

Advancing Vision Zero through Integrated Crash and Near-Miss Diagnostics: A Case Study of US-97 Intersections in Yakima County, Washington

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ABSTRACT

This study addresses two connected questions about safety conditions along the US-97 corridor in Yakima County, Washington, with a focus on intersection-level risk: where and when is severe crash risk concentrated, and whether video-based near-miss observations at selected intersections capture a similar severity signal. Using a two-level diagnostic framework aligned with the Safe System Approach, comprised of corridor-wide crash screening (Level 1) and a camera-based near-miss pilot at two intersections (Level 2), the study demonstrates that historical crash data identify both the spatial concentration of Killed or Seriously Injured (KSI) risk and a clear temporal severity pattern. Nighttime crashes exhibited a KSI rate of 8.7% versus 4.7% for daytime, 1.8 times higher. At two camera-equipped intersections, 75 near-miss events were detected; afternoon windows produced 73 events (Camera 8 mean TTC 0.37s; Camera 18 mean TTC 0.80s), while evening windows yielded only 2 events with a substantially lower mean time-to-collision (TTC) of 0.17s. A clear frequency-severity divergence is observed, directionally consistent with the temporal pattern identified in the crash record. Crash data provide the outcome layer; near-miss data offer a mechanism layer. Even under practical constraints, this pilot suggests the two sources function as complementary diagnostic indicators of risk rather than competing measures. This finding has direct implications for how safety monitoring systems are designed in practice.

Keywords: Vision Zero; Safe System Approach; surrogate safety measures; time-to-collision (TTC); near-miss analysis; rural highway safety

1. INTRODUCTION

1.1 Background and Policy Context

Rural highways kill disproportionately: while accounting for approximately 19 percent of the U.S. population and 30 percent of vehicle miles traveled, rural roads experience 45 percent of roadway fatalities, a rate approximately twice that of urban areas (USDOT, 2022). The core diagnostic challenge is that crash-based analysis requires years of accumulated data to detect patterns reliably, yet in rural corridors where crashes are infrequent and each event tends to be severe, the wait is rarely affordable (Nikolaou et al., 2023). Video-based near-miss detection offers a way to move earlier in the risk cycle: by measuring time-to-collision (TTC) and post-encroachment time (PET) during vehicle interactions that approach conflict thresholds without resulting in crashes, surrogate safety measures (SSMs) enable severity assessment before outcomes occur (Arun et al., 2021; Astarita et al., 2020; Chen et al., 2017).

This study is situated within the Safe System Approach adopted by USDOT's National Roadway Safety Strategy (USDOT, 2022), incorporated into Washington State law (RCW 47.04.010), and operationalized through the Target Zero plan (WTSC, 2024) and WSDOT's Executive Order E 1085.01 (WSDOT, 2023). Two principles are particularly relevant: severity-first prioritization (Killed or Seriously Injured outcomes over total crash counts) and proactive safety analysis, which motivates the use of surrogate measures alongside historical crash records (Nikolaou et al., 2023).

1.2 Study Context and Objectives

US-97 spans milepost 33.52 to 76.36, a 43-mile rural corridor in Yakima County characterized by 55 to 60 mph posted speeds, stop-controlled intersections, and substantial commercial vehicle traffic (Figure 1). From 2020 to 2024, the corridor recorded 689 crashes, of which 25 were Killed or Seriously Injured (KSI) at intersection locations, an average of 6.2% KSI crashes per intersection over five years. That rate is too sparse for conventional hotspot methods to isolate risk at any single location reliably. This sparsity shifts the analytical focus toward identifying temporal conditions under which severity is elevated, and it is precisely this shift that makes a parallel near-miss analysis potentially informative.

