MP240901
MITRE PRODUCT

Safety Analysis of Transit Bus Collisions and Operator Hours of Service

A Pilot Study in Multi-Agency Transit Safety Analytics

Authors:
Tony Colavito
Lindsay Blassic
Dr. Elham Sharifi

January 2025

McLean, VA

Executive Summary

Fatality rates associated with bus collisions are rising, evidenced by a 50% increase from the period 2018–2019 to 2020–2023 [1]. Operator fatigue is a potential hazard that may cause or contribute to bus collisions [2]. To address these safety concerns, MITRE and five transit agencies jointly explored how bus collisions correlate with the bus operator's recent time at work, referred to as hours of service, through a shared safety analysis partnership. Specifically, we analyzed 90 million operator work hours and 1,496 collisions reported to the National Transit Database across agencies serving Washington, D.C.; Philadelphia; Atlanta; Minneapolis-St. Paul; and San Diego for the years 2018–2023. This initial analysis found:

- Collision rates are higher than average during operator shifts following three days without working.
- Collision rates tend to increase as operators work longer shifts.

The analysis partners recommend that transit agencies, the Federal Transit Administration (FTA), and others in the transit safety community jointly advance additional research to drive safety actions related to operator work hours, including through shared, confidential access to bus collision and hours-of-service data.

Beyond identifying specific hours-of-service hazards related to bus collisions, the analysis partners also successfully demonstrated that multi-agency safety analytics can produce insights with potential to inform actions by each transit agency to reduce fatalities and injuries. Together, the partners securely analyzed sensitive agency data by deidentifying and aggregating it across the participating agencies, as governed by a jointly defined study plan and research partner agreements. Participating transit agencies saw value in the approach and are interested in continuing to perform shared analysis. In conducting this analysis, the partners also encountered delays and limitations due to analytic challenges with extracting consistent safety data within agencies as well as aligning data definitions across agencies.

Based on these findings as well as strong agency interest, the partners recommend transit agencies and the FTA:

- Pursue further shared, multi-agency safety data and analyses to address additional complex, priority safety and security challenges, including roadway and wayside worker protection, transit worker assaults, and battery electric bus fires.
- Build safety data standards to enable faster, more efficient, and more robust safety analyses across multiple agencies.

This report explores the findings and recommendations related to bus collisions, specifically, and for the broader opportunity of shared data and improved data standards, in detail.

Acknowledgments

The authors extend our gratitude to the individuals and organizations whose invaluable contributions made this research possible. We thank the participating transit agencies and the following individuals for contributing hours-of-service data, their insights into interpreting the analyses, and their expertise in shaping the resulting findings:

- Jayme Johnson and Don Varley, Washington Metropolitan Area Transit Authority
- Gina Savarese and Jesse Litvin, Southeastern Pennsylvania Transit Authority
- Ralph McKinney, Soo Yap, and Tom Slusher, Metropolitan Atlanta Rapid Transit Authority
- John Levin, Rachel Dungca, Shanta Hejmadi, and Andrew Brody, Metro Transit – Minneapolis/St. Paul
- Jared Garcia, San Diego Metropolitan Transit System

We are grateful to Michelle Michelini and Dr. Joe Kolly of The MITRE Corporation for their direction and guidance in shaping this effort, and to Dr. Travis Gaydos for guiding our statistical approach and interpretation of results. Additionally, we would like to acknowledge the diligent efforts of our document reviewers from the MITRE Corporation: Matt Hardison, Kate Berman, Alex Alshtein, Dr. Kristin Heckman, and Mary Bruzzese, whose reviews and feedback have been instrumental in refining this work. Thank you all for your commitment and collaboration.

About MITRE

MITRE's mission-driven teams are dedicated to solving problems for a safer world. Through our public-private partnerships and federally funded research and development centers, we work across government and in partnership with industry to tackle challenges to the safety, stability, and well-being of our nation.

Table of Contents

List of Figures

1 Introduction

Bus collisions and operator fatigue are priority safety hazards in public transportation. MITRE and five transit agencies analyzed how bus collisions correlate with operator work hours through a collaborative data-driven safety analysis. The objectives of the effort were to:

- Identify hours-of-service conditions that may cause or contribute to bus collisions. As an initial study, the results aim to define a risk profile that informs more targeted analysis in the future.
- Assess whether multiple transit agencies can securely share data and resources to efficiently analyze a sensitive safety topic and inform consensus action to reduce collisions.

