WHITE PAPER

TRANSOFT
SOLUTIONS

See Clearly or Miss Everything: The Safety Metrics that Matter

Introduction

"The answer is not simple" is painfully accurate in so many contexts. Imagine a doctor diagnosing someone's heart health using only blood pressure readings, ignoring cholesterol and triglyceride levels, heart rate variability, and coronary artery calcium score to gain a comprehensive understanding. Serious concerns would rightfully be raised.

Similarly, in proactive road safety analysis, numerous conflict metrics are essential to obtain an accurate, reliable, and robust understanding of road user risks. Using a single surrogate measure – such as time-to-collision or post-encroachment time – may be easily measured (or at least simplified) but will lead to woefully inadequate, inaccurate, and incomplete road user risks, impacting the decisions to save lives and reduce injury.

Road user risk is complex to evaluate, with multiple contributing factors and causes to evaluate. Therefore, it is not surprising that multiple elements need to be measured and evaluated together to provide a complete picture and lead to the most responsible decisions, similar to the doctor needing multiple measures of the patient's health to assess the full picture and make the best decision for that patient.

To illustrate the limitations of the standard critical conflict metrics, consider the following:

- **Post Encroachment Time (PET)** does not measure the speeds of involved road users and captures nothing about potential crash severity. PET also cannot measure certain types of road user crash risk, including rear-end, sideswipe, and head-on, which means these risks are completely omitted
- **Time-to-Collision (TTC)** does not account for extreme braking or other evasive actions road users may exhibit to avoid a crash, nor can it detect certain types of crash risk.
- **Deceleration Rate to Avoid Crash (DRAC)** alone has limited use and is best paired with other predictive metrics such as TTC.
- Perhaps, most critically, **PET**, **TTC** and **DRAC** metrics cannot predict the likelihood of injury or fatality of a crash.

The message is clear: solving the road user risk puzzle requires investigation into multiple complementary and overlapping dimensions of risk.

In this article, we will discuss challenges in assessing road safety risk, common and uncommon metrics used, gaps within those metrics, and why the winning combination of multiple metrics is critical to getting road safety right.

When lives are on the line, seeing the full picture can make all the difference.

Challenges in Proactive Road Safety Analysis

Assessing road safety risk in a proactive manner is challenging for many reasons. The most comprehensive picture, while inarguably valuable, is complex because it requires multiple measures of road user behavior. In turn, this increases the cost to evaluate, which directly challenges budget constraints.

It is easy to understand why organizations gravitate toward one metric for measuring road user risk. Single-metric approaches offer undeniable appeal: it requires simpler data collection and analysis processes, demands fewer resources to implement and maintain, and simplifies communication with stakeholders.

While budget constraints and resource limits are real barriers, the true cost of conceding to an oversimplified analysis of one single metric far outweighs those limitations. The true cost of not assessing risk at the most comprehensive level are continued crashes amongst all road users, cost of recovery, injury, and worse. As transportation professionals, we share the responsibility of leveraging the best possible technology, techniques, and know-how to solve the most complex of problems, especially when it leads to reduced injuries and deaths.

Understanding the Complexity and Why It Matters

Road safety is complex. By its nature, driver behavior, pedestrian behavior, and human behavior are generally complex. Understanding this complexity, however, is key to making decisions that also address this complexity and proactively improve safety for all road users. Capturing the nuances and sharing the most complete picture possible leads to better decision-making about mitigation strategies, countermeasure selection, and even better, long-term monitoring of the trends around safety risk.

To understand the complexity, we must understand the essential metrics, their power, and their limitations.

THE FIVE ESSENTIAL CONFLICT METRICS

Through extensive research, validation, and on-going knowledge-building, five critical metrics have emerged as providing the most comprehensive proactive and predictive view of road user safety risk:

- Post-Encroachment Time (PET)
- Time-to-Collision (TTC)
- Modified Time-to-Collision (MTTC)
- Deceleration Rate to Avoid Crash (DRAC)
- Delta-V Severity Indicator

The metrics form the foundation of robust safety analysis, and, when applied together, provide a complete picture of safety risk at any given location. By understanding what underlying crash risk each conflict measure captures and where and when it applies, it helps road safety managers select the right combination for their specific analysis needs.