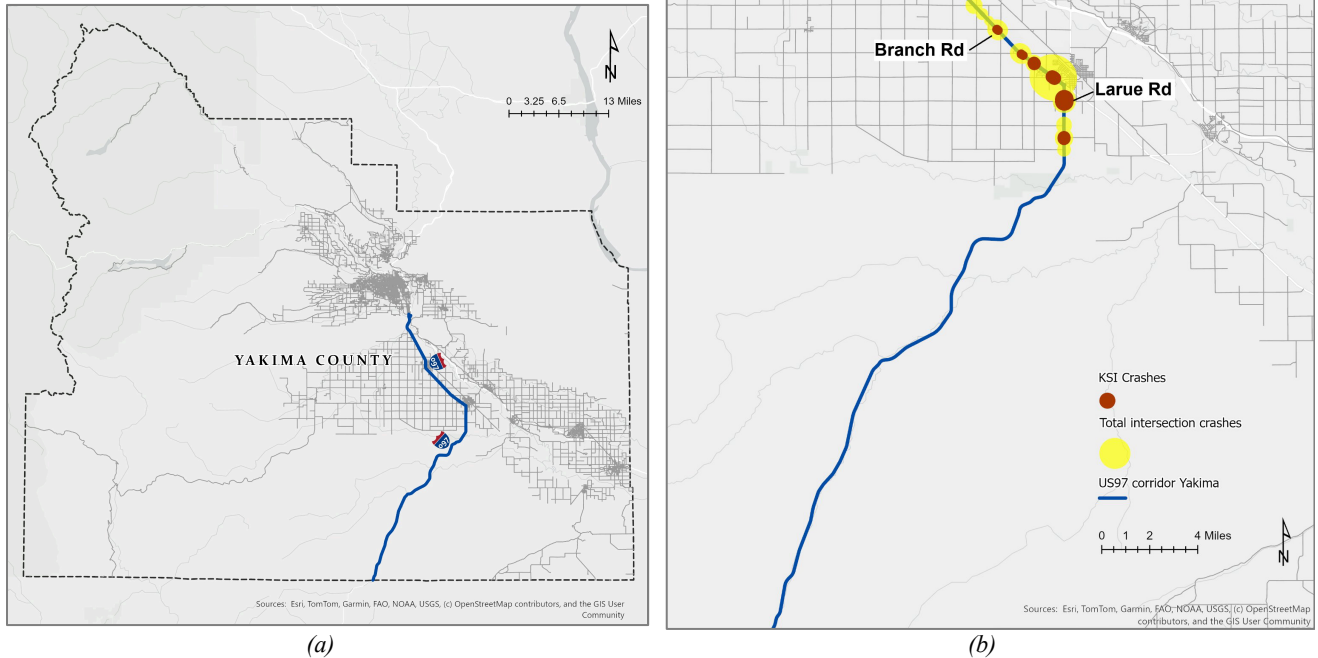


Figure 1. Study area and corridor overview. (a) US-97 corridor location within Yakima County, WA. (b) Crash and near-miss pilot sites along US-97 (MP 33.52 to 76.36): brown dots = KSI crashes; yellow circles = total crashes (size proportional to count); labeled intersections indicate the two near-miss pilot sites (Lateral 1 Road and Branch Road).

This study is motivated by a practical question: how can safety be understood in contexts where severe crashes are rare but consequential? Three questions organize this study. The first concerns crash records: where is severe crash risk spatially concentrated on US-97, and when is severity elevated by time of day and lighting condition? The second concerns near-miss data: at camera-equipped intersections, do evening vehicle conflict interactions exhibit tighter TTC margins than afternoon interactions, mirroring the nighttime KSI elevation in the crash record? The third concerns practice: what does the alignment, or lack of it, between the two data sources imply for rural corridor safety monitoring design?

1.3 Two-Level Diagnostic Design

The study uses a two-level design following directly from those questions. Level 1 draws on five years of WSDOT crash records to identify where KSI risk is spatially concentrated and when severity is elevated. Level 2 applies a TTC-based near-miss pilot at two intersections where camera infrastructure was operational, testing whether the temporal severity signal from Level 1 reappears in observed vehicle conflicts. Critically, the two levels are not measuring the same thing. Crash data provide an outcome layer: realized severity expressed as KSI outcomes. Near-miss data provide a mechanism layer: conflict dynamics in the moments before outcomes occur. They are complementary indicators, not interchangeable ones.

1.4 Literature Context

The Safe System Approach calls for proactive risk identification rather than reactive crash counting (USDOT, 2022; WTSC, 2024), a mandate that sits uneasily with the fundamental data problem in rural corridors: crash records accumulate slowly, and KSI events are too rare to support reliable site-level inference. Nikolaou et al. (2023) reviewed 34 SSM studies and found that surrogate data were collected in hours while matched crash data spanned three to six years. Yet crash data remain essential, as they establish the severity baseline against which surrogate measures are calibrated and interpreted (Astarita et al., 2020). This diagnostic

logic follows directly from that tension: use crash records to identify when severity is elevated, then examine whether near-miss data reflect the same pattern.