The participating transit agencies represent varying volumes of bus operations and geographic regions:

- Washington Metropolitan Area Transit Authority
- Southeastern Pennsylvania Transit Authority
- Metropolitan Atlanta Rapid Transit Authority
- Metro Transit – Minneapolis/St. Paul
- San Diego Metropolitan Transit System

This report describes the results of our analysis relating bus operator work hours with bus collisions, informing transit agencies about potential mitigations. This study also represents a blueprint to examine priority transit safety issues through collaborative safety analyses.

1.1 Shared Motivation: Reducing Bus Collisions

MITRE and the five participating transit agencies collaborated to analyze bus collisions and operator fatigue based on shared challenges in both areas:

- **Bus Collisions**: Fatality rates associated with bus collisions increased about 50% from about 3 fatalities per 100 million vehicle revenue miles during the period 2018–2019 to about 4.5 fatalities during the period 2020–2023 [1]. Based on this emerging trend, the Federal Transit Administration (FTA) recommended bus transit agencies identify specific hazards that may cause or contribute to bus collisions, assess the associated safety risk, and implement appropriate mitigations to reduce the likelihood and severity of those collisions [3]. The Transit Advisory Committee for Safety has provided recommendations for the FTA to pursue to effectively reduce bus collisions [4].
- **Operator Fatigue**: Driver sleepiness is a leading contributor to road crashes, accounting for an estimated 15–30% of all road traffic crashes globally [5], [6], [7]. Long considered a safety hazard in transportation safety [8], the transit community continues to grapple with operator fatigue resulting from long work hours [9]. Public transit is the only transportation mode without federal minimum standards for hours of service and fatigue risk management programs, though many states have regulations related to medical fitness for duty and fatigue management [4]. The FTA is considering proposing such standards to ensure transit workers obtain adequate rest, thereby reducing the risk of fatigue-related safety incidents [2], [4], [10].

1.2 Approach: Collaborative Safety Analytics

We are committed to improving safety with advanced analytics as the transit sector builds on its recent implementation of systematic safety management processes. To accelerate use of advanced analytics, we pooled our data and expertise to reduce duplicate investments in analytic capabilities, shore up findings about safety incidents that may occur too infrequently to characterize risks and trends by any one agency alone, and set up decisive action based on agreed-upon event definitions and data structures.

With this approach, MITRE served as a trusted third party to convene the agencies, identify shared safety challenges, and shape analyses based on available data; ingest and safeguard the pooled data; analyze the data at the direction and benefit of the agencies; and shape actionable results. The participating transit agencies prioritized and shaped the study objectives; provided sensitive operational, performance, and safety data; and provided expertise to interpret the data and results.

The agencies contributed to and reached consensus on an analytic plan, including the collision rate measure, hours-of-service elements to analyze, required data, assumptions, limitations, and schedule. MITRE and each agency entered into a research partnership agreement to safeguard the data, ensure the data will be used solely for safety purposes, and clarify each organization's rights to share aggregated results. As part of our partnership agreement, we did not analyze data attributed to any single agency. Agencies indicated that the confidentially guaranteed in the research partner agreement was a critical enabler for them to participate in the analysis.

Multi-organization collaborative safety analyses have proved successful as a repeatable approach to generate safety insights in transportation. Led by the U.S. Department of Transportation, collaborative analyses have securely delivered actionable insights to improve safety in aviation [11] and automotive [12] transportation; the rail sector is currently exploring this approach [13]. These efforts have been successful in examining collisions, minor incidents, near misses, and causal factors that help recognize safety hazards and mitigate them before they result in collisions.

1.3 Background: Related Work

Many factors influence an operator's potential for fatigue, such as rest time between shifts, consecutive workdays without a rest day, work environment, sleep habits, exercise habits, health, and accumulation of stress [14], [15]. In addition, many factors affect road safety, such as the operator, vehicle, driving environment, speed, other road users, and post-crash care [16], [17]. This multitude of factors complicates efforts to isolate the safety-related effects of individual factors [16], [18].

Previous researchers suggest using sophisticated statistical models to isolate how factors affect collision risk [18]. In 2016, Metro Transit used a machine learning approach, with its operational data finding that regular overtime increases operator risk of collision, but being out of practice even for a day also increases that risk [19]. Metro Transit also found that the time an operator has driven in a shift correlates with collisions, and that the relationship depends on whether the route is high or low frequency [19].

