g) for "emergency braking." Deceleration could be recorded for a future study in an instrumented vehicle, but braking force or other evasive maneuvers needed to be assumed for non-instrumented conflict partners. Therefore, the result is not a true Extended Delta-V value, but an estimated one. Other limitations the authors listed were that they had assumed an inelastic collision (precluding any secondary collisions), and factors such as driver age, vehicle safety systems, and the location/direction of collision were not accounted for, which can produce inaccurate estimates of injury and damage outcomes. Finally, the nature of evasive maneuvers is different for vehicles and VRUs, and the type of evasive maneuver performed was not evaluated.

In summary, most near-crash classification research has focused on objective data to determine a near-crash event severity. Advances in technology have made data collection more diverse and prolific, which can lead to reliance on automated and rigid algorithmic classification methods. However, relying on automated classification methods has limitations and does not always provide a full understanding of the conflict and all the contextual factors to be considered (Laureshyn et al., 2016). Subjective measurements will often have their reliability questioned, but the subjective component of data analysis still plays a key role in conflict research. Observation of severe conflict data (often in video format), when carefully constructed, usually results in a better understanding of a conflict and the unpredictable situations that can arise (Laureshyn et al., 2016) and can produce reliable results (Hydén, 1987).

The increased use of near-crashes as surrogate events is a good reason to develop more methods to compare and combine them with crash events; creating a severity scale for near-crash events will make it easier to identify similar types of crashes and near-crashes for analysis. The analysis method developed for this project and presented in this report suggests using a combination of objective measures and human observation to group near-crash events into standardized categories that are comparable to the crash categories already in use. Both objective and subjective criteria are used to factor in TTC; proximity, velocity, and direction of travel for all conflict partners; and relative vulnerability of conflict partners during the incident. Trained observers referenced collected kinematic data when viewing video data of near-crash cases to classify the event into a severity category.

CHAPTER 3. FOUNDATIONAL INPUTS AND METHODS

This section outlines the underlying conceptualization of near-crash severity that initially launched this protocol development project, the first effort to identify informative and suitable metrics for this observer-based near-crash rating scale, and the near-crash severity rating protocol's first iteration (Iteration 0).

DATA SOURCE – SHRP 2 NDS

To develop and test this near-crash severity rating protocol, this project sampled near-crash events from the existing SHRP 2 NDS (Dingus et al., 2015). The SHRP 2 NDS included an extensive naturalistic data collection effort from 2010 to 2013 with over 3,100 participants (ages 16–98) whose personal vehicles were instrumented with a data acquisition system that included cameras, accelerometers, GPS, forward radar, and vehicle network connections. In all, the SHRP 2 NDS collected more than 35 million miles of continuous naturalistic driving data spread across six sites in the U.S. Data collection sites were operated in Tampa, Florida; Bloomington, Indiana; Durham, North Carolina; Buffalo, New York; State College, Pennsylvania; and Seattle Washington. The SHRP 2 NDS data include fully annotated cases for over 1,500 crashes and nearly 7,000 near-crashes, and these data have been used in many important research endeavors, including on secondary task engagement, driver impairment, crash risk across different environmental factors, maneuver-based analyses (e.g., lane changes), and more.

To leverage the SHRP 2 NDS data for this near-crash severity protocol development project, we obtained approval from Virginia Tech's Institutional Research Board (VT IRB #17-110) and an executed VTTI Data Use License to govern the use and protection of the SHRP 2 NDS participant data. All data access took place from a secure data enclave at VTTI.

DATA REDUCTION AND PROTOCOL TESTING METHODS

For each iteration of protocol testing, a set of three experienced raters from VTTI's data reduction lab were provided with a set of randomly selected near-crash events of varying conflict types and asked to rate each event. That is, each event selected for that iteration received three severity level ratings, one from each data reductionist. Events were ordered differently and randomly for each rater. Raters worked independently, without access to each other's ratings or notes, and without discussing the cases with each other or the project leader until a debriefing meeting after each iteration. Of note, while three raters were employed in each iteration of testing the rating protocol, the intent is not to require three raters when applying the protocol to rate new events in the general course of data reduction. Rather, a process for training reductionists, proceeding with ratings, and performing necessary quality control is described with other application considerations included in Chapter 6.

Data reductionists performed each iteration of testing in VTTI's data reduction lab, where they were granted access to view the selected cases, including all collected videos (forward roadway, driver's face, dashboard/driver's hands, and rear roadway) and any kinematic data charts they deemed useful. The kinematic data used by data reductionists generally include subject vehicle speed, subject vehicle longitudinal and lateral acceleration, forward radar variables such as object range and relative speed, GPS location (along with associated satellite and street views), and certain vehicle network variables (e.g., turn signal, brake application) when available.

The selected events to be rated in each iteration were loosely stratified across different conflict types to ensure observation of a variety of urgency factors. The near-crash conflict types included rear-end striking or struck conflicts, intersection-related conflicts, sideswipe conflicts, opposite direction conflicts, road departures, backing-related (vehicle backing up) conflicts, VRU-related conflicts, and animal-related conflicts. Only near-crash cases with a single conflict component were included. That is, if one conflict led directly to another, creating a multi-conflict scenario, it was excluded. In addition to being stratified across conflict types, events to be rated in each iteration were also independently stratified across the range of key kinematic characteristics present during the conflict time window; this stratification took into account subject vehicle peak longitudinal and lateral acceleration values and forward radar-based peak TTC, when available. Based on a combination of the peak values, each event was assigned to one of three kinematic categories, and events of each conflict type were selected across these three kinematic categories. This selection process ensured that the rated events in each round would include both a variety of conflict types and a range of maneuver magnitudes.

DEFINING URGENCY IN RELATION TO NEAR-CRASHES

As noted in earlier sections of this report, there is a common theme of urgency metrics throughout the transportation research community related to SCEs, and especially related to near-crashes. As urgency increases, so does risk and the required response. For non-crash conflicts, in particular, where it is known that evasive maneuver(s) successfully avoided a collision, a more focused examination of the urgency–response relationship can be visualized.

Figure 2 displays two possible conceptualizations of the relationship between conflict urgency and the magnitude of the driver's evasive response for determining near-crash severity. These concepts provided inspiration during the development of the near-crash severity rating protocol, especially in framing the subjective assessment of the driver response's effect on the severity of a non-crash outcome. The difference between the two conceptualizations is that the chart on the right is more concerned with the difference between the evasive maneuver that was actually performed in relation to the evasive maneuver that was needed or judged as sufficient by the analyst. The evasive maneuver performed may be (and often is) an over- or under-reaction and could then itself then contribute to conflict urgency. Example scenarios for each level are provided below the figure to aid in conceptualizing the relationship.

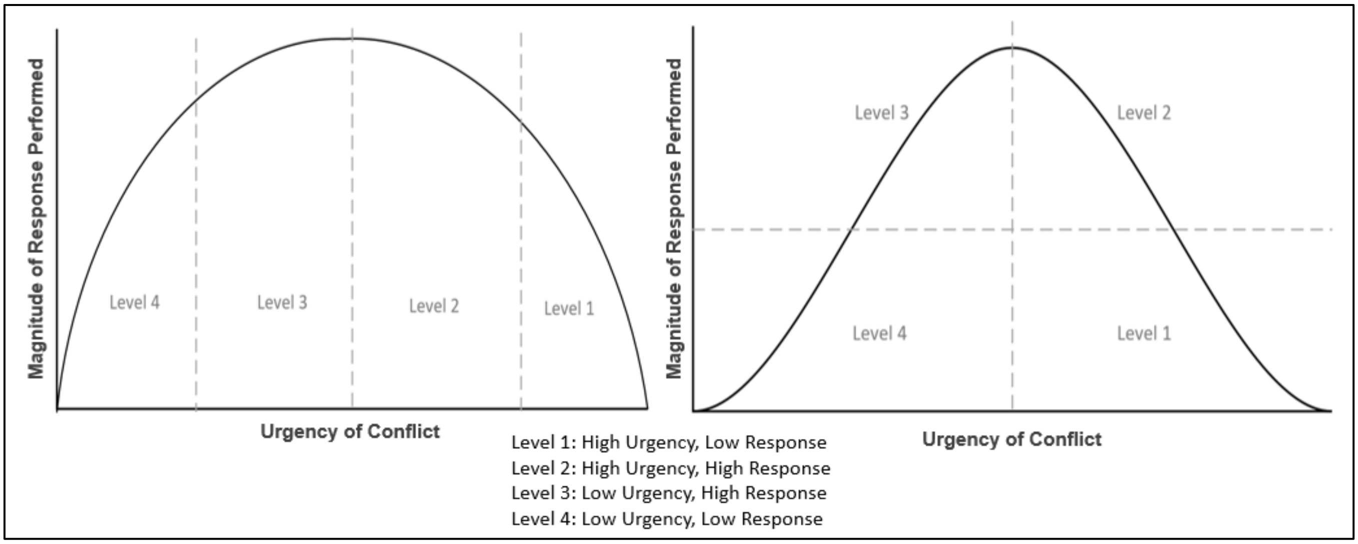

Figure 2. Diagram. Two conceptualizations of the relationship between conflict urgency and the magnitude of the evasive response performed in relation to near-crash severity.

- Level 1, High Urgency, Low Response: For example, a left-turn-across-path scenario with a very imminent crash, high approach speed, and close proximity where the braking/steering response was just sufficient to avoid a crash (left diagram). In some cases, the performed braking/steering response could/should have been stronger (or initiated earlier) and likely contributed to the urgency (right diagram).
- Level 2, High Urgency, High Response: For example, a lead vehicle deceleration with an imminent crash and close proximity where the braking response was sufficient to avoid a crash (left diagram) or perhaps significantly more than what was required to avoid a crash thereby deescalating the severity (right diagram).
- Level 3, Low Urgency, High Response: For example, a lower speed lead vehicle deceleration scenario where a high magnitude braking response was needed and performed sufficiently to avoid a crash.
- Level 4, Low Urgency, Low Response: For example, an animal is in the road creating a low-urgency scenario (e.g., low vehicle speed or plenty of time/distance to respond) and a low magnitude braking/steering response sufficient to avoid a crash is performed.

In developing the near-crash severity rating protocol, the first challenge was to define urgency, keeping objectivity, subjective influence, ease/efficiency of coding, and consistency in mind. There was no clear answer about how urgency should be observed or measured, what metrics should compose the required concept of urgency, or how different metrics should be weighted; the goal was to achieve a balance between actual kinematics, predictive outcomes, and perceived subjective risks. This balance was necessary for the final rating categories to be both repeatable and internally consistent across the range of events that exist in NDS data. A pre-development rating iteration was needed to identify and produce a list of factors that both effectively reflected urgency and enabled data reduction lab staff to consistently produce the severity rating values.

With the above conceptual image in mind, it was decided that the near-crash severity rating scale would be a 4-point rating scale, with Level 1 being the most severe and Level 4 the least severe.

While this approximately mirrors the four-level structure of the crash severity rating scale already in use by VTTI, direct comparisons between crash and near-crash severity levels were not a goal and are not advisable. For instance, a Level 1 near-crash cannot be interpreted as equivalent to a Level 1 crash because the outcome metrics that produced the crash (e.g., impact force, injury, damage) are both nonexistent (in actuality) and unavoidably ambiguous (in terms of potential) for the near-crash.