TTC measures the time remaining before a collision if vehicles maintain current trajectories; PET measures the elapsed time between successive encroachments at the same conflict point (Chen et al., 2017). Both correlate meaningfully with crash outcomes across facility types (Kronprasert et al., 2021; Astarita et al., 2020). Most relevant here is Kronprasert et al.'s (2021) observation that lower-volume conditions produce fewer but more severe conflicts, providing an empirical basis for expecting that evening near-miss events may exhibit lower TTC than afternoon events. Mishra et al. (2022) established that hours of video can surface safety signals otherwise requiring years of crash accumulation. Astarita et al. (2020) validated that surrogate-based estimates are statistically comparable to observed crash counts. Taken together, the literature supports a layered reading: crash records capture outcomes; TTC-based conflict data capture the mechanism preceding those outcomes.

2. METHODOLOGY

In simple terms, Level 1 identifies when and where severe crashes occur, while Level 2 examines whether near-miss interactions reflect the same severity pattern.

2.1 Corridor-Wide Crash Screening (Level 1)

Level 1 addresses the first research question: where is KSI risk spatially concentrated, and when is crash severity elevated? Crash data were obtained from WSDOT for SR-97 (MP 33.52 to 76.36), covering January 1, 2020 through December 31, 2024, derived from Police Traffic Collision Reports (WSDOT, 2024). Under 23 U.S. Code Sections 148 and 407, these records are protected from discovery or admission as evidence in legal proceedings. A binary KSI flag was constructed for fatal and suspected serious injury crashes, consistent with Safe System severity-first principles (USDOT, 2022; RCW 47.04.010). Crashes were classified as Day (6:00 AM to 5:59 PM) or Night (6:00 PM to 5:59 AM) to align with pilot observation windows; lighting condition categories were retained for supplementary severity analysis.

Crash records were geocoded and projected to NAD 1983 HARN StatePlane Washington South (EPSG:2927, US Feet). Intersecting the US-97 centerline with the local road network produced 202 raw intersection points; a 25-foot buffer, multipart-off dissolve, and Feature To Point conversion consolidated these into 80 clean nodes. A 500-foot Near analysis threshold assigned each crash to its nearest node (intersection-related: 403 crashes) or classified it as midblock (286 crashes), a threshold appropriate for rural high-speed conditions. Three severity classifications were constructed from structured injury indicator fields in the crash records: KSI (fatal or serious crashes ≥ 1), Injury (minor injury or possible injury crashes ≥ 1), and PDO (property damage only), verified against the most severe injury type field through spot checks. This indicator-based approach was chosen for reproducibility and to avoid ambiguity in text-based injury descriptions.

2.2 Camera-Based Near-Miss Pilot (Level 2)

Level 2 addresses the second question: does a severity signal analogous to the nighttime KSI elevation appear in TTC-based vehicle conflict observations at camera-equipped intersections? The crash screening is corridor-wide; the near-miss pilot is site-specific and camera-bounded. Each camera captures only a partial intersection view, so the pilot provides exploratory temporal insight into conflict severity rather than a complete spatial risk assessment, and it is not intended to validate the Level 1 hotspot ranking. The pilot should therefore be interpreted as a temporal diagnostic test under real-world data constraints rather than a comprehensive spatial validation.

Site Selection

Sites were selected from intersections with nonzero KSI history and confirmed camera availability, completed calibration, and intersection-facing views. Table 1 applies a two-stage logic: severity-based KSI rate screening first identifies priority nodes; a camera feasibility overlay then determines which are actionable for near-miss analysis. The two highest-ranked intersections meeting all three criteria, US-97 at Lateral 1 Road (Camera 8) and US-97 at Branch Road (Camera 18), were selected as pilot sites; these cameras provided intersection-facing views with completed calibration. Results should be interpreted as a camera-level temporal test, not a validation of corridor-wide hotspot priorities.