More research is needed on the relationships between hours-of-service regulations, driver fatigue, and collision risk [18], [21]. The FTA has identified the need for voluntary standards, recommended practices, and other forms of guidance [22]. Such guidance requires hours-of-service policies that define the limits for driving time, time on duty, time off duty between shifts, maximum work week hours, maximum number of consecutive workdays, and emergency service provisions to reduce or mitigate fatigue risk [22]. Fatigue and safety researchers focusing on commercial motor vehicles are on a similar track, calling for work that leverages new data collection efforts; taps or enhances existing sources of data; and supports discrete, smaller-scale studies for identifying patterns and associations and possibly understanding causal relationships [16].

2 Analysis and Results

In this analysis, we explore potential patterns among bus collisions and operator hours-of-service conditions. This section summarizes the analysis method, describes results, and discusses the analysis limitations.

2.1 Method

This subsection describes the data used, the processes for examining hours of service and calculating collision rates, and our analysis assumptions.

2.1.1 Data Summary

For data capturing operators' work time, the participating transit agencies provided the clock-in and clock-out times for every operator shift from January 2018 through December 2023. The resulting data pool featured about 15,750 unique bus operators working 90 million hours over 10 million shifts. Transit agencies asked to analyze total work time, including training, pre-route inspections, and paperwork, rather than only the time operating the bus or time in revenue service because total work time data was more readily accessible and better indicates worker fatigue. MITRE prepared the hours-of-service data for analysis by removing null values, duplicates, shifts that overlapped for the same operator, and absences.

We analyzed collisions from the National Transit Database (NTD) involving a moving transit agency bus for the period January 2018–December 2023. We did not consider buses that were standing or parked because we assume those collisions are not related to the operator's work hours. Among the five participating transit agencies, the study used 2,589 bus collisions that resulted in 35 fatalities, 3,558 injuries, and about $20 million in property damage [23].[1] Over this same period, the five agencies recorded 770 million vehicle revenue miles and 72 million vehicle revenue hours [24].

In total, our analysis included 1,496 of the 2,589 bus collisions (58%). This represents all collisions that we could reasonably match with operator shifts. Section 2.3 describes the challenges associated with matching the collision data to the operator shifts and recommends data standards to improve this matching process for future analyses.

2.1.2 Examining Hours of Service

We prioritized analysis of the following five hours-of-service elements:

[1] Analysis considered 2,589 of the 3,470 directly operated motor bus collisions in which a revenue vehicle was not stopped or parked.

1. Time of Collision in Operator's Shift – Work duration from when the operator's shift began to the collision time (expressed in hours)
2. Immediate Rest Duration – Duration from the end of the operator's prior shift to the start of the operator's current shift (expressed in hours)
3. Work Hours on the Previous Day – Duration the operator worked on the immediately preceding day (expressed in hours)
4. Work Hours in the Previous Week – Duration the operator worked in the immediately preceding seven days (expressed in hours)
5. Immediate Rest Days – The operator's consecutive rest days since a workday or consecutive workdays since a rest day (expressed in days)

For each of the hours-of-service elements, we set up shift conditions for analysis using the smallest whole hour as increments (or day when measuring rest days and workdays). For example, the shift conditions we examined for the time of the collision in the operator's shift are zero to one hour, one to two hours, and so on; this ensured detailed resolution. We combined shift conditions only if they did not include 10 or more collisions[2] or 2% of the total hours worked. We assigned shifts to the day that the shift started. For example, for a shift that started Friday evening and spanned into Saturday morning, we totaled the work hours for the full shift and considered it a Friday shift; this has implications for the hours-of-service elements examining work hours on the previous day and in the previous week, and the immediate rest days.

2.1.3 Calculating Collision Rates

This analysis systematically measures the safety risk using the collision rate per operator hour worked under a shift condition. Generally, the following equation calculates collision rate for each shift condition:

$$\left(\begin{array}{c}\text{Collision rate under}\\ \text{given shift condition}\\ \text{with independence}\end{array}\right) = \frac{\text{Total bus collisions with the given shift condition}}{\text{Total shift hours worked with the given shift condition}}$$

We use this equation to calculate the collision rate overall and for each shift condition, then compare the collision rates for each shift condition to the overall collision rate using a *t*-test ($\alpha = 0.05$). To use a *t*-test, we assume the collision rates are independent for each shift condition. This assumption is valid for the first hours-of-service element (i.e., time of collision in operator's shift) because only up to one hour from each shift is included in the total hours worked within each shift condition. For example, all operators who worked at least four hours contribute one hour to the three-to-four-hour increment, and some operators who worked more than three, but less than four, hours contribute a partial hour to that increment. This method ensures that at most one hour from each shift is counted in the total hours for that increment, thereby maintaining the independence of hours within each increment. As a result, we calculate the collision rate using the equation above.