For this initial information gathering stage, also referred to as "Iteration 0" of the near-crash severity rating scale test, 76 near-crashes were selected as described above. Each rater was asked to review each case and provide their "gut rating" of severity for each near-crash on the following scale, with the category labels and parenthetical phrases shown below as the only definition guidance provided:

- Level 1 − Critical Severity (very near miss or very high risk)
- Level 2 − High Severity (close near miss or high risk)
- Level 3 − Moderate Severity (near miss or elevated risk)
- Level 4 − Low Severity (still a near-crash but low risk)

Raters were instructed to interpret the above category labels and phrases in a way they thought most appropriate. The main objective of this exercise was to observe what metrics and conceptual tools they would use, how they would coalesce those observations in order to assign severity levels, and what additional guidance they felt they needed.

The "near miss" verbiage in the categories provided was intended to capture the concept of collision imminence, which is related to the amount of time or space available or remaining to avoid a crash. For example, a "very near miss" would provide very little time for the driver to react and/or the conflict partners would reach very close proximity. The "risk" verbiage was intended to capture the concept of potential collision severity, which is related to the potential damage or injury that could have resulted had a crash not been avoided (this can only be subjectively predicted). For example, a "very high risk" scenario may be one with very high approach speeds and/or a large mass differential (e.g., a vehicle and pedestrian).

During this initial "gut rating" exercise, the data reductionists were also asked to provide a brief descriptive narrative (e.g., one to three sentences) of their reasoning for each event to explain why they assigned the severity category that they did. Finally, a debrief meeting was held to provide an in-person forum for data reductionists and the project leader to exchange any other thoughts and insights that came from this first iteration. Thus, in this first iteration with the minimal guidance described above, each data reductionist was asked to independently rate and provide explanations for the same 76 events.

ITERATION 0 RESULTS

The results of this "gut reaction" exercise were compiled in several ways. The assigned ratings were compared across raters to get an initial measure of consistency and identify types of cases that tended to be least consistent across raters. The descriptive narratives were used to understand how different raters might approach assessing the same event and how those different approaches might lead to different or similar ratings. Finally, the ratings and narratives combined were used to identify specific factors or metrics raters used in different types of events, and this information ultimately served as the foundation for defining the necessary urgency metrics and developing the first draft of a more instructive set of severity definitions and accompanying assessment aids.

Table 3 provides a consistency matrix that shows how well the “gut rating” iteration produced consistent ratings across raters. Among the three raters and 76 events, all three raters produced the same severity level (range = 0, agree = 3) for 22% of the near-crash events. At least two of the raters agreed (agree = 3 or 2) for 75% of the near-crash events. For 66% of the near-crash events, the distance between the highest and lowest assigned severity level was one level or less (range = 0 or 1). These agreement metrics (bolded in Table 3) are the baseline to which later iterations were compared; Table 3 will appear throughout this report with additional iterations added to the right.

Table 3. Summary of rater agreement on near-crash severity ratings across 76 near-crashes using a minimal guidance approach.

<table>
<tr><td></td><td>Iteration</td><td colspan="3">0 (Gut Reaction)</td></tr>
<tr><td></td><td># Events</td><td colspan="3">76</td></tr>
<tr><td></td><td># Raters</td><td colspan="3">3</td></tr>
<tr><td></td><td></td><td>#</td><td>%</td><td>%</td></tr>
<tr><td rowspan="4">Range between highest & lowest ratings</td><td>Range 0[a]</td><td>17</td><td>22%</td><td rowspan="2">66%[b]</td></tr>
<tr><td>Range 1</td><td>33</td><td>43%</td></tr>
<tr><td>Range 2</td><td>18</td><td>24%</td><td></td></tr>
<tr><td>Range 3</td><td>8</td><td>11%</td><td></td></tr>
<tr><td rowspan="3"># of raters assigning the same rating</td><td>Agree 3[a]</td><td>17</td><td>22%</td><td rowspan="2">75%[b]</td></tr>
<tr><td>Agree 2</td><td>40</td><td>53%</td></tr>
<tr><td>Agree 1</td><td>19</td><td>25%</td><td></td></tr>
</table>

[a]Rows for “Range 0” (all ratings are the same) and “Agree 3” (all raters agree) represent perfect agreement.
[b]No more than one level of separation between raters (Range 0 + Range 1) or two raters agreeing (Agree 3 + Agree 2) was considered a good target.

Selected example excerpts from the ratings results and descriptive narratives are listed in Table 4. In all cases listed, the range between highest and lowest ratings was two or more levels, and it is clear that different raters used different reasoning in this minimal guidance approach.

Table 4. Selected ratings and narratives from the minimal guidance approach where the range between highest and lowest ratings was two or more levels.

Event	Incident Type	Rater #	Initial Rating	Rater Descriptive Narrative
151568418	Animal	1	4	The SV [subject vehicle] brakes and slows down to allow a deer to cross the road. Despite it being nighttime, the subject driver sees the deer with plenty of time to react and avoids incident with the correct course of action.
		2	2	Medium sized animal and very near miss
		3	2	Conflict with deer, 50 mph. Deer about a car length away at closest. High damage to vehicle possible, deer would hit on the lower part of the vehicle.
151084862	Pedestrian	1	3	The SV is forced to swerve to miss some crossing pedestrians. The driver was paying attention and had time to prepare and there was no oncoming traffic to worry about while swerving. It is raining during the event and the roadway is wet. It doesn't affect the action, but it could have ended worse if they had slid.
		2	1	Weather and extremity of maneuver needed to avoid the pedestrian, and very high risk to the pedestrian.
		3	1	SV swerves around a pedestrian walking into the middle of the road in the rain. SV doesn't slow initially, likely assuming pedestrian would wait to cross.
151606600	Vehicle backing	1	3	The SV swerves hard to avoid a vehicle that has backed out into the roadway. I rank this one a very high 3. The SV is traveling at a high speed and does jerk hard, but he does maintain control and doesn't have to make a drastic move to avoid the other vehicle. This is close to a 2 though.
		2	1	Seems high risk because of the high speed of SV, and the lateness of the avoidance maneuver due to the impairment of the driver.
		3	1	SV is going 75 mph in a residential area. V2 [second vehicle] is backing into the road and across the double yellow. <1 sec between reaction and impact, SV has to swerve in the rain. Mainly making this a [1] because of the speed.
151575013	Opposite direction	1	3	The SV is forced to brake when they meet another vehicle on a roadway where there is not enough room for them to pass each other. The trees make it difficult to see and the roadway is narrow but the speed the SV is traveling is slower and the two vehicles have enough time to react and correct the situation.
		2	1	Rapid maneuver needed due to lack of visibility. Even though it's a low-speed area, the fact the direction is opposite increases the risk.
		3	3	Head-on, 15 mph for both vehicles. Unsure if this should be low 2 or high 3. Leaning towards 3 for the lower speed. Both vehicles had to react.
183520547	Opposite direction	1	4	The SV swerves slightly when another vehicle slightly crosses over into the SV's lane. The speed of the vehicles isn't too fast or too slow and the SV reacts correctly.

Event	Incident Type	Rater #	Initial Rating	Rater Descriptive Narrative
		2	1	A little bit difficult to code, it seems like a dangerous/high risk situation because of the fast reaction needed and severity of the crash avoided, but the driver seems less concerned and only has to make a small avoidance maneuver.
		3	2	V2 comes over a hill and is somewhat towards the middle of the road. <1 sec from reaction to impact, >40 mph, partial head-on threat.
142029712	Opposite direction	1	3	The SV pulls to the right while rounding a curve to avoid an oncoming vehicle that crosses the lane line. The subject driver reacts quickly that results in the vehicle jerking hard to the right, but the speed is low, and an accident is avoided.
		2	3	A severe crash is avoided with little time to react.
		3	4	About a second from reaction to collision. 30 mph, significant damage if hit occurs. Steering required; I don't think just braking would cut it.
151859374	Rear-end, striking	1	4	The SV attempts to change lanes but is forced to pull back to the right quickly when another vehicle changes lanes. The subject driver reacts quickly and has plenty of room to maneuver around the other vehicle to avoid any kind of impact.
		2	2	Higher risk due to speed difference between vehicles, low time to react.
		3	3	SV 45 mph, and V2 ~20 mph, both cutting over solid white lines into a lane. SV swerves away, never closer than about 80% of a lane.
183520574	Rear-end, striking	1	4	The SV has to change lanes to avoid contact with another vehicle that changes lanes in front of them. The subject driver had plenty of time to react and avoided an accident. The roadway was wet from rain but had no impact on the situation.
		2	2	High risk due to speed difference with vehicle that is cutting off the SV.
		3	3	Wet conditions. V2 cuts across a painted gore to get into SV's lane. SV initially at 57 mph, relative speed between the two lower. SV only slow to 50, but that's because their plan is to get over. More severe reactions were available.
61426981	Intersection	1	4	The SV is forced to brake and come to a stop in the middle of an intersection to allow a vehicle to complete a turn from the opposite direction. The other vehicle should've yielded but the subject driver reacted correctly to avoid an accident. The roadway is wet from the rain, but it doesn't have an impact on the situation and there is no rear traffic present to be affected.
		2	1	Very rapid maneuver needed, and weather increases the risk.
		3	3	V2 turns left across SV's path, SV with the green light. More than a second to impact, but in rainy/wet conditions. If SV didn't react contact with SV side would have occurred.

Event	Incident Type	Rater #	Initial Rating	Rater Descriptive Narrative
151606606	Intersection	1	4	The SV stops at a stop sign but brakes hard before pulling out due to a fast-moving vehicle. I think it was a slight overreaction by the subject driver but it's better to be safe.
		2	2	V2 travelling at a fast speed, and very fast reaction needed from SV.
		3	3	SV turning wide, but also slow. Brakes quickly and facial reaction makes closeness of event seem higher.

After reviewing the first set of events and the rating results (including severity levels assigned, rating narratives, and debrief meeting discussion), a variety of metrics the data reductionist used to classify urgency were identified. The metrics determined to be both useful in assigning meaningful and consistent ratings (once some guidance is developed) and feasible for data reductionist application are listed below:

- Conflict partner relative mass (e.g., animal size, object size, vehicle size)
- Absolute and relative vehicle speeds
- Minimum distance between conflict partners
- TTC (e.g., relative speed and distance combined)
- Perception of observed evasive maneuver appropriateness
- Driver attention or impairment
- Availability of evasive maneuver space (e.g., no traffic in adjacent lane)
- Lighting/weather/other extenuating environmental conditions
- Likely angle of collision

All these results supported the development of the project's first formal near-crash severity rating protocol (Iteration 1) as described in the next chapter.

CHAPTER 4. PRIMARY PROTOCOL DEVELOPMENT

In synthesizing information from the literature review, the initial information-gathering phase (e.g., the "gut reaction" test), and general transportation safety knowledge, several main themes emerged as essential to assessing urgency and severity as they pertain to near-crash events in naturalistic data.

- While near-crash severity levels will not be directly comparable to crash severity levels, a near-crash severity rating protocol should be based on an estimation of collision imminence and potential collision severity in terms of potential impact forces, injury, and damage.
- Six characteristics of near-crash conflicts and the conflict partners involved must be considered in estimating collision imminence and potential collision severity, although it is possible, for combined metrics such as TTC to encompass multiple components:
    - speed,
    - distance,
    - timing,
    - direction,
    - vulnerability (e.g., mass differential), and
    - likely position of impact.
- The physical and combined dynamic properties of all conflict partners during the conflict time window should be part of assessing near-crash severity.
- The critical conflict time window for assessing near-crash severity begins just prior to the start of the first evasive action performed by any conflict partner (e.g., just prior to the first braking or steering action, just before a pedestrian stops or changes direction) and ends just after the conflict reaches its most critical point (e.g., the peak of the conflict, often the time of minimum TTC).
- While speed, location, acceleration, etc., can be measured for an instrumented subject vehicle, these metrics can and must also be estimated (e.g., from radar or video) for all other conflict partners.
- Once speed and distance are known or estimated for all conflict partners, TTC can also be estimated.
- Relative vulnerability of conflict partners depends on their mass differential (e.g., a commercial truck versus sedan versus pedestrian) and the presence of protective barriers (e.g., riding in an enclosed vehicle versus walking or bicycling).
- Driver state (e.g., distraction, impairment, age, experience/skill level) and passive environmental factors (e.g., weather, lighting), while important contributors to the likeliness of a crash or near-crash occurring, do not factor directly into near-crash severity except for their contribution to the actual timing and kinematic metrics described above. In other words, driver distraction or poor weather, while they may create more interesting data, contribute to near-crash severity assessment only because they ultimately affect the timing and effectiveness of evasive maneuvers (which then affects metrics such as TTC).