Post-Encroachment Time (PET)

Post-Encroachment Time (PET) measures the minimum time gap between one road user leaving and another road user arriving at a conflict point. This is shown in Figure 1 below as the time between the yellow vehicle departing the conflict point and the red vehicle arriving at the conflict point. PET = 0 represents a crash, as this indicates road users occupy the same point in space at the same time. For $0 < PET < 3$ seconds, increased future crash risk for this type of conflict has been substantiated. PET is particularly reliable for predicting vulnerable road user crashes and crossing crashes at intersections.

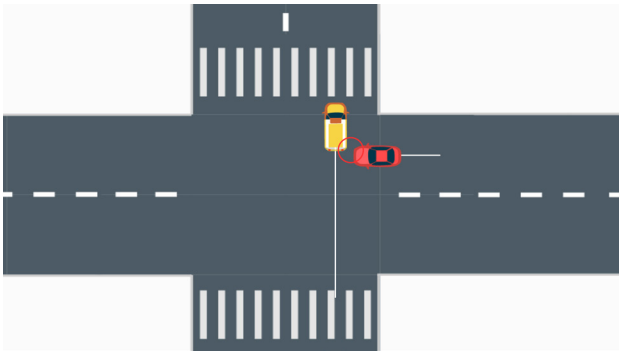

Figure 1. *Illustration of Post-Encroachment Time (PET)*

While valuable, PET cannot predict future crash risk for a variety of crash types including rear-end, head-on, and side-swipe crashes. Moreover, PET does not consider the speeds of the interacting road users. Thus, an interaction between two high-speed turning vehicles and one interaction between two slow turning vehicles could have the same PET values but will objectively carry different crash risks due to the reduced possibility of a successful evasion in the former case.

Time-to-Collision (TTC)

Time-to-Collision (TTC) measures the minimum temporal distance between two road users on a collision course, essentially answering "how long until they crash if neither change their current velocity or direction changes?" When one or more road users changes direction or speed, the minimum TTC is recorded (e.g., 0.5 seconds indicates that a collision was narrowly avoided). This is illustrated in Figure 2 for a rear-end conflict.

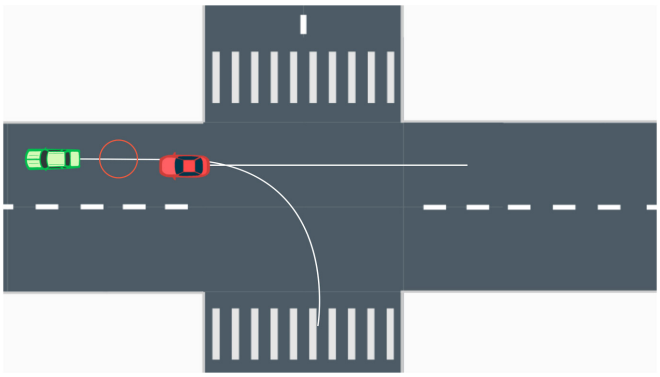

Figure 2. *Example of Time-to-Collision (TTC) Measurement*

For this metric, a TTC = 0 is defined as a crash, whereas 0 < TTC < 3 seconds is correlated with increased probability of future crashes occurring. This metric is reliable for predicting head-on and rear-end crashes, as well as some vulnerable road user (VRU) crashes.

It should be noted that the TTC calculation requires a prediction of where road users will be in the future based on their current trajectory and assuming constant velocity. TTC has a limitation in that it does not account for acceleration or deceleration in its prediction of road-user trajectory. If two vehicles, for example, are already decelerating to avoid a crash with each other, then TTC may indicate a risk that has already been mitigated. Regardless of this limitation, TTC has been shown to be a reliable predictor of crash risk, especially for TTC values less than 1.5 seconds.

> ***"What's easy to measure is not always what matters most."***

Modified Time-to-Collision (MTTC)

As an enhancement to TTC, Modified TTC (MTTC) measures the minimum temporal distance prior to collision while assuming constant acceleration or deceleration. The measurement shown in Figure 3 below is similar to that shown in Figure 2, as this modified metric accounts for braking or swerving that may be involved in conflict events from either or both road users. For example, rear-end conflicts almost always involve vehicle braking, which makes MTTC a superior metric for rear-end crash risk compared to TTC.