In contrast, for the other four elements, all hours worked in a single operator's shift are included in the aggregated shift condition. Here, the work hours within each shift depend on the previous hours worked in that shift. To use the *t*-test for these elements, we accounted for this dependency

[2] The threshold for meaningful statistical analysis.

by calculating the collision rate per hour per shift. Specifically, we calculate the collision rate for each shift (using the equation above) and then divide the sum of these rates by the number of shifts:

$$\begin{pmatrix} \text{Collision rate under} \\ \text{given shift condition} \\ \text{with dependence} \end{pmatrix} = \frac{\text{Total of shift collision rates with the given shift condition}}{\text{Total number of shifts with the given shift condition}}$$

This approach accounts for the dependency between hours within a shift, allowing us to use the *t*-test for comparison.

2.1.4 Assumptions

We made simplifying assumptions based on the exploratory nature of this analysis and to rapidly examine the correlation between bus collisions and the operator's work hours. These assumptions should be part of considering how to use the analysis results and we recommend future work examine how these factors interact with bus collisions and operator work hours. We assumed the following:

- All shift conditions have a similar distribution of attributes:
  - Exposure to motor vehicles, persons, fixed objects, and other hazards that could result in a collision
  - Vehicle miles traveled
  - Light conditions, time of day, and day, evening, and night shifts
  - Operator experience and skill
  - Operator health, behavior, and riskiness
  - Continuous and split shifts
  - On-time performance
  - Bus length and age
- Bus operators do not engage in secondary employment when not working a shift.
- An operator cannot be involved in more than one collision during a shift.

Transit agencies do not schedule operators the same way. For the purposes of this study, the transit agencies agreed to the following shift definitions:

- Continuous shifts occur when an operator signs out and in with a rest duration of one hour or shorter.
- Split shifts occur when an operator signs out and in with a rest duration of more than one hour and fewer than eight hours. We combined these shift segments and analyzed them like a continuous shift.
- Separate shifts occur when an operator signs out and in with eight hours or more of rest.

We removed the rest time that occurred during shifts in our hours-of-service calculations.

2.2 Results: Potential Safety Hazards

This subsection features results for two hours-of-service elements: the time of collision in the operator's shift, and the operator's immediate rest days and workdays. These elements have the most operationally meaningful results. These two elements leverage the full hours-of-service data set with 90 million work hours. The remaining three elements use a subset of the hours-of-service data. We found the results of these three elements to be less operationally meaningful. Appendix A details our interpretations of these results and recommendations for future exploratory work.

For each hours-of-service element, we compared the collision rates for each shift condition to the overall collision rate using a *t*-test ($\alpha = 0.05$) and depicted the relationships with a graph. We interpret this graph as follows:

- The overall collision rate is the black horizonal line.
- The collision rate for each shift condition is a blue dot.
- The 95% confidence interval for each shift condition is a gray rectangle.
- If the blue dot does not appear inside the gray bar, then the collision rate represents a statistically significant difference from the overall average collision rate and the blue dot is circled in orange.

2.2.1 Time of Collision in the Operator's Shift

Figure 1 shows the collision rate based on the time of collision in the operator's shift in hours. We combined increments when collisions occurred 12 or more hours into the shift because these hours did not have enough data. The horizonal axis labels [1,2) indicate the increment includes shifts that were exactly one hour and does not include shifts that were exactly two hours.