ITERATION 1 PROTOCOL

For the first true iteration (Iteration 1) of the near-crash severity rating protocol and testing, the above concepts were distilled into operational definitions for the four levels of severity using a two-requirement system with a special case for tire strikes. At their core, the definitions are based on objective metrics such as relative speed, time-to-collision, and type of conflict, but with room for subjective risk assessments.

1. For a given severity level, a near-crash has to satisfy a specific minimum relative velocity (approach speed) threshold between the conflict partners.
2. **PLUS** at least one additional criterion from a list of three must be present:
   a) A higher specific relative velocity (approach speed) threshold between the conflict partners,
   b) OR a drop to a specific minimum TTC or less,
   c) OR the near-crash meets the criteria for the next level lower severity AND a specific vulnerability is present due to conflict partner types or mass differential.
3. Near-crashes where impact with a curb, other low-risk tire strike, or small/light/non-fixed objects or small animals are imminent are always classified as Level 4 (Lower Severity) unless another high-risk outcome is likely (e.g., looming risk for pedestrian strike or vehicle rollover).

The full final version of these definitions appears in Appendix A. Although the version of definitions used in this first iteration was slightly shorter than what appears in Appendix A, the thresholds are the same.

In addition to the detailed definitions, several visual aids and calculation guides were needed. These aids would support data reductionists in consistently and quickly estimating vehicle speeds, distance, TTC, and mass differentials, and would facilitate unit conversions, as different data charts and vehicles report data in different ways. In addition, these aids needed to address the complexity of estimating the required metrics across the wide variety of conflict scenarios (e.g., those that occur within versus outside the forward radar field of view, those involving stationary versus moving conflict partners, those that would result in longitudinal versus lateral versus glancing impacts).

Six separate visual aids were developed for Iteration 1 to support data reductionist work, and they were incorporated into a Quick Reference Sheet, similar to that shown in Appendix C. Those components developed for Iteration 1 are listed below and pictured individually in Figure 3 through Figure 8.

1. Calculation guide and visual aid for determining relative velocity (Figure 3)
2. Guide for estimating other conflict partner speed and calculating TTC (Figure 4)
3. TTC lookup table and speed/distance conversion reference sheet (Figure 5)
4. Conflict partner mass and relative vulnerability considerations (Figure 6)
5. Quick guide to converting units of speed (Figure 7)
6. Guide to estimating distance from video (Figure 8)

These quick reference components remained the same for future iterations, though their layout on the Quick Reference Sheet (Appendix C) did shift, and an additional component (the Criteria Matrix, Appendix B) was added later for Iteration 2.

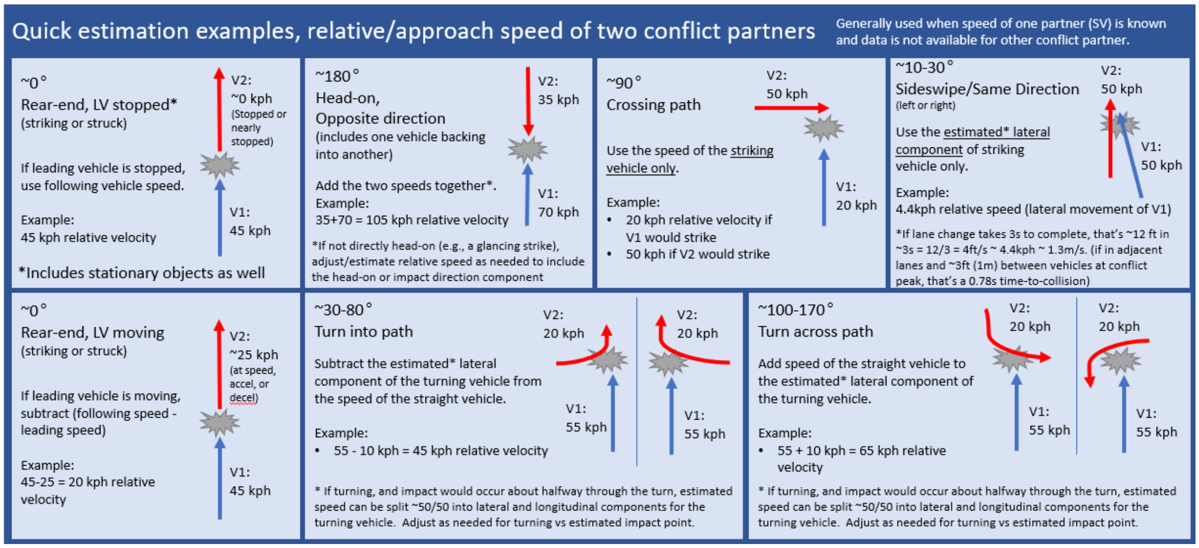

Figure 3. Illustration. Calculation guide and visual aid for determining relative velocity (approach speed) between conflict partners, given different types of conflicts. Included in Quick Reference Sheet (Appendix C).

To estimate V2 speed (without radar data), use available video plus:

- Speed limit of road
- Motion of V2 relative to V1 (slower/faster/similar)
- Visual cues (no motion, or motion relative to fixed objects)
- Logical, experience-based reasoning (e.g., approximate speed during turn or specific maneuver)

To estimate time-to-collision (TTC), estimate distance (in m or ft) and approach speed (in m/s or ft/s, respectively) at a given point in time:

TTC = distance/speed (Ex: 10m ÷ 15m/s = 0.67 seconds)

Figure 4. Illustration. Guide for estimating other conflict partner speed in the absence of radar data and calculating TTC once approach speed is known or estimated.

Time to Collision and Speed Conversion Cheat Sheet

Relative/Approach Speed				Distance		TTC
mph	kph	m/s	f/s	m	ft	sec
5	8	2	7.5	1	3.2	0.50
5	8	2	7.5	2	6.4	1.00
5	8	2	7.5	3	9.6	1.50
5	8	2	7.5	5	16	2.50
10	16	4	15	1	3.2	0.25
10	16	4	15	2	6.4	0.50
10	16	4	15	3	9.6	0.75
10	16	4	15	5	16	1.25
10	16	4	15	10	32	2.50
15	24	6	22.5	1	3.2	0.17
15	24	6	22.5	2	6.4	0.33
15	24	6	22.5	3	9.6	0.50
15	24	6	22.5	5	16	0.83
15	24	6	22.5	10	32	1.67
20	32	8	30	1	3.2	0.13
20	32	8	30	2	6.4	0.25
20	32	8	30	3	9.6	0.38
20	32	8	30	5	16	0.63
20	32	8	30	10	32	1.25
20	32	8	30	15	48	1.88
25	40	10	37.5	1	3.2	0.10
25	40	10	37.5	2	6.4	0.20
25	40	10	37.5	3	9.6	0.30
25	40	10	37.5	5	16	0.50
25	40	10	37.5	10	32	1.00
25	40	10	37.5	15	48	1.50
25	40	10	37.5	20	64	2.00
30	48	12	45	1	3.2	0.08
30	48	12	45	2	6.4	0.17
30	48	12	45	3	9.6	0.25
30	48	12	45	5	16	0.42
30	48	12	45	10	32	0.83
30	48	12	45	15	48	1.25
30	48	12	45	20	64	1.67

Relative/Approach Speed				Distance		TTC
mph	kph	m/s	f/s	m	ft	sec
35	56	14	52.5	1	3.2	0.07
35	56	14	52.5	2	6.4	0.14
35	56	14	52.5	3	9.6	0.21
35	56	14	52.5	5	16	0.36
35	56	14	52.5	10	32	0.71
35	56	14	52.5	15	48	1.07
35	56	14	52.5	20	64	1.43
35	56	14	52.5	25	80	1.79
40	64	16	60	1	3.2	0.06
40	64	16	60	2	6.4	0.13
40	64	16	60	3	9.6	0.19
40	64	16	60	5	16	0.31
40	64	16	60	10	32	0.63
40	64	16	60	15	48	0.94
40	64	16	60	20	64	1.25
40	64	16	60	25	80	1.56
45	72	18	67.5	1	3.2	0.06
45	72	18	67.5	2	6.4	0.11
45	72	18	67.5	3	9.6	0.17
45	72	18	67.5	5	16	0.28
45	72	18	67.5	10	32	0.56
45	72	18	67.5	15	48	0.83
45	72	18	67.5	20	64	1.11
45	72	18	67.5	25	80	1.39
45	72	18	67.5	30	80	1.67
50	80	20	75	1	3.2	0.05
50	80	20	75	2	6.4	0.10
50	80	20	75	3	9.6	0.15
50	80	20	75	5	16	0.25
50	80	20	75	10	32	0.50
50	80	20	75	15	48	0.75
50	80	20	75	20	64	1.00
50	80	20	75	25	80	1.25
50	80	20	75	30	96	1.50
50	80	20	75	35	112	1.75

Relative/Approach Speed				Distance		TTC
mph	kph	m/s	f/s	m	ft	sec
55	88	22	82.5	1	3.2	0.05
55	88	22	82.5	2	6.4	0.09
55	88	22	82.5	3	9.6	0.14
55	88	22	82.5	5	16	0.23
55	88	22	82.5	10	32	0.45
55	88	22	82.5	15	48	0.68
55	88	22	82.5	20	64	0.91
55	88	22	82.5	25	80	1.14
55	88	22	82.5	30	96	1.36
55	88	22	82.5	35	112	1.59
60	96	24	90	1	3.2	0.04
60	96	24	90	2	6.4	0.08
60	96	24	90	3	9.6	0.13
60	96	24	90	5	16	0.21
60	96	24	90	10	32	0.42
60	96	24	90	15	48	0.63
60	96	24	90	20	64	0.83
60	96	24	90	25	80	1.04
60	96	24	90	30	96	1.25
60	96	24	90	35	112	1.46
60	96	24	90	40	128	1.67
65	104	26	97.5	1	3.2	0.04
65	104	26	97.5	2	6.4	0.08
65	104	26	97.5	3	9.6	0.12
65	104	26	97.5	5	16	0.19
65	104	26	97.5	10	32	0.38
65	104	26	97.5	15	48	0.58
65	104	26	97.5	20	64	0.77
65	104	26	97.5	25	80	0.96
65	104	26	97.5	30	96	1.15
65	104	26	97.5	35	112	1.35
65	104	26	97.5	40	128	1.54

Figure 5. Illustration. TTC lookup table and speed/distance conversion reference sheet.

Categories for conflict partner mass / relative vulnerability

Category 1 (vulnerable):	Category 2 (light):	Category 3 (heavy):
Pedestrian	Light vehicles	Bus, RV, Box truck
Bicycle	(Car, Van, SUV, Pickup)	Tractor trailer
Motorcycle	(no large trailers)	Construction vehicle
Or similar…	Or similar…	Light vehicle w/ large trailer
		Or similar…

If conflict partners are in two different categories, near-crash severity rating may be elevated one level (if 1v2 or 2v3) or one to two levels (if 1v3).