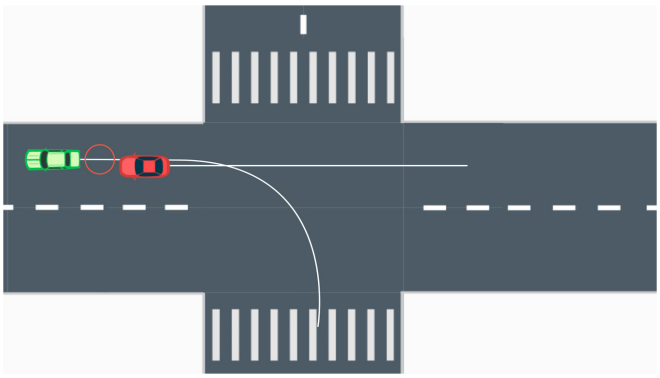

Figure 3. *Illustration of Modified Time-to-Collision (MTTC)*

Deceleration Rate to Avoid Crash (DRAC)

Deceleration Rate to Avoid Crash (DRAC) measures the braking intensity required to prevent a crash. This metric excels at predicting rear-end crashes and following-too-closely scenarios, providing crash risk insights at locations where hard braking is frequent. When combined with MTTC, DRAC provides powerful predictive capability for rear-end crash frequency.

Research has shown that MTTC, combined with DRAC, currently represents the best combination of metrics for rear-end crash frequency estimation[1]. MTTC can be used for the same conflict types as TTC and may provide a more realistic conflict by incorporating acceleration and deceleration behaviors.

One might ask, "why use TTC at all then?" The answer is that acceleration is determined via the second derivative of position using velocity estimates calculated every 30th of a second. This can magnify sensor calibration errors, leading to exaggerated estimates of acceleration and deceleration. In short, small velocity errors due to limitations of the technology become large when squared. Despite this technical complexity, MTTC's ability to capture real-world driving behavior makes it invaluable for comprehensive analysis and it serves as a strong complement to TTC.

Delta V Severity Metric

Unlike the previous critical conflict metrics, which provide insight into specific crash types, location, and involved road users, Delta V estimates the severity or injury potential of the conflicts if they become crashes. Delta-V measures the kinetic energy through the masses of road users, expected impact angles, and closing speeds.

Delta-V provides a critical new dimension to proactive safety analysis: it's not just about how often and where conflicts occur, but about the consequences to involved road users when conflicts become crashes.

As one might imagine, two "similar" sites might experience equal conflict counts but possess vastly different injury potential. Delta V helps differentiate the risk at these locations and provide evidence to identify and justify effective interventions to reduce harm. This severity prediction metric is essential for allocating safety resources effectively. It also helps to differentiate sites with high conflict counts and low severity from sites with low conflict counts and high severity, so conflict rates alone are not misleading investment decisions.

GAPS WHEN USING METRICS INDEPENDENTLY AND INDIVIDUALLY

Understanding the five essential metrics makes it clear that each metric has limitations, and relying on a single metric exposes gaps in road safety analysis. Even if multiple metrics are utilized, gaps remain.

As shown above, PET, TTC, MTTC, and DRAC all have value and collectively may even capture crash risk across a wide range of crash types (i.e., crash types missed by TTC are captured by PET and vice versa). Even if these four metrics are captured at a given location, these still do not provide the complete picture of the road safety risks.

The winning strategy is a combination of all five of the key metrics from above, as illustrated in the following section.

"The winning strategy is measuring the right combination of metrics, not just collecting more data."

Winning Framework: All Lenses for One Clear View

The previous sections identify the value of the key metrics and the limitations of each. Various combinations of these metrics also provide additional valuable information, leading to the essential five metrics above.

For example, MTTC is optimal for crash scenarios involving heavy braking, while DRAC can (and should) be coupled with MTTC to reveal true crash risk for specific crash types, such as rear-ends and side-swipes. Finally, Delta-V is used to identify severe crash risks with the intent to guide investment decision-making for crashes that inflict the most societal harm.

As more metrics are added to an analysis of road safety, the picture of true road safety risks becomes progressively clearer, and we gain more clarity about what is happening and how to improve for the future.