Table 1. Top Ten High-KSI-Rate Intersections and Pilot Site Selection, US-97 Corridor (2020 to 2024)

Rank	Node ID	Intersection	Crashes	Killed/Seriously Injured (KSI)	KSI Rate	Camera Infrastructure	Video Data
1	4	US-97 & Larue Rd	11	4	36.4%	Camera 25; calibration done	No
2	13	US-97 & Robbins Rd	6	2	33.3%	No cameras deployed	No
3	2	US-97 & Rocky Ford Rd	7	2	28.6%	No cameras deployed	No
4	57/60	US-97 & Lateral 1 Rd *	12	2	16.7%	Cameras 7/8/10; calibration done	Yes
5	16	US-97 & McDonald Rd	6	1	16.7%	No cameras deployed	No
6	78	US-97 & Main St	6	1	16.7%	No cameras deployed	No
7	39	US-97 & S Camas Rd	13	2	15.4%	No cameras deployed	No
8	23/24	US-97 & Branch Rd *	15	2	13.3%	Cameras 16/17/18; calibration done	Yes
9	41	US-97 & W 9th St	10	1	10.0%	No cameras deployed	No
10	45/46	US-97 & W Wapato Rd	31	3	9.7%	Cameras 39/40/41/42; pending calibration	No

Note: Ranked by KSI rate descending. Two-stage logic: severity screening identifies priority nodes; camera feasibility overlay determines actionable sites. Pilot sites shaded green. KSI rate = KSI crashes / total intersection-related crashes.