Figure 6. Illustration. Categories for conflict partner mass and relative vulnerability, to be used in elevating near-crash severity level as appropriate.

Quick Conversions:
1 mph = 1.6 kph
1 mph = 0.4 m/s
1 mph = 1.5 f/s

1 kph = 0.6 mph
1 kph = 0.3 m/s
1 kph = 0.9 kph

1 m/s = 2.2 mph
1 m/s = 3.6 kph
1 m/s = 3.3 f/s

1 f/s = 0.7 mph
1 f/s = 1.1 kph
1 f/s = 0.3 m/s

Figure 7. Illustration. Quick guide to converting units of speed.

Distance Estimate Visualization*

1m ~ width of sidewalk, doorway, or 1 long stride
2m ~ half a standard lane width, height of doorway
3m ~ standard lane width, standard painted dash on road, 2 adult heights
5m ~ length of car/sedan, 5 long strides
10m ~ 2 car lengths, delivery/box truck, or start of 1 dashed line to next
15m ~ 3 car lengths, standard bus, or semi-trailer (no tractor)
20m ~ 4 car lengths, tractor + single trailer combined, or articulated bus
30m ~ 6 car lengths, tractor + 2 full-length trailers combined
40m ~ 8 car lengths, 2 tennis court lengths
50m ~ 10 car lengths, 2 tractor/single trailer combinations

*(*for use when radar data for conflict partner is not available or when estimating distance to predicted site of impact)*

Figure 8. Illustration. Guide to estimating distance from video.

ITERATION 1 RESULTS

To test Iteration 1 of the near-crash severity rating protocol, data reductionists were provided with the full severity variable and level definitions (similar to Appendix A), as well as the Quick Reference Sheet (similar to Appendix C but without the Criteria Matrix, which was developed later).

A total of 32 near-crash events were selected for this testing iteration, and events were selected using a similar conflict type and kinematic stratification process outlined earlier. All elements outlined under the Data Reduction and Protocol Testing Methods section in Chapter 3 were again administered, including the use of three independent raters for each event.

During the Iteration 1 pre-test meeting, the following material and concepts were reviewed in detail with the data reductionists:

- The conceptual relationship between crash severity and near-crash severity
- The importance of objectivity in ratings, and when subjectivity is needed (e.g., VRU and other situations with significant mass differentials)
- A review of the near-crash outcome operational definition
- A review of Iteration 1 of the near-crash severity variable description and associated severity level definitions (a printed copy of these definitions was provided to each reductionist)
- A review of materials (See Figure 3 through Figure 8) included in the Quick Reference Sheet (a printed copy of the Quick Reference Sheet was provided to each reductionist)

Data reductionists were encouraged to ask as many questions as they wanted during the training session but were asked not to discuss events or ask questions while the test was in progress.

Once all data reductionists had completed their ratings for Iteration 1, their near-crash severity ratings were compiled, and another debrief meeting was held to discuss what protocol elements were working and what elements might need revision or addition.

Table 5 updates the previous rater consistency matrix (Table 3) to add Iteration 1 results for comparison to Iteration 0. For Iteration 1, among the three raters and 32 events, all three raters produced the same severity level (range = 0, agree = 3) for 9% of the near-crash events. At least two of the raters agreed (agree = 3 or 2) for 66% of the near-crash events. For 53% of the near-crash events, the distance between the highest and lowest assigned severity level was one level or less (range = 0 or 1). As noted in Iteration 0, these agreement metrics (bolded in Table 5) are the basis for comparing iterations; an improvement in the near-crash severity rating protocol would result in an increase of these agreement metrics.

Table 5. Summary of rater agreement on near-crash severity ratings, comparing Iteration 0 (76 events, minimal guidance) to Iteration 1 (32 events, first full protocol).

	Iteration	**Iteration 0**			**Iteration 1[c]**		
	# Events	76			32		
	# Raters	3			3		
		#	%	%	#	%	%
Range between highest & lowest ratings	**Range 0[a]**	17	**22%**	**66%[b]**	3	**9%**	**53%[b]**
	Range 1	33	43%		14	44%	
	Range 2	18	24%		14	44%	
	Range 3	8	11%		1	3%	
# of raters assigning the same rating	**Agree 3[a]**	17	**22%**	**75%[b]**	3	**9%**	**66%[b]**
	Agree 2	40	53%		18	56%	
	Agree 1	19	25%		11	34%	

[a] *Rows for "Range 0" (all ratings are the same) and "Agree 3" (all raters agree) represent perfect agreement.*

[b] *No more than one level of separation between raters (Range 0 + Range 1) or two raters agreeing (Agree 3 + Agree 2) was considered a good target.*

[c] *Due to normal data reduction staff attrition, one of the three raters from Iteration 0 was not available for later iterations and was replaced with a new rater in Iteration 1.*

The rater agreement metrics were lower for Iteration 1 compared to Iteration 0. For the range metric (range = 0 or 1), Iteration 1 (first full protocol) went down to 53% compared to 66% for Iteration 0 ("gut reaction" approach). Similarly, for the agree metric (agree = 3 or 2), Iteration 1 went down to 66% compared to 75% for Iteration 0.

Rather than these declines in agreement being a discouraging sign, they were interpreted as side effects from acclimating to a very new and different type of protocol and building experience/comfort with the new metrics the raters were being asked to estimate. The debriefing meeting that followed confirmed this explanation. Data reductionists expressed enthusiasm for the new protocol, but also admitted that they spent a significant amount of time during Iteration 1 working out the process for estimating the metrics. They explained that they grew more comfortable with the protocol the further they got into the test (however, because events were presented to each rater in a separate random order, this acclimation effect could not be measured). The raters also had some good questions and suggestions that led to protocol revisions for Iteration 2. A sample of this feedback is listed below.

- More explicit instructions were needed for defining at what point in time during the conflict to estimate relative speeds. The peak conflict time was difficult to estimate. To address this, the protocol was updated for Iteration 2 to instruct raters to:
    - Use the start of the subject driver's reaction as a surrogate for the pre-evasion time (start of near-crash severity assessment window) if a better pre-evasion time cannot be easily determined.
    - Use the peak times from the subject vehicle's acceleration data in combination with visual confirmation of other conflict partners' evasive maneuver(s) as a surrogate for the peak conflict time if a more precise peak conflict time cannot be determined.

- TTC was difficult to estimate when both conflict partners are moving because the multi-dimensional dynamics preclude a simple frame of reference location on which to base the distance component. To address this, the protocol was updated for Iteration 2 to instruct the raters to:
    - Use the relative approach speed of the conflict partners at a given point in time and the estimated distance of any conflict partner to the likely site of impact at that same point in time.

- The near-crash severity level definitions, in their text-based/bulleted format, were difficult to quickly refer to and follow a logical flow of rating. To address this:
    - The Quick Reference Sheet was updated for Iteration 2 to provide a Near-Crash Severity Criteria Matrix (shown in Appendix B) as a guided, easier, faster way to determine the appropriate severity level. This matrix breaks down the two-part qualification process into one row for each severity level, and the rater then moves across the columns within a given row to confirm the rating.

- Some raters tended to conflate risk with urgency and crash severity with near-crash severity. For example, they may rate a near-crash as very severe if a collision could have resulted in injury, even though the kinematics and timing of evasion provided ample time to minimize the urgency, and this tendency produces inconsistencies and additional subjectivity in the ratings. To address this, the protocol was updated for Iteration 2 to instruct the raters to avoid creating direct comparisons between the existing crash and new near-crash severity protocol.

- There was a general lack of clarity as to the level of certainty required in metric estimations and the amount of time that a given rating should take. To address this, in addition to the above updates, the variable operational definition was updated for Iteration 2 to provide a per-event time guideline and reiterate that metric estimations are necessary.

- Finally, data reductionists expressed a need for additional training/guidance in the form of example pre-rated events with descriptions for how the ratings were assigned. To address this, a representative set of 17 near-crashes were provided to data reductionists to review prior to Iteration 2. This compilation included the conflict type, the severity rating assigned by the researcher using Iteration 2 of the protocol, a listing of the calculated/estimated relevant speeds, distances, and TTCs, and written notes. Data reductionists were encouraged to review the video and time series data for these events along with the provided ratings and notes prior to starting the next iteration. This list of sample events appears as Appendix D.

ITERATION 2 PROTOCOL

Iteration 2 of the near-crash severity rating protocol and testing were very similar to Iteration 1, except for the protocol updates incorporated after the Iteration 1 debrief. In addition, Figure 9 depicts the Criteria Matrix, which was added to the Quick Reference Sheet for Iteration 2. This figure, which appears on its own as Appendix B, can also be printed as a stand-alone reference sheet.

Refer to data dictionary/project protocol for full definitions. The matrix below is a highlights summary only.

Near-Crash Severity, Criteria Matrix (12-2-2022)

	MUST HAVE	PLUS ONE OF			But...
	Relative Approach Velocity	Relative Approach Velocity	Minimum Time-to-Collision	Special Risk	Low-Risk Exclusion
I - Critical Severity	>= 30mph (48kph, 15m/s)	>= 50mph (80kph, 22m/s)	<=0.5s	High Severity + specific vulnerability	Excludes potential curb and low-risk tire strikes as well as small/light, non-fixed objects/small animals unless another high-risk outcome is likely (e.g., looming risk for pedestrian strike or vehicle rollover).
II - High Severity	>= 15mph (25kph, 7m/s)	>= 35mph (55kph, 15m/s)	<=1.0s	Moderate Severity + specific vulnerability	
III - Moderate Severity	---	>= 15mph (25kph, 7m/s)	<=1.5s	Lower Severity + specific vulnerability	
IV - Lower Severity	Any near-crash that does not meet the requirements for higher severity. Includes potential curb and low-risk tire strikes as well as small/light, non-fixed objects/small animals unless another high-risk outcome is likely and criteria are met for a more severe rating.				

Figure 9. Illustration. Near-crash severity criteria matrix, added to Iteration 1 protocol for quick reference and a more guided severity level assignment.

ITERATION 2 RESULTS

To test Iteration 2 of the near-crash severity rating protocol, the data reductionists from Iteration 1 were provided with the updated full severity variable and level definitions (as they appear in Appendix A), a separate copy of the Criteria Matrix (as it appears in Appendix B), and the updated Quick Reference Sheet (as it appears in Appendix C).

A total of 32 near-crash events were again selected for this testing iteration, and events were selected using a similar conflict type and kinematic stratification process outlined earlier. All elements outlined under the Data Reduction and Protocol Testing Methods section in Chapter 3 were again administered, including the use of three independent raters for each event.

During the Iteration 2 pre-test meeting, several protocol updates, reference updates, and guidance points were reviewed in detail with the data reductionists, as described below:

- Updates to near-crash severity variable definition:
    - See Appendix A for updated version.
    - Added "This rating should be able to be determined quickly during the course of regular full conflict annotation, taking no more than a couple of minutes for this variable alone."
    - Added term "pre-evasion time"
    - Added term "conflict peak time"
    - Added aids/surrogates for measurement times:

        - If the pre-evasion point is difficult to determine quickly, then Subject Reaction Start can be used as an estimated surrogate.
        - If the conflict peak time is difficult to determine, then the peak of the evasive responses can be used as a surrogate by considering the subject vehicle's longitudinal (X direction) and lateral (Y direction) acceleration data and the other conflict partner's acceleration as perceived through the video.
        - TTC estimates are calculated using the relative approach velocity between the conflict partners at a given point in time and the estimated distance of either vehicle to the likely site of impact at that same time.
    - Added: "Note: near-crash severity ratings do not translate into crash severity ratings. For example, a Level 1 near-crash would not necessarily have resulted in a Level 1 Crash, and a Level 3 near-crash would not have necessarily resulted in a Level 3 Crash."