Consider an intersection analyzed through progressively comprehensive lenses:

- **Using PET only:** Vulnerable road user risk and crossing conflicts are identified using PET. An analysis flags pedestrian safety concerns, and crosswalk improvements are installed. Because only PET is used, many other crash types are ignored. Without Delta-V, it is not known how severe the pedestrian crashes are likely to be.
- **Adding TTC/MTTC:** By applying new metrics, sideswipe risks become apparent. The TTC conflict heat maps reveal an unsafe merge pattern involving right-turns on one of the intersection entry points that PET does not detect.
- **Adding DRAC:** Examination of DRAC results indicate that rear-end crash potential is within the top worst 10% of all sites in a particular region, associated with road users on two approaches. Through engineering review, the evidence suggests that distractions and site distance issues on two approaches contribute to excessive speeds and late, heavy braking.
- **Adding Delta V:** Delta-V is considered across all conflict metrics to determine the severity risk profile of the intersection. Final comprehensive analysis reveals that the most severe crash risk occurs on one (of the four) pedestrian crossings where site distance is restricted, and for the merge lane risk that is undetected by PET alone. Rear-end crash risk, though not contributing significantly to severity, needs to be addressed on two approaches.

Although hypothetical, this scenario plays out regularly in road safety analyses. A comprehensive analysis always provides a more complete, clearer, and more accurate insights into crash risk than more limited conflict metric-based risk analysis.

APPLYING THE WINNING STRATEGY

When combined, the five metrics support a comprehensive safety analysis across all road users and enable crash severity analysis for optimal countermeasure identification and investment. Moreover, a before-and-after safety analysis using multiple metrics can quickly reveal the safety benefits of investments, enabling reliable analysis of targeted crash type and severity improvements.

Research further supports the comprehensive approach of using multiple metrics by demonstrating that the accuracy and precision of crash predictions are not simply proportional to the number of conflict metrics used. Instead, strategic combinations of metrics provide significantly better insights into crash contributing factors, crash severity, and appropriate mitigative measures. This hypothetical and common scenario underscores a simple truth: no single metric can capture the full complexity of traffic risk. A multi-metric approach, used thoughtfully rather than indiscriminately, provides the most reliable foundation for understanding conflict patterns, prioritizing interventions, and ultimately improving safety outcomes.

The landscape is also evolving. In California, Caltrans' 2023 guidance on applying the Highway Safety Manual[2] for project development explicitly notes that relying only on total collisions is the least preferred option for decision-making because it obscures critical differences in risk. WSDOT's Safety Analysis Guide[3] similarly promotes a data-driven process that uses predictive methods, severity-focused performance (aligned with Target Zero), and multiple safety measures to identify and treat locations with elevated potential for fatal and serious injury crashes.

These developments aren't arbitrary. They are based on mounting research evidence and real-world experience, which shows that comprehensive analysis leads to better safety outcomes. The industry is catching up to what the data has been saying: single metrics leave too much risk unaddressed.

> ***"Road user risk is complex, and no single metric can capture that complexity."***

The Future of Road Safety Analysis is Now

The approach to road safety management has evolved from reactive crash evaluation to proactive and even predictive analysis, relying on the use of critical conflicts.

Emerging trends point toward the use of AI-powered analysis, sophisticated predictive modeling, and proactive interventions that prevent crashes before they occur. Technologies are bringing these capabilities within reach of agencies and safety professionals looking to move beyond reactive approaches that continue to result in crashes, injuries, and lives lost.

The fundamental shift is this: agencies and practitioners moving from asking "what happened?" to "what's likely to happen, and how can we prevent it?" This is accompanied by the always-present challenge of how to direct limited resources to locations where interventions will have the greatest impact.

When looking at strategies to answer these questions and overcome these challenges, it is critical to be aware of the dangerous blind spots created by reliance on anything less than the Winning Strategy described above. Only with all of the lenses can a comprehensive and clear view of safety risk be seen. It is only through this clear view that responsible and defensible decisions can be made to change the future, reduce injuries, and save lives.

In road safety, what we don't know can hurt people. The conflicts that go undetected will continue to result in crashes. This Winning Strategy doesn't just improve data—**it saves lives**.

This article is part of our **All Lenses. One Clear View.** campaign, where we're empowering transportation professionals with the analytics they need to make life-saving decisions. When it comes to road safety and operations, understanding what defines truly reliable, high-quality analytics isn't just important—it's the foundation for saving lives.

More content coming soon as we continue to uncover what truly defines reliable analytics

REFERENCES

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2. Application of the Highway Safety Manual Methodology for Project Development, Caltrans (2023).

3. "Safety Analysis Guide", Washington State DOT (sections describing use of HSM predictive methods, Target Zero emphasis on fatal and serious injury, and project-level safety analysis).