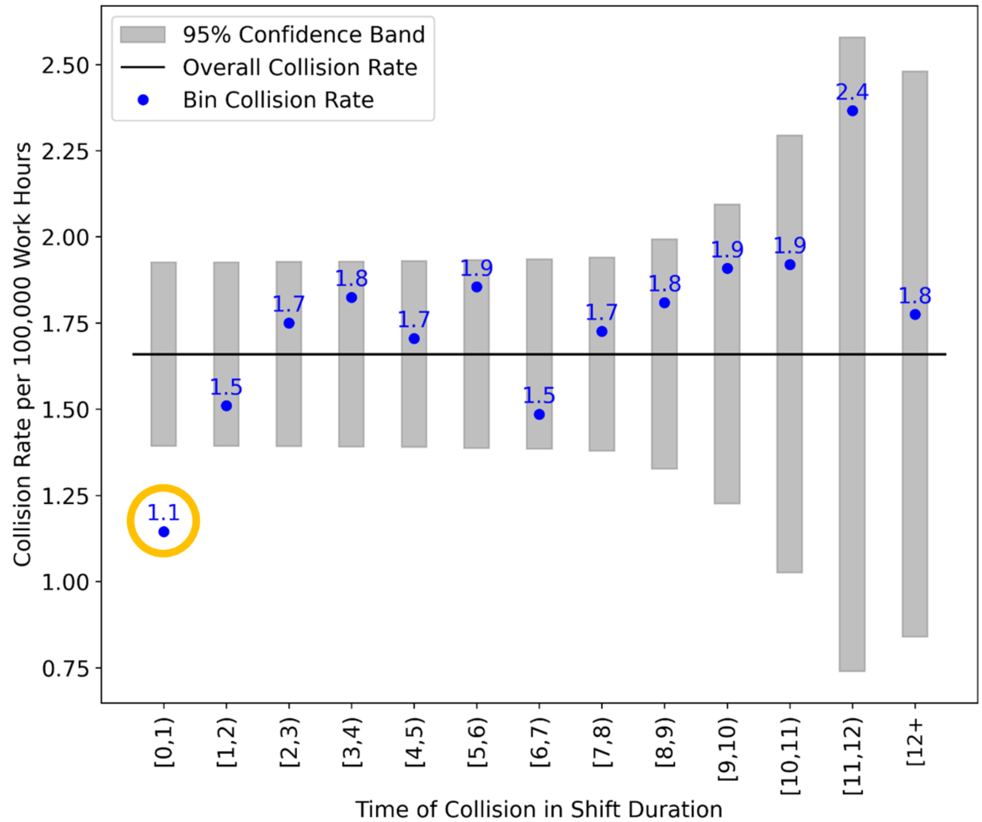

Figure 1. Bus Collision Rate by Time of Collision in Operator's Shift

Based on Figure 1, the collision rate during the first hour of a shift is lower than the average collision rate. Transit agencies indicated this result aligns with operations, as the bus operator typically does not spend the beginning of a shift behind the wheel, instead doing paperwork, reviewing routes, and inspecting the vehicle, among other duties. This data appears to bring down the average collision rate, as the hours 1–2 and 6–7 are the only others below average. For future work, we recommend analyzing the collision rates considering only the time when an operator is behind the wheel. We also recommend future work to standardize definitions for types of hours worked so transit agencies can voluntarily incorporate them into their operations and facilitate additional multi-agency analysis.

Transit agencies also noted increasing collision rates from hour 6 through hour 12 in Figure 1, but recognized that these collision rates are not statistically different from the average. Operationally, this potential trend occurs after a mid-shift meal break, which operators typically take in the fourth to sixth hours, potentially explaining the slight variation in collision rate during these hours. The collision rates are highest beyond the ninth hour and the confidence intervals are also larger based on the limited data available for these shifts. To investigate this potential trend and mitigate it accordingly, we recommend a future study with more bus collision and hours-of-service data involving additional transit agencies and considering less-severe collisions.

We also recommend the transit community consider what collision rate per shift represents an acceptable level of safety and develop and implement mitigations accordingly.

2.2.2 Operator's Immediate Rest Days and Workdays

Figure 2 captures the collision rate by the operator's immediate rest days and workdays. Rest days are on the left side, workdays are on the right, and "Null" indicates the initial shift for a new employee who had neither a rest day nor a workday on the previous day.