- <u>Added to near-crash severity level definitions:</u>
    - See Appendix A for updated version.
    - Changed the speed requirements from pre-evasion time to "at any point from pre-evasion to conflict peak."

- <u>Availability and use of new Near-Crash Severity Criteria Matrix</u>
    - See Figure 9 and Appendix B.

- <u>Added to Quick Reference Sheet:</u>
    - See Appendix C for updated version.
    - Reference to distance to predicted point of impact (green distance visualization area on back of sheet)
    - Reference to optional use of Windows Calculator unit converter feature (yellow area on back of sheet)

- <u>Additional Guidance:</u>
    - Assess speed data critically for sanity. If the speed data are lagging behind due to hard braking, adjust as needed by taking the speed from a point or two ahead of the target timestamp.
    - Note that some types of near-crashes are more likely to rate as a higher severity because they tend to produce higher relative speeds (e.g., rear-end conflicts tend to be lower, while crossing and oncoming conflicts tend to be higher).
    - Do not force events into higher or lower severity levels to try to balance out the event set as a whole.

Again, data reductionists were encouraged to ask as many questions as they wanted during the pre-testing training session but were asked to not discuss events or ask questions while the test was in progress.

Once all data reductionists had completed their ratings for Iteration 2, their near-crash severity ratings were compiled, and another debrief meeting was held to discuss what protocol elements were working and what elements might need revision or addition.

Table 6 updates the previous rater consistency matrix (Table 4) to add Iteration 2 results for comparison to Iterations 0 and 1. For Iteration 2, among the three raters and 32 events, all three raters produced the same severity level (range = 0, agree = 3) for 25% of the near-crash events. At least two of the raters agreed (agree = 3 or 2) for 94% of the near-crash events. For 75% of the near-crash events, the distance between the highest and lowest assigned severity level was one level or less (range = 0 or 1). As noted earlier, these agreement metrics (bolded in Table 6) are the basis for comparing iterations; an improvement in the near-crash severity rating protocol would result in an increase of these agreement metrics.

Table 6. Summary of rater agreement on near-crash severity ratings, comparing Iteration 2 test results to prior iterations.

	Iteration	**Iteration 0**			**Iteration 1**[c]			**Iteration 2**		
	# Events	76			32			32		
	# Raters	3			3			3		
		#	%	%	#	%	%	#	%	%
Range between highest & lowest ratings	**Range 0**[a]	17	**22%**	**66%**[b]	3	**9%**	**53%**[b]	8	**25%**	**75%**[b]
	Range 1	33	43%		14	44%		16	50%	
	Range 2	18	24%		14	44%		8	25%	
	Range 3	8	11%		1	3%		0	0%	
# of raters assigning the same rating	**Agree 3**[a]	17	**22%**	**75%**[b]	3	**9%**	**66%**[b]	8	**25%**	**94%**[b]
	Agree 2	40	53%		18	56%		22	69%	
	Agree 1	19	25%		11	34%		2	6%	

[a] *Rows for "Range 0" (all ratings are the same) and "Agree 3" (all raters agree) represent perfect agreement.*

[b] *No more than one level of separation between raters (Range 0 + Range 1) or two raters agreeing (Agree 3 + Agree 2) was considered a good target.*

[c] *Due to normal data reduction staff attrition, one of the three raters from Iteration 0 was not available for later iterations and was replaced with a new rater in Iteration 1. Iteration 2 included the same raters as Iteration 1.*

The rater agreement metrics increased substantially for Iteration 2 compared to both prior iterations. For the range metric (range = 0 or 1), the Iteration 2 score went up to 75% compared to the prior 53% (Iteration 1, first full protocol) and 66% (Iteration 0, "gut reaction" approach). Similarly, for the agree metric (agree = 3 or 2), Iteration 2 went up to 94% compared to the prior 66% (Iteration 1) and 75% (Iteration 0).

These agreement metrics were very encouraging, both as a sign of performance for the protocol being developed and as a sign that the raters had acclimated to the process. The debriefing meeting that followed confirmed both areas of improvement. Data reductionists reported that once they stopped worrying about trying to make events fit into a hypothetical or abstract distribution of severity levels, they became much more confident and were able to be more objective about each individual case. They also reported an increased reliance on the objective metrics and numbers (even if those metrics had to be estimated) and reported a decrease in focusing on "gut reactions." Given this, they reported that their "gut reaction" did still lead them at times to recalculate the metric estimates as a second check (which should be encouraged).

CHAPTER 5. FINAL PROTOCOL VALIDATION

After the success of Iteration 2, no further changes were made to the observer-based, naturalistic near-crash severity rating protocol or the visual decision aids that accompany it. However, one final testing iteration was conducted to exercise the protocol with a larger set of events.

For Iteration 3 testing, the data reductionists from Iterations 1 and 2 were again provided with the updated full severity variable and level definitions (Appendix A), a separate copy of the Criteria Matrix (Appendix B), and the updated Quick Reference Sheet (Appendix C).

A total of 100 near-crash events were selected for this final testing iteration, and events were selected using a similar conflict type and kinematic stratification process outlined earlier. All elements outlined under the Data Reduction and Protocol Testing Methods section in Chapter 3 were again administered, including the use of three independent raters for each event.

During the Iteration 3 pre-test meeting, several items were reviewed with data reductionists, as outlined below:

- Animal-related near-crashes: No updates were made to the near-crash severity rating protocol, but based on a question from a data reductionist about large versus small animals and their associated risks, especially as it pertains to the near-crash severity level, raters were instructed to use the animal size definitions outlined in the full SCE reduction protocol (VTTI, 2015). Those definitions appear below (Table 7) for reference:

Table 7. Distinction between large and small animals from VTTI's full SCE reduction protocol (VTTI, 2015).

Variable Name	Category	Category Definition	Examples and Hints
Object/Animal 2,3 Type	Deer, elk, moose, bear (or similar)	Any type of live, large animal.	
Object/Animal 2,3 Type	Other animal	Any type of live, small animal.	Ex., Dog, cat, squirrel, rabbit, bird, opossum

- Trust in metrics: Raters were reminded to trust the objectivity of the estimated metrics to the extent possible.

- Prior guidance: Raters were instructed to continue to use the guidance provided in the Iteration 2 pre-testing meeting (see Chapter 4, Iteration 2 Results).

Again, data reductionists were encouraged to ask as many questions as they wanted during the pre-testing meeting but were asked to not discuss events or ask questions while the test was in progress.

Once all data reductionists had completed their ratings for Iteration 3, their near-crash severity ratings were compiled.

Table 8 updates the previous rater consistency matrix (Table 6) to add Iteration 3 results for comparison to Iterations 0, 1, and 2. For Iteration 3, among the three raters and 100 events, all three raters produced the same severity level (range = 0, agree = 3) for 32% of the near-crash events. At least two of the raters agreed (agree = 3 or 2) for 85% of the near-crash events. For 77% of the near-crash events, the distance between the highest and lowest assigned severity level was one level or less (range = 0 or 1). As noted earlier, these agreement metrics (bolded in Table 8) are the basis for comparing iterations; an improvement in the near-crash severity rating protocol would result in an increase of these agreement metrics.

Table 8. Summary of rater agreement on near-crash severity ratings, comparing the final test results (Iteration 3) to prior iterations.

	Iteration	**Iteration 0**			**Iteration 1[c]**			**Iteration 2**			**Iteration 3**		
	# Events	76			32			32			100		
	# Raters	3			3			3			3		
		#	%	%	#	%	%	#	%	%	#	%	%
Range between highest & lowest ratings	**Range 0[a]**	17	**22%**	**66%[b]**	3	**9%**	**53%[b]**	8	**25%**	**75%[b]**	32	**32%**	**77%[b]**
	Range 1	33	43%		14	44%		16	50%		45	45%	
	Range 2	18	24%		14	44%		8	25%		20	20%	
	Range 3	8	11%		1	3%		0	0%		3	3%	
# of raters assigning the same rating	**Agree 3[a]**	17	**22%**	**75%[b]**	3	**9%**	**66%[b]**	8	**25%**	**94%[b]**	32	**32%**	**85%[b]**
	Agree 2	40	53%		18	56%		22	69%		53	53%	
	Agree 1	19	25%		11	34%		2	6%		15	15%	

[a] *Rows for "Range 0" (all ratings are the same) and "Agree 3" (all raters agree) represent perfect agreement.*

[b] *No more than one level of separation between raters (Range 0 + Range 1) or two raters agreeing (Agree 3 + Agree 2) was considered a good target.*

[c] *Due to normal data reduction staff attrition, one of the three raters from Iteration 0 was not available for later iterations and was replaced with a new rater in Iteration 1. Iterations 1, 2, and 3 included the same raters.*

Two of the three rater agreement metrics continued to increase in Iteration 3 compared to prior iterations.

- For the range metric (range = 0 or 1), the Iteration 3 score went up to 77% compared to the prior 75% (Iteration 2), 53% (Iteration 1), and 66% (Iteration 0).
- Of note, the frequency of total agreement across all three raters (range = 0, agree = 3) continued to increase in Iteration 3 to 32% of all near-crash events, compared to the prior 25% (Iteration 2), 9% (Iteration 1), and 22% (Iteration 0).

One of the agreement metrics did decline slightly. The agree metric (agree = 3 or 2) went down for Iteration 3 to 85% compared to the prior 94% (Iteration 2), 66% (Iteration 1), and 75% (Iteration 0).

Figure 10 and Figure 11 display these agreement metrics graphically across iterations. The improvement in agreement with each of the three primary iterations (1, 2, 3) is evident, particularly with respect to the frequency with which there is full rater agreement (all raters agree on the same rating) or the range in ratings within one severity level.

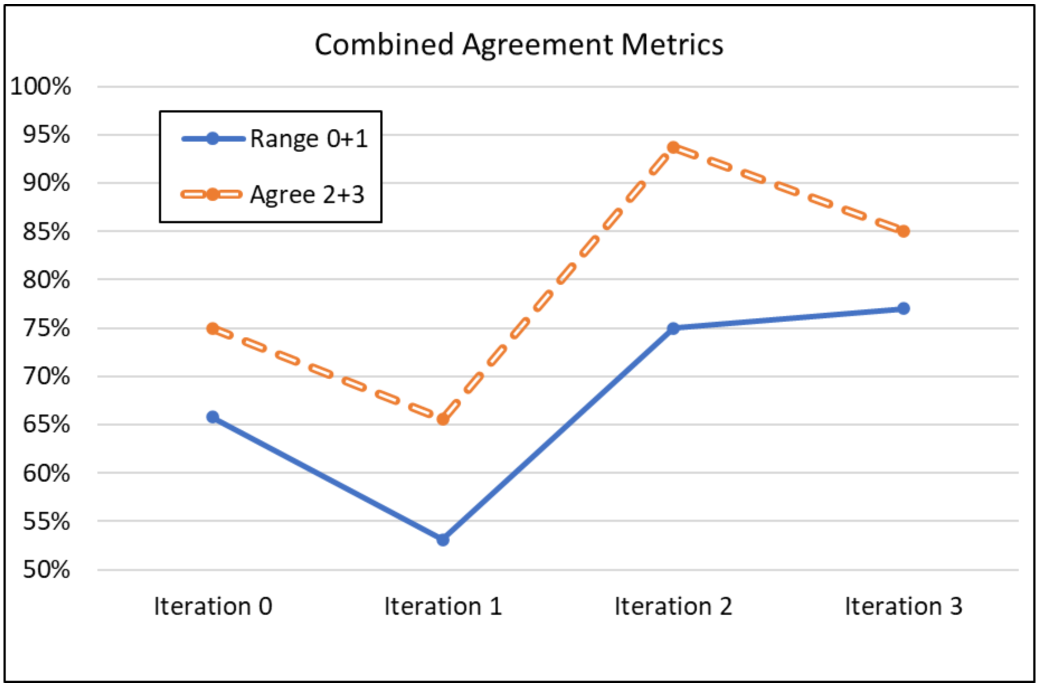

Figure 10. Graph. Percentage of near-crash events from each iteration where all three raters assigned ratings within 1 severity level (Range 0+1) or where at least two of the raters assigned the same severity level (Agree 2+3).