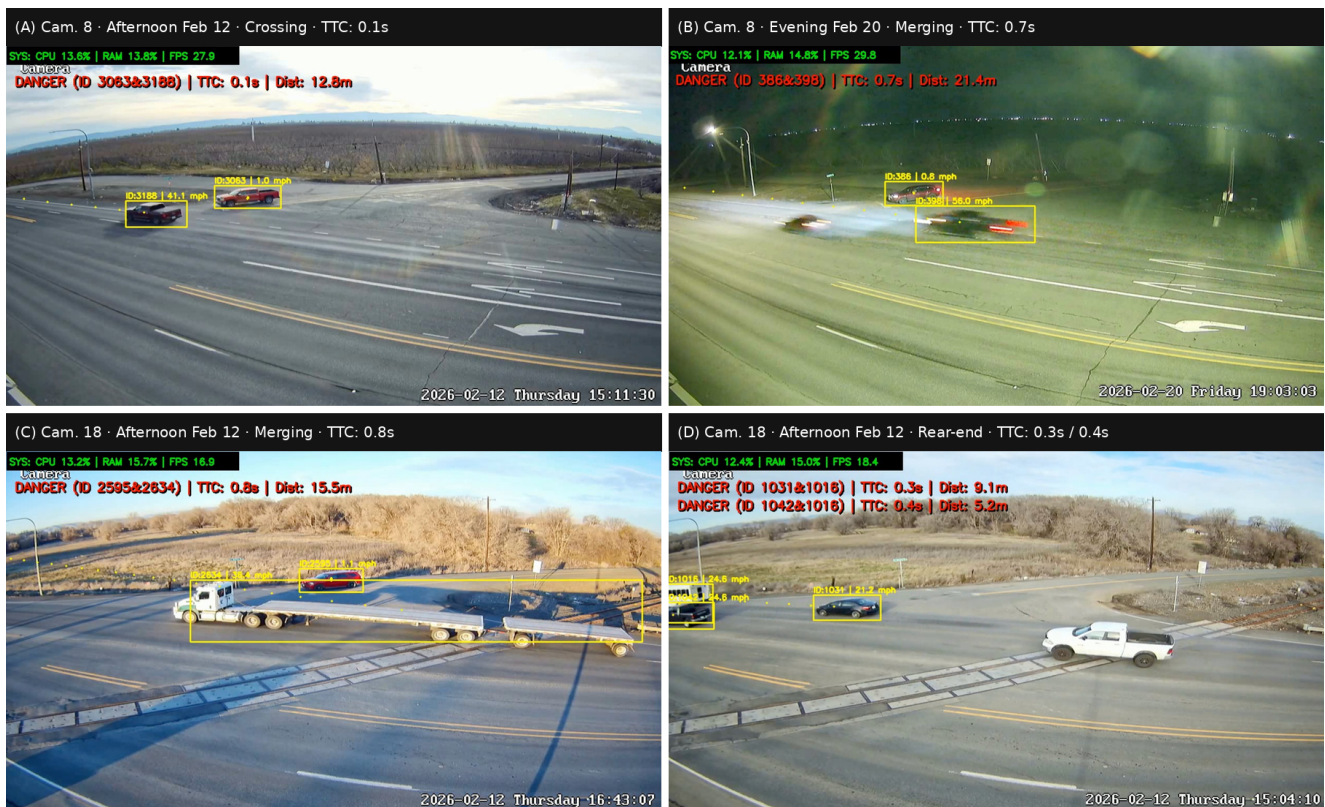


Figure 2. Representative near-miss conflict events from the AIWaysion video analytics platform at the two pilot intersections, February 2026. (A) Camera 8, afternoon Feb 12: crossing conflict, TTC 0.1s, Dist 12.8m. (B) Camera 8, evening Feb 20: merging conflict, TTC 0.7s, Dist 21.4m. (C) Camera 18, afternoon Feb 12: merging conflict involving commercial vehicle, TTC 0.8s, Dist 15.5m. (D) Camera 18, afternoon Feb 12: simultaneous rear-end conflicts, TTC 0.3s/0.4s. Yellow bounding boxes, vehicle IDs, speed readings, and red DANGER alerts are generated in real time by the platform.

Detection Platform and Parameters

Near-miss events were identified using the AIWaysion video analytics platform, which applies computer vision to detect vehicles, extract trajectories, project future positions, and flag vehicle pair interactions meeting specified thresholds. Detection parameters were held fixed across all four windows: TTC threshold of 1 second or less; minimum inter-vehicle distance of 1.0 meter; and camera-specific region-of-interest boundaries. This configuration represents an exploratory baseline rather than an optimized site-specific setting.

Observation Windows

Camera 8 recorded afternoon observations on February 12, 2026 (approximately 15:00-17:00) and evening observations on February 20, 2026 (approximately 19:00-21:00). Camera 18 recorded afternoon observations on February 12, 2026 (approximately 15:00-17:00) and evening observations on February 20, 2026 (approximately 19:00-21:00). Evening windows were included despite lower expected counts, reflecting the principle that severity-sensitive conflicts, not merely high-frequency interactions, should drive monitoring design (Kronprasert et al., 2021). Figure 2 illustrates representative near-miss conflict events detected at both pilot sites.

3. RESULTS

3.1 Corridor-Wide Crash Screening

Spatial Distribution of KSI Risk

Of 689 corridor crashes, 403 (58.5%) were assigned to 80 intersection nodes and 286 (41.5%) were midblock. Among intersection-related crashes, 25 were KSI (6.2% rate). The KSI burden is sharply concentrated: five intersections account for 13 of 25 KSI events (52%), and US-97 at Larue Road recorded both the highest absolute count (4 KSI events) and the highest KSI rate (36.4%). Table 1 presents the full top-ten ranking and indicates which nodes had active camera infrastructure.

Temporal Severity Patterns

Nighttime crashes ($n = 150$) exhibited a KSI rate of 8.7% compared with 4.7% for daytime ($n = 253$) (Table 2, Figure 3), a 1.8-fold difference; nighttime hours account for only 37% of all intersection-related crashes yet 52% of KSI outcomes. Among lighting conditions, all four dark categories produced KSI rates at or above the Daylight baseline of 5.1%. Dark with Street Lights On recorded the highest KSI rate at meaningful sample size (9.9%, $n = 81$), while Dark, No Street Lights (5.5%, $n = 55$) marginally exceeded the Daylight baseline. Dark with Street Lights Off (25.0%, $n = 4$) and Dark with Unknown Lighting (20.0%, $n = 5$) show elevated rates but should be interpreted with caution given small samples. This pattern directly motivates the Level 2 window design: if nighttime conditions produce disproportionately severe crash outcomes, the near-miss pilot should test whether evening vehicle conflicts exhibit correspondingly tighter TTC margins.