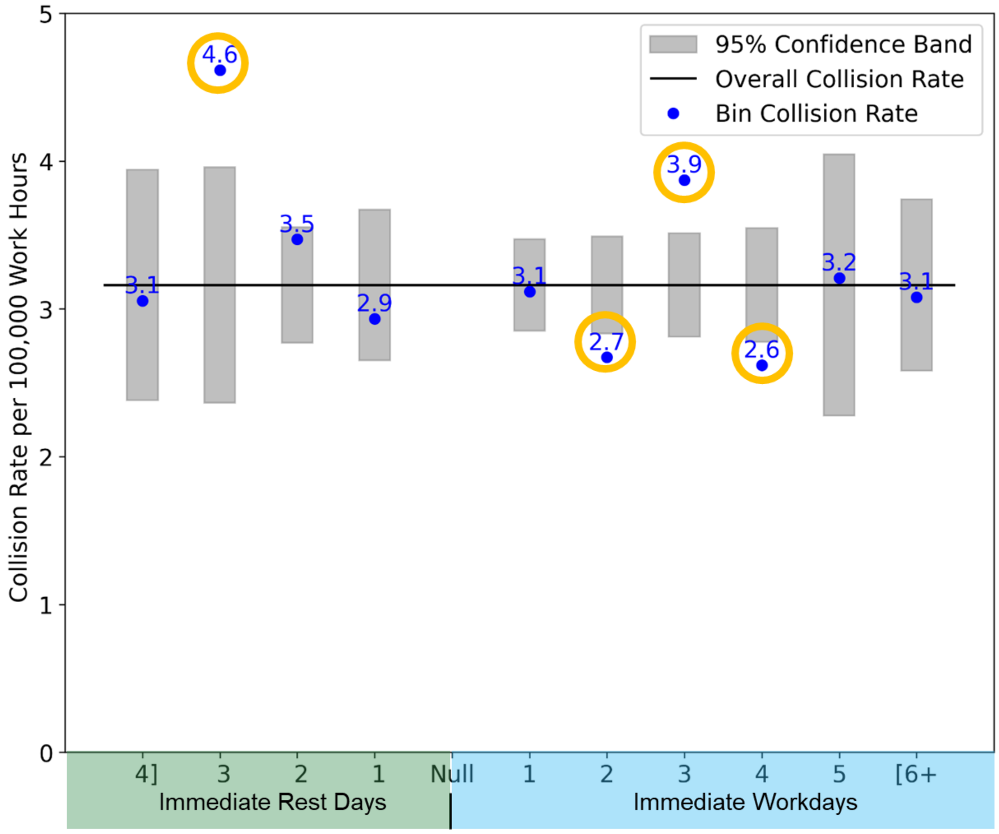

Figure 2. Bus Collision Rate by Operator's Immediate Rest Days and Workdays

Based on Figure 2, the collision rate following three rest days is higher than the average collision rate. Transit agencies confirmed this result aligns with their operational experience and internally generated safety trends. In general, many people spend long weekends pursuing activities that can sometimes result in them returning to work fatigued; this is likely also true for bus operators. Operationally, the higher collision rate may result from lower-performing operators taking long weekends more often or from long-duration shifts following a three-day weekend to make up for the missed time in the schedule. We recommend additional research into the collision rate after a three-day weekend, particularly examining operator experience and unusually long and short shifts, to assess this hazard and begin to formulate potential mitigations.

We are uncertain how to interpret the statistically significant differences in collision rate following two, three, and four consecutive workdays. One hypothesis is that this result may be influenced by operational changes during the pandemic, such as reducing bus routes, reducing the hours of operation provided to communities, or rotating operators to limit exposure to germs. Another hypothesis is that, considering operators typically work five consecutive days, operators drive more safely on the last day (after four consecutive days) knowing their days off are around the corner. We recommend exploring this potential trend with additional transit agencies and less severe collisions.

2.3 Discussion

Based on the exploratory nature of this analysis and the results, this subsection discusses the analysis limitations and potential actions to mitigate hazards associated with operator work hours.

2.3.1 Analysis Limitations

We acknowledge the following limitations associated with this analysis and offer recommendations for future work to improve the approach.

Transit Agency Operations: Although the participating transit agencies represent a range of sizes and geography for U.S. operations, this initial analysis considers only the five agencies that contributed data. We recommend additional agencies contribute collision and hours-of-service data to improve operational representation in future analyses.

Bus Collision Severity: This initial analysis examines bus collisions reported to NTD because this provides a standard collision definition to calculate a rate. The NTD captures the most severe collisions—those that result in fatality or harm to persons that requires immediate medical attention away from the scene; estimated property damage equal to or exceeding $25,000; and a vehicle to be towed away from the scene. Transit agencies contributed sensitive data about less-severe incidents, which are more frequent and can provide insights into trends about hazards before they result in severe collisions. We recommend future work invest in standardizing incident definitions and causal factors to set up analysis for lower-severity incidents. Such work can be valuable to identify and assess hazards associated with collisions beyond the operator's work hours.