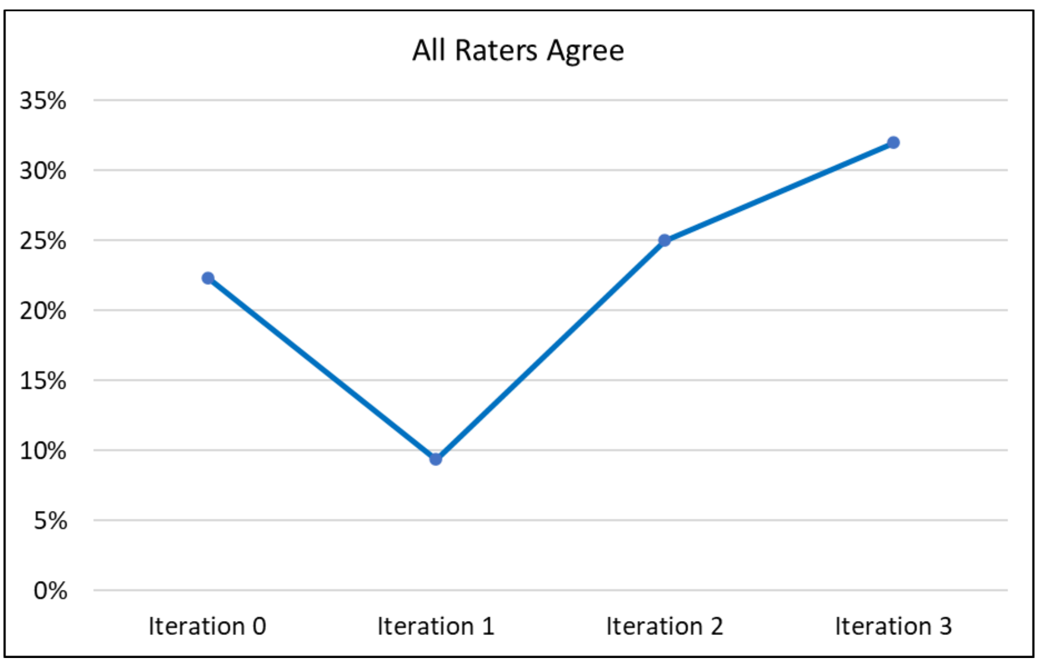

Figure 11. Graph. Percentage of near-crash events from each iteration where all three raters assigned the same severity level rating.

The continued increase in two of the three rater agreement metrics was an encouraging sign of protocol performance and rater acclimation to the protocol. The decline in one of the three metrics (Agree 2+3) may be indicative of rater fatigue with the larger event set, the fact that ratings took place over a longer period of time (multiple work shifts rather than being completed in 1 or 2 days, as prior), the likelihood that the set of 100 events rated in Iteration 3 inherently contained a wider variety of scenarios than the smaller event sets rated previously, or of the variation to be expected in such a protocol.

For this final iteration of 100 events, agreement metrics for different conflict types were also analyzed. Table 9 provides the average agreement scores across different types of conflicts. Overall, the average number of the three raters in agreement is 2.2 (considered to be good at or above 2), and the average range in ratings for a given event is 0.9 (considered to be good at or below 1). VRU-related and backing-related near-crashes are the only conflict types that fall short on both metrics (1.8 and 1.5 respectively for VRU-related; 1.8 and 1.3 respectively for backing-related). Road departure near-crashes fall short on the average rating range metric (1.3). These values are shown in red and bold text in Table 9. This likely reflects the uniqueness, wide range of contexts, and added complexity of the conflicts included in the VRU, backing, and road departure near-crash categories. In addition, these conflict types tend to have limited visibility from the perspective of the instrumented vehicle's cameras, and available kinematic data can be very limited (e.g., lack of radar data). Mitigating efforts to bring scores for these categories of events in line with other conflict types would require additional quality control considerations, such as additional training or definition development.

Table 9. Average rater agreement scores across different conflict types.

Conflict Type	Average # Raters Agreeing[a] (3=max)	Average Rating Range[b] (0-3)
Rear-end conflict	2.3	0.7
Sideswipe, same direction	2.2	0.9
Intersection	2.2	0.9
Opposite direction	2.1	1.0
Road departure	2.0	**1.3**
Backing-related	**1.8**	**1.3**
Animal-related	2.6	0.6
VRU-related	**1.8**	**1.5**
Overall	*2.2*	*0.9*

[a] *Three raters scored each event. Average number of raters agreeing greater than or equal to 2 is considered good; 3 is the best possible score.*

[b] *Range between assigned severity levels for a given event, averaged across events. An average rating range less than or equal to 1 is considered good; 0 is the best possible score.*

CHAPTER 6. DISCUSSION AND APPLICATION

As stated previously, the final version of the observer-based, naturalistic near-crash severity rating definitions and all the visual/decision aids developed to accompany the definitions are included in this report as Appendices A, B, and C:

- Appendix A: Full Definitions for Observer-Based, Naturalistic Near-Crash Severity
  Provides a full description of the final Near-Crash Severity variable and full definitions for the four severity levels.

- Appendix B: Near-Crash Severity: Quick Reference Criteria Matrix
  Provides a quick reference matrix of the final Near-Crash Severity level definitions for faster classification. The matrix assumes familiarity with the full definitions in Appendix A.

- Appendix C: Near-Crash Severity: Quick Reference Sheet
  Provides a two-page quick reference cheat sheet for applying the Near-Crash Severity variable and its four severity levels to naturalistic data. The Quick Reference Sheet includes the Criteria Matrix from Appendix B, as well as diagrams, tables, and text to help users estimate distance between conflict partners, conflict partner speeds, and TTCs; assign relative conflict partner vulnerability using mass categories; and convert between common speed units.

The final rating scale has four levels of near-crash severity: critical, high, moderate, and lower severity. The rating process is based on an assessment of video and time series data related to the initial relative approach speeds of the conflict partners, the timing/progression of evasive maneuvers by the conflict partners, and the relative risk presented by the type of and/or mass differential between conflict partners. The definitions and decision aids provide examples and guidance for determining and/or estimating each component while factoring in unique situational characteristics. Ultimately, the included matrix guides the rater to an objective assessment of severity level, which may be assigned or adjusted at the rater's discretion based on perceived vulnerability of conflict partners.

In the final two iterations of testing reported here (both of which used the final protocol documents appearing in Appendices A, B, and C), three raters independently assigned severity levels to each event in a sample of near-crashes stratified by incident type. At least two of the three raters assigned identical ratings in 85% to 94% of these cases. In addition, when looking at all three independent ratings, 75% to 77% of the cases in these final iterations received either three identical ratings (e.g., all three ratings were high severity) or ratings within one level of severity difference (e.g., the ratings were a mix of high and critical severities only). Given that these ratings rely largely on observer- and video-based kinematic estimations combined with subjective risk and timing assessments, the results indicate that this rating scale can be implemented reliably and that the results can contribute meaningfully to future research.

It is important to note that, while events for each iteration were selected to present a range of kinematic values to the protocol testing iterations, there is no utility in analyzing or assessing the resulting near-crash severity rating levels in relation to those kinematic metrics. As discussed throughout this report, the magnitude of an evasive maneuver is a poor predictor of collision imminence, potential collision severity, and the overall urgency of the near-crash that the protocol aims to assess.

While three raters were employed in each iteration of testing the near-crash severity rating protocol, the intent is not to require three raters when applying the protocol to rate new events in the general course of data reduction. Rather, this section describes a process for training reductionists, proceeding with ratings, and performing necessary quality control. Training data reductionists new to this protocol is an essential part of obtaining good agreement. It is recommended that training for this near-crash severity rating scale take place in conjunction with or after the larger SCE annotation training process. Any rater using the near-crash severity rating protocol should also have the full SCE annotation training. This is because the full SCE annotation training serves as an important foundation for many of the metrics and conflict visualizations critical to the near-crash severity rating. During training, it is important to emphasize that the magnitude of observed evasive maneuvers, while a useful consideration, does not translate into a near-crash severity level directly. Drivers often over- or underreact, and the goal of this severity rating is to evaluate the actual severity of an event in terms of risk, rather than how severe the driver appears to believe it is relative to their own subjective risk tolerance. Raters must go through the process of estimating speeds, times, and other key metrics laid out in the definitions.

Data reductionists who are applying the near-crash severity rating protocol will need access to all critical data views that are available. At minimum, this includes all collected videos (both external and internal to the vehicle) and key kinematic data charts. Key kinematic data includes (when available) subject vehicle speed, subject vehicle longitudinal and lateral acceleration, any available object range and relative speed variables, GPS location (along with associated satellite and street views), and certain vehicle network variables (e.g., brake/throttle application). In general, the more data sources available to the raters applying this protocol, the better the results will be, and if fewer data sources are available or the most critical data sources are inaccessible or difficult to interpret, severity ratings will be more difficult to assign, and results will be less reliable. While working, data reductionists should have an open dialog with senior team members, quality assurance staff, and project leaders.

It is VTTI's policy and recommendation that all SCE annotations, once completed by an initial rater, be reviewed in full by a second rater. That second rater should be a quality control–level or senior-level data reductionist at minimum, and any disagreements between the initial rater and the reviewer should be resolved between them or through a third manager-level reviewer if needed. The near-crash severity rating, if assigned using the protocol described in this report and provided in the appendices, should undergo this same level of multi-person review. The rating results reported here include an 80%+ inter-rater reliability within one severity level, and it is expected that the multi-person quality control method employed for other SCE-related annotation variables will produce at least that level of reliability when applied to new events during the standard primary event assessment process. Additional quality control measures should be implemented for VRU, backing, and road departure near-crash severity ratings due to their lower rater agreement metrics. This may include additional training and sample events within these conflict types, limiting the rating or quality assurance reviews of these conflict types to specific experienced raters, and adding another layer of quality control such as a third reviewer for these conflict types.

Finally, in the interest of exercising this observer-based, naturalistic near-crash severity rating protocol to as many different events as possible, intra-rater testing was not conducted, as this would require repeating events in subsequent iterations, thereby reducing the overall number and variety of events included. No events were repeated in successive iterations during this project; however, such intra-rater testing procedures may present a good avenue for future research.