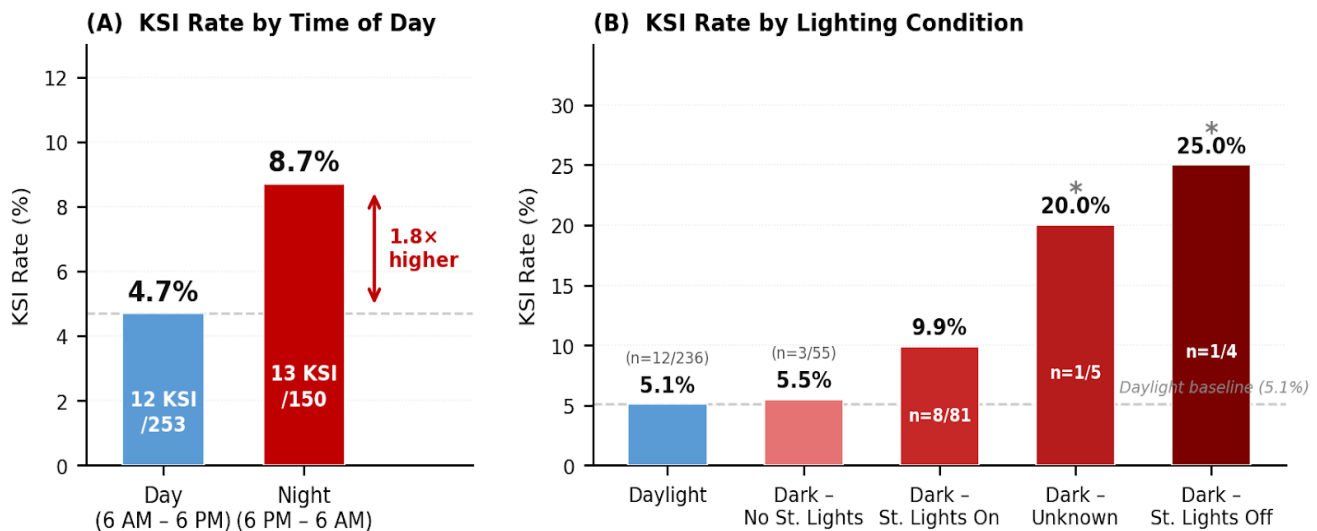


Figure 3. Crash severity patterns. Panel A: KSI rate by time of day; nighttime rate (8.7%) is 1.8 times the daytime rate (4.7%). Panel B: KSI rate by lighting condition, ranked ascending; all dark categories equal or exceed the Daylight baseline (5.1%), with Dark with Street Lights On the highest-rate dark condition at sufficient sample size (9.9%, $n = 81$). Small-sample categories ($n < 6$) marked with asterisks. Dawn ($n = 10$), Dusk ($n = 10$), and Other ($n = 2$) recorded zero KSI events and are excluded from Panel B.

Table 2. Crash Severity by Time of Day, Intersection-Related Crashes (2020 to 2024)

Time Period	Total Crashes	KSI Crashes	KSI Rate
Day (6:00 AM to 5:59 PM)	253	12	4.7%
Night (6:00 PM to 5:59 AM)	150	13	8.7%
Total (intersection-related)	403	25	6.2%

Note: KSI rate = KSI crashes / total crashes per time period.

Level 1 establishes a temporal severity signal: nighttime KSI rate is 1.8 times the daytime rate, and Dark with Street Lights On conditions produce the highest KSI rate among lighting categories with sufficient sample size. Level 2 now tests whether that signal reappears in near-miss TTC data, specifically whether evening vehicle interactions are tighter (lower TTC) than afternoon interactions, even when they are fewer in number.

3.2 Near-Miss Pilot Results

The near-miss pilot produced 75 detected vehicle interaction events across four observation windows (Table 3, Figure 4). The results show a preliminary divergence between event frequency and TTC-based conflict severity that is directionally consistent with the temporal pattern observed in the crash data.

Afternoon observation periods were high in frequency but relatively lower in severity. Camera 8 recorded 35 events during the February 12 afternoon window (mean TTC 0.37s; median 0.15s), with 80% of events falling below the 0.5-second threshold. Camera 18 recorded 38 afternoon events with a substantially different distribution (mean TTC 0.80s; median 0.84s), with 42% of events below 0.5 seconds. The Camera 8 afternoon distribution is heavily left-skewed: the majority of events cluster near zero, with a sparse tail extending to 2.47 seconds.

Evening observation periods produced far fewer events but exhibited lower TTC values. Camera 8 recorded only 2 events during the February 20 evening window, both with TTC values below 0.20 seconds and a mean of 0.17s. Camera 18 recorded zero events during its evening window. The pattern parallels Level 1 directly: fewer crashes occur at night, but a higher share are KSI; fewer near-miss events are detected in the evening, but TTC margins are tighter. The evening sample at Camera 8 ($n = 2$) is far too small for statistical inference; this should be read as a directional observation rather than a confirmed finding.