Collision Data Quality: We matched only 58% of bus collisions from NTD to operator shifts due to the quality of collision data that agencies report to NTD and how agencies record operators involved in collisions. Specifically, transit agencies typically submit to NTD an initial assessment of the collision to meet the FTA's reporting requirement within 30 days of the collision. Via a separate workflow, agencies investigate the event and update internal data. The result is that the NTD and agency-internal collision data does not have a common incident identifier and often the time, description, location, and other key data attributes do not align. Further, agencies have not historically kept consistent records identifying which operators were involved in which collisions, though more recent collisions typically contain higher-quality information. We recommend future work to define workflows that guide transit agencies' recordkeeping and management of collision data.

Operator Duty Time: This initial analysis examines the time that an operator is on duty. This is consistent with traditional fatigue risk management. However, we recommend future analysis examine the time only when an operator is driving as well.

Time of Day and Day of the Week: This analysis did not consider the correlation between the collision rate and the time of day or the day of the week due to limited time and funding, though we have the data required to conduct the analysis. Research into professional drivers shows that the operator's circadian rhythm affects fatigue [25]. The Federal Aviation Administration (FAA) limits the maximum duty time for flight crews based on the shift's start time [26]. We recommend future analysis consider the collision rate by time of day and day of week as a safety measure.

Operator Sleep: This analysis does not consider the operator's amount and quality of sleep, which literature has identified as a key determinant in fatigue. We are not aware of recorded sleep data for bus operators. We recommend future studies examine the availability of operator sleep data to incorporate into the results.

2.3.2 Potential Actions to Mitigate Hazards Associated with Operator Work Hours

After considering the results and limitations, MITRE held a working session with the participating transit agencies to brainstorm potential actions. All agreed that the results were not sufficiently conclusive to act on.

Considering the exploratory nature of this pilot analysis, we considered potential ways agencies could incorporate the learnings into operations. If results were validated with additional data and agencies, agencies indicated they would explore adjusting operator scheduling practices to increase the shift types exhibiting the lowest collision rates and reduce shifts with the highest collision rates. We identified methods to adjust operator schedules, such as allocating funds to additional bus operators, negotiating hours-of-service rules with labor unions, exploring fatigue risk management programs, and coordinating with the FTA on hours-of-service and fatigue-related rulemaking. Based on the commercial motor vehicle industry's experience, we recommend any hours-of-service regulations account for the trade-off between the potentially decreased service hours, frequency, and routes with decreased collision risk [18].

The Toolbox for Transit Worker Fatigue [27] provides transit agencies with resources, methods, and techniques to reduce operator fatigue and minimize its effects, such as managing personal habits and behaviors, like sleep, exercise, and caffeine consumption; managing how operators report for duty with a fatigue hotline, rest breaks, and work variety; and managing personnel assignments, particularly through the extraboard and during special events.

We agreed that continuing to investigate how safety correlates with operator work hours would be worthwhile. Some agencies indicated plans to continue the work within their agency. We recommend analysis of more data addressing the identified limitations to deliver results that are robust enough to spur transit agencies to invest in mitigation.

3 Recommendations to Advance Transit Safety

Improving transit safety requires the entire transit community—including transit agencies, the FTA, labor unions, contractors, equipment suppliers, trade associations, and others—to contribute their expertise and data toward harmonized efforts. We recommend the transit community invest in the following three areas:

Analyze Bus Safety Hazards Associated with Hours of Service and Operator Fatigue: We found that collision rates are higher than average during shifts following three days without working and a pattern of increasing collision rates as operators work longer shifts. We recommend the transit community drive safety action related to these hours-of-service patterns with more bus collision and hours-of-service data. Specifically, we recommend involving more transit agencies and considering less severe collisions.

We also recommend future analysis address the limitations identified in Section 2.3.1 as follows:

- Analyze collision rates considering only the time when an operator is behind the wheel.

- Analyze collision rates after a three-day weekend, particularly examining operator experience and unusually long and short shifts.
- Analyze collision rates by time of day and day of the week.
- Analyze collision rates with interactions among hours-of-service elements (e.g., previous day’s work duration and rest duration).

We also see opportunities to leverage machine learning to more thoroughly identify potential trends in how hours of service correlate with safety.