APPENDIX A. FULL DEFINITIONS FOR OBSERVER-BASED, NATURALISTIC NEAR-CRASH SEVERITY

(Updated 12-2-2022)	Near-Crash Severity
General Variable Description	The objective for rating near-crash severity is to estimate and represent how collision imminence and the severity of the crash that would have occurred had the evasive maneuvers not been taken or not been successful. This rating should be able to be determined quickly during the course of regular full conflict annotation, taking no more than a couple of minutes for this variable alone. Note: near-crash severity ratings do not translate into crash severity ratings. For example, a Level 1 near-crash would not necessarily have resulted in a Level 1 Crash, and a Level 3 near-crash would not have necessarily resulted in a Level 3 Crash. A near-crash severity rating is based on the combined magnitude of each of the conflict partners' (vehicle, person, animal, and/or object) dynamics starting just prior to any evasive response by any conflict partner (the last "pre-evasion" time) and continuing through the most critical conflict point (usually minimum time-to-collision, or peak conflict time). The specific point of each assessment depends on the metric being considered, and because kinematic data are rarely available for all conflict partners, this assessment and rating is generally estimated. If the pre-evasion point is difficult to determine quickly, then Subject Reaction Start can be used as an estimated surrogate. If the conflict peak time is difficult to determine, then the peak of the evasive responses can be used as a surrogate by considering the subject vehicle's X and Y acceleration data and the second vehicle's (V2's) acceleration as perceived through the video. Time-to-collision estimates are calculated using the relative approach velocity between the conflict partners at a given point in time and the estimated distance of either vehicle to the likely site of impact at that same time. Relative vulnerability of the conflict partners is also factored into the assessment. Driver state (distraction, impairment, age, experience/skill level, etc.) and passive environmental factors (e.g., weather, lighting) do not factor in, except for their contribution to the actual timing and kinematic metrics described above. This variable is coded for events where the corresponding Event Severity = Near-crash (or where Event Severity = Non-Subject Conflict and that conflict is a near-crash).
1 Critical Severity	Critical Severity Near-Crash. Any near-crash where the relative approach velocity of conflict partners at any point from pre-evasion to conflict peak is at least 30 mph (48 kph, 12 m/s) AND at least one of the following additional criteria is satisfied: a) at any point from pre-evasion to conflict peak, the conflict partners approach each other at a relative velocity of 50 mph (80 kph, 22 m/s) or more; b) OR the minimum time-to-collision reaches 0.5 second or less; c) OR the criteria for high severity near-crash are met AND the conflict partner type or mass differential creates a specific vulnerability. The Critical Severity near-crash rating excludes potential curb and other low-risk tire strikes as well as small/light non-fixed objects and small animals unless another high-risk outcome is likely (e.g., looming risk for pedestrian strike or vehicle rollover).

(Updated 12-2-2022)	**Near-Crash Severity**
2 **High** **Severity**	High Severity Near-Crash. Any near-crash that does not meet the requirements for a Critical Severity near-crash but where the relative approach velocity of conflict partners at any point from pre-evasion to conflict peak is at least 15 mph (25 kph, 7 m/s) AND at least one of the following additional criteria is satisfied: a) at any point from pre-evasion to conflict peak, the conflict partners approach each other at a relative velocity of 35 mph (55 kph, 15 m/s) or more; b) OR the minimum time-to-collision reaches 1.0 second or less; c) OR the criteria for moderate severity near-crash are met AND the conflict partner type or mass differential creates a specific vulnerability. The High Severity near-crash rating excludes potential curb and other low-risk tire strikes as well as small/light non-fixed objects and small animals unless another high-risk outcome is likely (e.g., looming risk for pedestrian strike or vehicle rollover).
3 **Moderate** **Severity**	Moderate Severity Near-Crash. Any near-crash that does not meet the requirements for a Critical or High Severity near-crash but where at least one of the following criteria is satisfied: a) at any point from pre-evasion to conflict peak, the conflict partners approach each other at a relative velocity of 15 mph (25 kph, 7 m/s) or more; b) OR the minimum time-to-collision reaches 1.5 seconds or less; c) OR the criteria for lower severity near-crash are met AND the conflict partner type or mass differential creates a specific vulnerability. The Moderate Severity near-crash rating excludes potential curb and other low-risk tire strikes as well as small/light non-fixed objects and small animals unless another high-risk outcome is likely (e.g., looming risk for pedestrian strike or vehicle rollover).
4 **Lower** **Severity**	Lower Severity Near-Crash. Any near-crash that does not meet the requirements for a Critical, High, or Moderate Severity near-crash. The Lower Severity near-crash rating includes potential curb and other low-risk tire strikes as well as small/light non-fixed objects and small animals unless another high-risk outcome is likely and criteria described above are met for a more severe rating.

APPENDIX B. NEAR-CRASH SEVERITY: QUICK REFERENCE CRITERIA MATRIX

<table>
<tr><th colspan="6">Near-Crash Severity, Criteria Matrix (12-2-2022)</th></tr>
<tr><th rowspan="2"></th><th>MUST HAVE</th><th colspan="3">PLUS ONE OF</th><th>But...</th></tr>
<tr><th>Relative Approach Velocity</th><th>Relative Approach Velocity</th><th>Minimum Time-to-Collision</th><th>Special Risk</th><th>Low-Risk Exclusion</th></tr>
<tr><td>I - Critical Severity</td><td>>= 30mph (48kph, 15m/s)</td><td>>= 50mph (80kph, 22m/s)</td><td><=0.5s</td><td>High Severity + specific vulnerability</td><td rowspan="3">Excludes potential curb and low-risk tire strikes as well as small/light, non-fixed objects/small animals unless another high-risk outcome is likely (e.g., looming risk for pedestrian strike or vehicle rollover).</td></tr>
<tr><td>II - High Severity</td><td>>= 15mph (25kph, 7m/s)</td><td>>= 35mph (55kph, 15m/s)</td><td><=1.0s</td><td>Moderate Severity + specific vulnerability</td></tr>
<tr><td>III - Moderate Severity</td><td>---</td><td>>= 15mph (25kph, 7m/s)</td><td><=1.5s</td><td>Lower Severity + specific vulnerability</td></tr>
<tr><td>IV - Lower Severity</td><td colspan="5">Any near-crash that does not meet the requirements for higher severity.
Includes potential curb and low-risk tire strikes as well as small/light, non-fixed objects/small animals unless another high-risk outcome is likely and criteria are met for a more severe rating.</td></tr>
</table>

APPENDIX C. NEAR-CRASH SEVERITY: QUICK REFERENCE SHEET

See the next page for a printable version of the Near-Crash Severity Quick Reference Sheet. Printing the Quick Reference Sheet requires legal-sized (8.5”x14”) paper (either two sheets printed on one side or a single double-sided sheet).

12-2-2022

Near-Crash Severity Rating: Quick Reference Sheet

(Note the importance of estimating...)

This reference supplements (does not replace) the full definitions. Refer to full definitions before using.

Quick estimation examples, relative/approach speed of two conflict partners

Generally used when speed of one partner (SV) is known and data is not available for other conflict partner.

~0° Rear-end, LV stopped*
(striking or struck)

V2: ~0 kph (Stopped or nearly stopped)

V1: 45 kph

If leading vehicle is stopped, use following vehicle speed.

Example:
45 kph relative velocity

*Includes stationary objects as well

~180° Head-on, Opposite direction
(includes one vehicle backing into another)

V2: 35 kph

V1: 70 kph

Add the two speeds together*.
Example:
35+70 = 105 kph relative velocity

*If not directly head-on (e.g., a glancing strike), adjust/estimate relative speed as needed to include the head-on or impact direction component

~90° Crossing path

V2: 50 kph

V1: 20 kph

Use the speed of the <u>striking vehicle only</u>.

Example:
- 20 kph relative velocity if V1 would strike
- 50 kph if V2 would strike

~10-30° Sideswipe/Same Direction
(left or right)

V2: 50 kph

V1: 50 kph

Use the <u>estimated* lateral component</u> of striking vehicle only.

Example:
4.4kph relative speed (lateral movement of V1)

*If lane change takes 3s to complete, that's ~12 ft in ~3s = 12/3 = 4ft/s ~ 4.4kph ~ 1.3m/s. (if in adjacent lanes and ~3ft (1m) between vehicles at conflict peak, that's a 0.78s time-to-collision)

~0° Rear-end, LV moving
(striking or struck)

V2: ~25 kph (at speed, accel, or decel)

V1: 45 kph

If leading vehicle is moving, subtract (following speed - leading speed)

Example:
45-25 = 20 kph relative velocity

~30-80° Turn into path

V2: 20 kph | V1: 55 kph

V2: 20 kph | V1: 55 kph

Subtract the estimated* lateral component of the turning vehicle from the speed of the straight vehicle.

Example:
- 55 - 10 kph = 45 kph relative velocity

* If turning, and impact would occur about halfway through the turn, estimated speed can be split ~50/50 into lateral and longitudinal components for the turning vehicle. Adjust as needed for turning vs estimated impact point.

~100-170° Turn across path

V2: 20 kph | V1: 55 kph

V2: 20 kph | V1: 55 kph

Add speed of the straight vehicle to the estimated* lateral component of the turning vehicle.

Example:
- 55 + 10 kph = 65 kph relative velocity

* If turning, and impact would occur about halfway through the turn, estimated speed can be split ~50/50 into lateral and longitudinal components for the turning vehicle. Adjust as needed for turning vs estimated impact point.

Quick Conversions:

1 mph = 1.6 kph
1 mph = 0.4 m/s
1 mph = 1.5 f/s

1 kph = 0.6 mph
1 kph = 0.3 m/s
1 kph = 0.9 kph

1 m/s = 2.2 mph
1 m/s = 3.6 kph
1 m/s = 3.3 f/s

1 f/s = 0.7 mph
1 f/s = 1.1 kph
1 f/s = 0.3 m/s

To estimate V2 speed (without radar data), use available video plus:
- Speed limit of road
- Motion of V2 relative to V1 (slower/faster/similar)
- Visual cues (no motion, or motion relative to fixed objects)
- Logical, experience-based reasoning (e.g., approximate speed during turn or specific maneuver)

To estimate time-to-collision (TTC), estimate distance (in m or ft) and approach speed (in m/s or ft/s, respectively) at a given point in time:
TTC = distance/speed (Ex: 10m ÷ 15m/s = 0.67 seconds)

Categories for conflict partner mass / relative vulnerability

<u>Category 1 (vulnerable):</u>	<u>Category 2 (light):</u>	<u>Category 3 (heavy):</u>
Pedestrian	Light vehicles	Bus, RV, Box truck
Bicycle	(Car, Van, SUV, Pickup)	Tractor trailer
Motorcycle	(no large trailers)	Construction vehicle
Or similar...	Or similar...	Light vehicle w/ large trailer
		Or similar...

If conflict partners are in two different categories, near-crash severity rating may be elevated one level (if 1v2 or 2v3) or one to two levels (if 1v3).