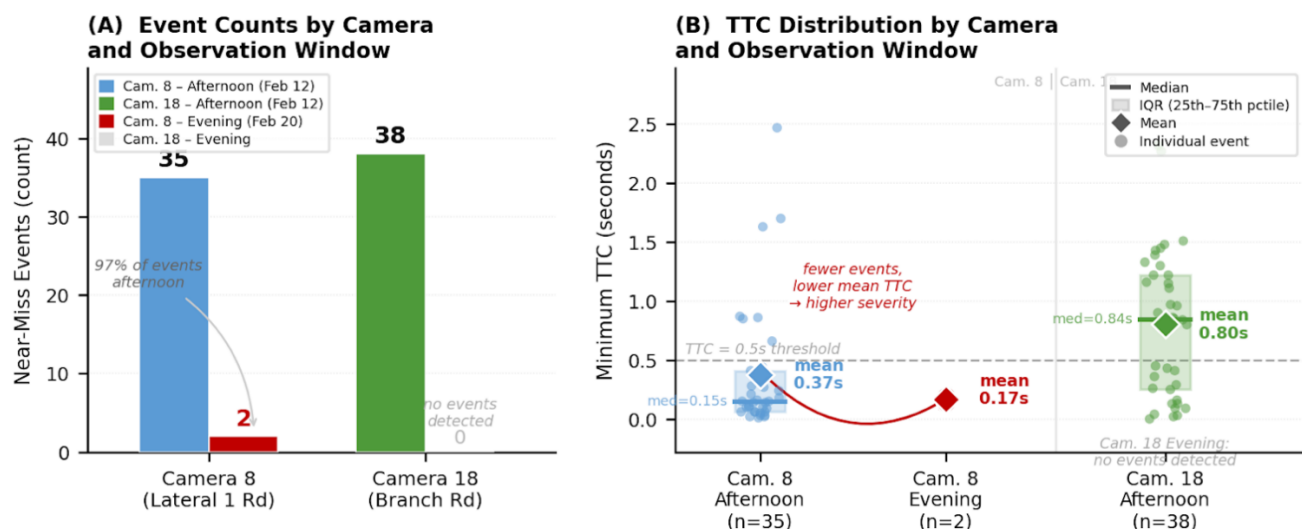


Figure 4. Near-miss pilot results. Panel A: Event counts by camera and observation window; afternoon periods account for 97% of all detected events (73 of 75). Panel B: TTC distributions; Camera 8 evening events (mean TTC = 0.17s, n = 2) show markedly lower TTC than the afternoon distribution (mean = 0.37s, n = 35); Camera 18 afternoon events show a wider spread (mean = 0.80s). Dashed line = 0.5-second severity threshold. Box = IQR; line = median; diamond = mean.

Table 3. Near-Miss Events by Camera and Observation Window

Camera	Window	Events	Mean TTC (s)	TTC <0.5s	Total
Camera 8	Afternoon (approximately 15:00-17:00)	35	0.37	80%	37
Camera 8	Evening (approximately 19:00-21:00)	2	0.17	100%	
Camera 18	Afternoon (approximately 15:00-17:00)	38	0.80	42%	38
Camera 18	Evening (approximately 19:00-21:00)	0	n/a	n/a	
Total		75	0.59	n/a	75

Note: TTC = time-to-collision. TTC <0.5s column shows share of events at or below the severity threshold. Total column reflects camera-level subtotals (Camera 8: 37; Camera 18: 38). Camera 8: afternoon Feb 12 (~15:00-17:00); evening Feb 20 (~19:00-21:00). Camera 18: afternoon Feb 12 (~15:00-17:00); evening Feb 20 (~19:00-21:00).

4. DISCUSSION

4.1 Outcome Layer and Mechanism Layer

The results of this study are best understood by first being clear about what each data source measures. Crash records capture the outcome layer: realized severity, expressed as fatalities and serious injuries with known spatial locations and temporal attributes. Near-miss data capture the mechanism layer: vehicle interaction dynamics in the moments before an outcome might occur, characterized by TTC and minimum inter-vehicle distance. These two layers are not measuring the same phenomenon at different scales; they are measuring different stages of the same underlying risk process. Importantly, the two layers should not be interpreted as directly comparable metrics, but as complementary indicators of different stages within the same risk process.

KSI rate (KSI crashes / total intersection-related crashes) was used rather than absolute counts to normalize for exposure differences across nodes. A key finding is that high crash frequency and high KSI concentration do not fully overlap: several lower-volume intersections recorded disproportionately high KSI rates, confirming that severity-based screening surfaces candidates that frequency-first approaches would miss. Branch Road (rank 8) and Lateral 1 Road (rank 4) were the highest-ranked intersections meeting all three selection criteria and were selected as pilot sites. This selection logic (severity rate over absolute count) reflects a methodological implication that extends beyond this corridor: monitoring systems calibrated to frequency alone will systematically underweight the intersections where per-event severity risk is highest.