Time to Collision and Speed Conversion Cheat Sheet

12-2-2022

Relative/Approach Speed				Distance		TTC
mph	kph	m/s	f/s	m	ft	sec
5	8	2	7.5	1	3.2	0.50
5	8	2	7.5	2	6.4	1.00
5	8	2	7.5	3	9.6	1.50
5	8	2	7.5	5	16	2.50
10	16	4	15	1	3.2	0.25
10	16	4	15	2	6.4	0.50
10	16	4	15	3	9.6	0.75
10	16	4	15	5	16	1.25
10	16	4	15	10	32	2.50
15	24	6	22.5	1	3.2	0.17
15	24	6	22.5	2	6.4	0.33
15	24	6	22.5	3	9.6	0.50
15	24	6	22.5	5	16	0.83
15	24	6	22.5	10	32	1.67
20	32	8	30	1	3.2	0.13
20	32	8	30	2	6.4	0.25
20	32	8	30	3	9.6	0.38
20	32	8	30	5	16	0.63
20	32	8	30	10	32	1.25
20	32	8	30	15	48	1.88
25	40	10	37.5	1	3.2	0.10
25	40	10	37.5	2	6.4	0.20
25	40	10	37.5	3	9.6	0.30
25	40	10	37.5	5	16	0.50
25	40	10	37.5	10	32	1.00
25	40	10	37.5	15	48	1.50
25	40	10	37.5	20	64	2.00
30	48	12	45	1	3.2	0.08
30	48	12	45	2	6.4	0.17
30	48	12	45	3	9.6	0.25
30	48	12	45	5	16	0.42
30	48	12	45	10	32	0.83
30	48	12	45	15	48	1.25
30	48	12	45	20	64	1.67

Relative/Approach Speed				Distance		TTC
mph	kph	m/s	f/s	m	ft	sec
35	56	14	52.5	1	3.2	0.07
35	56	14	52.5	2	6.4	0.14
35	56	14	52.5	3	9.6	0.21
35	56	14	52.5	5	16	0.36
35	56	14	52.5	10	32	0.71
35	56	14	52.5	15	48	1.07
35	56	14	52.5	20	64	1.43
35	56	14	52.5	25	80	1.79
40	64	16	60	1	3.2	0.06
40	64	16	60	2	6.4	0.13
40	64	16	60	3	9.6	0.19
40	64	16	60	5	16	0.31
40	64	16	60	10	32	0.63
40	64	16	60	15	48	0.94
40	64	16	60	20	64	1.25
40	64	16	60	25	80	1.56
45	72	18	67.5	1	3.2	0.06
45	72	18	67.5	2	6.4	0.11
45	72	18	67.5	3	9.6	0.17
45	72	18	67.5	5	16	0.28
45	72	18	67.5	10	32	0.56
45	72	18	67.5	15	48	0.83
45	72	18	67.5	20	64	1.11
45	72	18	67.5	25	80	1.39
45	72	18	67.5	30	80	1.67
50	80	20	75	1	3.2	0.05
50	80	20	75	2	6.4	0.10
50	80	20	75	3	9.6	0.15
50	80	20	75	5	16	0.25
50	80	20	75	10	32	0.50
50	80	20	75	15	48	0.75
50	80	20	75	20	64	1.00
50	80	20	75	25	80	1.25
50	80	20	75	30	96	1.50
50	80	20	75	35	112	1.75

Relative/Approach Speed				Distance		TTC
mph	kph	m/s	f/s	m	ft	sec
55	88	22	82.5	1	3.2	0.05
55	88	22	82.5	2	6.4	0.09
55	88	22	82.5	3	9.6	0.14
55	88	22	82.5	5	16	0.23
55	88	22	82.5	10	32	0.45
55	88	22	82.5	15	48	0.68
55	88	22	82.5	20	64	0.91
55	88	22	82.5	25	80	1.14
55	88	22	82.5	30	96	1.36
55	88	22	82.5	35	112	1.59
60	96	24	90	1	3.2	0.04
60	96	24	90	2	6.4	0.08
60	96	24	90	3	9.6	0.13
60	96	24	90	5	16	0.21
60	96	24	90	10	32	0.42
60	96	24	90	15	48	0.63
60	96	24	90	20	64	0.83
60	96	24	90	25	80	1.04
60	96	24	90	30	96	1.25
60	96	24	90	35	112	1.46
60	96	24	90	40	128	1.67
65	104	26	97.5	1	3.2	0.04
65	104	26	97.5	2	6.4	0.08
65	104	26	97.5	3	9.6	0.12
65	104	26	97.5	5	16	0.19
65	104	26	97.5	10	32	0.38
65	104	26	97.5	15	48	0.58
65	104	26	97.5	20	64	0.77
65	104	26	97.5	25	80	0.96
65	104	26	97.5	30	96	1.15
65	104	26	97.5	35	112	1.35
65	104	26	97.5	40	128	1.54

Refer to data dictionary/project protocol for full definitions. The matrix below is a highlights summary only.

Near-Crash Severity, Criteria Matrix (12-2-2022)

	MUST HAVE	PLUS ONE OF			But...
	Relative Approach Velocity	Relative Approach Velocity	Minimum Time-to-Collision	Special Risk	Low-Risk Exclusion
I - Critical Severity	>= 30mph (48kph, 15m/s)	>= 50mph (80kph, 22m/s)	<=0.5s	High Severity + specific vulnerability	Excludes potential curb and low-risk tire strikes as well as small/light, non-fixed objects/small animals unless another high-risk outcome is likely (e.g., looming risk for pedestrian strike or vehicle rollover).
II - High Severity	>= 15mph (25kph, 7m/s)	>= 35mph (55kph, 15m/s)	<=1.0s	Moderate Severity + specific vulnerability	
III - Moderate Severity	---	>= 15mph (25kph, 7m/s)	<=1.5s	Lower Severity + specific vulnerability	
IV - Lower Severity	Any near-crash that does not meet the requirements for higher severity. Includes potential curb and low-risk tire strikes as well as small/light, non-fixed objects/small animals unless another high-risk outcome is likely and criteria are met for a more severe rating.				

Distance Estimate Visualization*

1m ~ width of sidewalk, doorway, or 1 long stride
2m ~ half a standard lane width, height of doorway
3m ~ standard lane width, standard painted dash on road, 2 adult heights
5m ~ length of car/sedan, 5 long strides
10m ~ 2 car lengths, delivery/box truck, or start of 1 dashed line to next
15m ~ 3 car lengths, standard bus, or semi-trailer (no tractor)
20m ~ 4 car lengths, tractor + single trailer combined, or articulated bus
30m ~ 6 car lengths, tractor + 2 full-length trailers combined
40m ~ 8 car lengths, 2 tennis court lengths
50m ~ 10 car lengths, 2 tractor/single trailer combinations

*(*for use when radar data for conflict partner is not available or when estimating distance to predicted site of impact)*

APPENDIX D. SAMPLE NEAR-CRASH EVENTS AND SEVERITY RATINGS FOR RATER ACCLIMATION

SHRP 2 NDS Event ID	Conflict Type	Near-Crash Severity	Maximum Approach Speed	Distance, Conflict Peak Time	Approach Speed, Conflict Peak Time	TTC, Conflict Peak Time	Notes
151570819	Rear-end	Level 1 - Critical	51 kph (V2 stopped) (~32.5 mph)	12 m	51 kph (V2 stopped) (~32.5 mph, 14 m/s)	0.86	Because V2 is stopped (stationary), the max speed time and peak time can be the same. Estimated distance as one dashed line to next plus just a bit.
36842965	Intersection	Level 1 - Critical	38 kph (~25 mph, V2 crossing so all V1 speed)	4 m	26 kph (7 m/s)	0.57	Numbers put this in Moderate, but mass differential raises it to Critical.
29858005	Intersection	Level 1 - Critical	82 kph (~50 mph)	5 m	46 kph (12 m/s)	0.42	Both speed and TTC qualify this for Critical.
29859095	Intersection	Level 2 - High	52 kph (32 mph)	4 m	19 kph (5 m/s)	0.8	TTC keeps this from being critical. NOTE: Network Speed is actually using GPS in this case (and a few others), which tends to lag by about second, so I took the next speed point which seems to match video better.) You can tell this is an issue when the data points are spaced out like this to ~1/second or when the speed clearly does not reflect the video.
128906347	Intersection	Level 2 - High	20 mph (V2 est) + 9 kph (half of V1) = 20 + 5 = 25 mph (15 kph)	2.5 m	~10 mph (4.7 m/s)	0.93	Crossing scenario with ~45 degree approach and potential impact direction
143062693	Intersection	Level 2 - High	64 kph (40 mph, V1) + ~20% of V2 est (8 kph, 5 mph) = 72 kph, 45 mph	25 m	47 kph (30 mph, V1) + ~20% of V2 est (8 kph, 5 mph) = 55 kph, 35 mph	0.71	See notes on others about GPS speed being used on network speed graph. Solid High Severity.

SHRP 2 NDS Event ID	Conflict Type	Near-Crash Severity	Maximum Approach Speed	Distance, Conflict Peak Time	Approach Speed, Conflict Peak Time	TTC, Conflict Peak Time	Notes
151859528	Sideswipe	Level 2 - High	Completes lane change in 2 s, which is 12 ft in 2 s or 6 ft/s = 4 mph	.5 m	6 ft/s = 1.8 m/s	0.28	Relative speed means this does not go higher than Moderate without other extenuating circumstances. Shortness of time to react could be extenuating, plus the nearness of the concrete wall limiting evasive options. Bumping to High.
151864736	Rear-end	Level 2 - High	63 kph-~25 kph = 38 kph (~25 mph)	5 m	51 kph-~25 kph = 26 kph (~15 mph, 6 m/s)	0.83	Estimated peak distance as ~1 car length (5 m) This meets both the min speed (25 mph max approach speed) and TTC (.8 s) for a Level 2 High Severity.
17750276	Rear-end	Level 3 - Moderate	12 kph (~8 mph)	1 m	8 kph (2 m/s)	0.5	Max relative speed is < 15 mph, so cannot be High or Critical (even though TTC qualifies it for Critical). Combination of factors meets Moderate criteria.
61432334	Rear-end	Level 3 - Moderate	16 kph (~10 mph)	0.5 m	12 kph (3 m/s)	0.17	Max relative speed is < 15 mph, so cannot be High or Critical (even though TTC qualifies it for Critical). Combination of factors meets Moderate criteria.
136174965	Rear-end	Level 3 - Moderate	52 kph-~20 kph = 32 kph (~20 mph)	3 m	26 kph-~20 kph = 6 kph (~5 mph, 1.6 m/s)	1.88	After the event, lead vehicle is going about 20 kph (same as subject), so I estimate V2 speed at 20 kph in speed calculations. Estimated peak distance using painted dashed line (3 m). (If farther back, could have said that plus 1 Car length [5 m + 3 m] = 8 m, for example.)
61287691	Rear-end	Level 3 - Moderate	84 kph-~35 kph = 49 kph (~30 mph)	10 m	64 kph-~35 kph = 37 kph (~23 mph, 9 m/s)	1.11	Estimated peak distance as start of one dashed line to next (10 m) This meets both the min speed (25 mph max approach speed) and TTC (1.1 s) for a Level 3 Moderate severity.
35257201	Rear-end	Level 3 - Moderate	22 kph (V2 stopped) (~13.5 mph)	3 m	16 kph (V2 stopped) (~10 mph, 4 m/s)	0.75	Speed is just under qualifying for High (even though TTC is qualifying), so ranking this as Moderate.

SHRP 2 NDS Event ID	Conflict Type	Near-Crash Severity	Maximum Approach Speed	Distance, Conflict Peak Time	Approach Speed, Conflict Peak Time	TTC, Conflict Peak Time	Notes
151856554	Rear-end	Level 3 - Moderate	30 kph-~20 kph = 10 kph (~7 mph)	1.5 m	27 kph-~20 kph = 7 kph (~5 mph, 2 m/s)	0.75	Speed is under qualifying for High (even though TTC is qualifying), so ranking this as Moderate.
151878865	Intersection	Level 3 - Moderate	41 kph, 25 mph (V2 would be going straight across at point of collision, so just V1 speed)	6 m (width of side street)	12 kph, 3 m/s (speed chart lagged, took a couple points later that made sense with video)	2	Use predicted point of collision for distance/speed. Solid Moderate.
116592039	Sideswipe	Level 3 - Moderate	Completes lane change in 2 s, which is 12 ft in 2 s or 6 ft/s = 4 mph	1 m	6 ft/s = 1.8 m/s	0.56	Relative speed means this does not go higher than Moderate without other extenuating circumstances. Shortness of time to react could be extenuating, but I think the impact force would have been minimal at these speeds. Leaving as Moderate.
151860002	Intersection	Level 4 - Lower	20 kph (not sure which vehicle would strike, but both are going about 20 kph, 12 mph)	4 m	10 kph (2.7 m/s)	1.48	This is really borderline between Level 3 and 4 (Lower and Moderate). I think that the speed is still reading a bit higher than actual here. Putting this in Lower severity for that reason.

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