This study did not achieve formal validation, which would require matched spatial and temporal data alongside statistical modeling capable of linking conflict characteristics to crash rates. What this pilot shows is directional alignment: the temporal severity signal from Level 1 (nighttime KSI rate 1.8 times the daytime rate) has a plausible parallel in Level 2 (evening TTC mean of 0.17s versus 0.37s in the afternoon), consistent with the layered diagnostic framework described by Arun et al. (2021) and empirically supported by Astarita et al. (2020).

4.2 Frequency-Severity Divergence and Monitoring Implications

The most practically significant finding is not that evening conditions are dangerous, a fact already well documented in the crash record. The more important observation is that a frequency-based monitoring approach would systematically miss the severity signal: afternoon periods produce more detected events (73 versus 2), suggesting lower risk by a count-based criterion, yet the TTC distribution tells the opposite story. Evening interactions are tighter by mean TTC (0.17s versus 0.59s). The same inversion appears in the crash data: nighttime accounts for only 37% of intersection crashes but 52% of KSI outcomes.

For practitioners, this means that monitoring systems designed around event counts alone may systematically misidentify risk conditions. This divergence has direct operational implications. Monitoring systems calibrated to maximize event counts will underweight precisely the time periods in which conflict

severity is highest. Observation windows, alert thresholds, and deployment decisions should be designed with severity sensitivity as the primary criterion (Scholl et al., 2019; Kronprasert et al., 2021; Mishra et al., 2022).

4.3 Complementary Diagnostics for Rural Corridors

Five years of crash records, 80 intersection nodes, and 25 KSI events yield an average of 0.34 KSI crashes per intersection over the study period. This is the baseline condition of rural highway safety analysis: events are too rare and too spread to support reliable site-level inference by conventional methods. Near-miss analysis addresses a genuinely different dimension, generating safety-relevant observations in hours rather than years (Nikolaou et al., 2023) and characterizing the mechanism layer that crash records cannot describe.

Neither source alone is sufficient. Crash records anchor the severity baseline and provide the temporal signal (that nighttime conditions are disproportionately fatal) that gives near-miss observations their interpretive context. Near-miss data, in turn, offer a window into the conflict dynamics that precede outcomes, potentially revealing whether those dynamics vary by time of day in ways that the crash record can suggest but not confirm. Used together, with more observation time and systematic validation, the integrated approach offers a practical path toward severity-sensitive rural corridor monitoring that the Safe System Approach requires.

4.4 Limitations

Three categories of limitation constrain interpretation of these findings.

Sampling: Approximately 8 hours of near-miss observation across 2 of 80 corridor nodes produced only 2 evening events at Camera 8 and zero at Camera 18, making statistical inference about evening TTC distributions impossible (Nikolaou et al., 2023).

Detection and validation: TTC thresholds and region-of-interest boundaries were fixed for internal consistency but not calibrated to this corridor or validated against independent observations. Findings should not be generalized beyond the specific corridor and conditions described here.

5. CONCLUSIONS

This study tested whether a temporal severity pattern visible in five years of corridor crash records would appear in a brief near-miss pilot at two camera-equipped intersections. The results, while preliminary, show consistent directional patterns across both data sources.

On the crash side, five years of WSDOT records identify where KSI risk is spatially concentrated (five intersections account for over half of all KSI events) and when severity is elevated. Nighttime crashes exhibit a KSI rate 1.8 times higher than daytime, and Dark with Street Lights On conditions produce the highest rate among lighting categories with meaningful sample size (9.9%, $n = 81$). Crash data provide the outcome layer.

On the near-miss side, the pilot detected a preliminary frequency-severity divergence that is directionally consistent with the crash pattern. Afternoon periods produced more events (73) with higher mean TTC (0.59s); evening periods produced fewer events (2 at Camera 8, zero at Camera 18) with lower mean TTC (0.17s). Near-miss data provide a mechanism layer.

The practical implication is that crash and near-miss data measure different stages of the same risk process; a monitoring strategy relying on only one will systematically miss what the other reveals. Used together, with more observation time and systematic validation, the integrated approach offers a practical path toward the severity-sensitive rural corridor monitoring that the Safe System Approach requires. Practically, agencies should consider integrating surrogate safety measures into routine monitoring frameworks, especially in low-frequency, high-severity environments. More broadly, this study suggests that severity-oriented monitoring frameworks are essential for improving safety outcomes in rural highway systems.

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