Expand Multi-Agency Approach to Safety Analysis: We successfully demonstrated that multiple transit agencies can securely share data and resources to efficiently analyze a sensitive safety topic and formulate actions to reduce collisions. We see particular value in multi-agency analysis to inform proactive FTA rulemaking decisions with a high-resolution national perspective. We recommend that transit agencies and the FTA pursue multi-agency safety analyses to address shared safety and security challenges. Shared safety and security challenges that may benefit from multi-agency analysis include roadway and wayside worker protection, transit worker assaults, battery electric bus fires, rail operator fatigue, and street-running rail collisions. At the agency level, we also see an opportunity for transit agencies to set target levels of safety and act with mitigations accordingly.

Use Safety Data Standards to Unlock More Value: We encountered analytic challenges with extracting consistent safety data within agencies as well as aligning data definitions across agencies. These data challenges delayed our analysis process and limited the effectiveness of the results. We also identified untapped safety analysis potential related to collisions that are not reported to NTD, definitions of event types and causal factors, and linkage between operations and incident data. We recommend the transit community set and use industry-wide safety data standards to unlock faster, more efficient, and more robust shared analyses. Specifically, we recommend standards for safety incident definitions, data attribute definitions, data collection, data formats, and identifiers shared across data sets. The use of safety data standards is foundational to identify and assess hazards associated with transit incidents.

4 References

[1] FTA, FTA Safety Update, July 2024, https://www.transit.dot.gov/sites/fta.dot.gov/files/2024-07/FTA-Safety-Update-07-10-2024.pdf

[2] FTA, Transit Worker Hours of Service and Fatigue Risk Management, October 2023, https://www.federalregister.gov/documents/2023/10/30/2023-23916/transit-worker-hoursof-service-and-fatigue-risk-management

[3] FTA, Bus-to-Person Collisions Safety Advisory 23-1, September 2023, https://www.transit.dot.gov/regulations-and-programs/safety/bus-person-collisions-safety-advisory-23-1

[4] Transit Advisory Committee for Safety (TRACS), Reducing Bus Collisions Report: Ensuring Safety for Pedestrians and Cyclists, 2024, https://www.transit.dot.gov/sites/fta.dot.gov/files/2024-07/Reducing-Bus-Collisions-TRACS-Final-Report.pdf

[5] T. Åkerstedt, Consensus statement: Fatigue and accidents in transport operations, *Journal of Sleep Research*, vol 9, no. 4, pp. 395–395, 2000.

[6] J. Connor, R. Norton, S. Ameratunga, E. Robinson, I. Civil, R. Dunn, …, and R. Jackson, Driver sleepiness and risk of serious injury to car occupants: Population-based case control study, *BMJ*, vol. 324, no. 7346, p. 1125, 2002.

[7] S. Bioulac, J. A. M. Franchi, M. Arnaud, P. Sagaspe, N. Moore, F. Salvo, and P. Philip, Risk of motor vehicle accidents related to sleepiness at the wheel: A systematic review and meta-analysis, *Sleep*, vol. 41, no. 7, 2018.

[8] National Transportation Safety Board, Most Wanted List Archive, accessed December 16, 2024, https://www.ntsb.gov/Advocacy/mwl/Pages/mwl_archive.aspx

[9] TRACS, TRACS 14-02 Report: Establishing a Fatigue Management Program for the Bus and Rail Transit Industry, 2016, https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/TRACS_Fatigue_Report_14-02_Final_(2).pdf

[10] American Public Transportation Association, Fatigue Management Program Requirements, 2017, https://www.apta.com/wp-content/uploads/Standards_Documents/APTA-RT-OP-S-023-17.pdf

[11] FAA, Aviation Safety Information Analysis and Sharing (ASIAS) , accessed December 16, 2024, https://portal.asias.aero/overview

[12] National Highway Traffic Safety Administration, Partnership for Analytics Research in Traffic Safety (PARTS), accessed December 16, 2024., https://www.nhtsa.gov/parts-partnership-for-analytics-research-in-traffic-safety

[13] Federal Railroad Administration, Railroad Information Sharing Environment (RISE), accessed December 16, 2024, https://railroads.dot.gov/railroad-safety/divisions/safety-partnerships/railroad-information-sharing-environment-rise

[14] H. Biggs, D. Dingsdag, and N. Stenson, Fatigue factors affecting metropolitan bus drivers: A qualitative investigation, *Work*, vol. 32, no. 1, pp. 5–10, 2009, doi: 10.3233/WOR-2009-0810.

[15] K. A. Miller, A. J. Filtness, A. Anund, S. E. Maynard, and F. Pilkington-Cheney, Contributory factors to sleepiness amongst London bus drivers, *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 73, pp. 415–424, August 2020, doi: 10.1016/j.trf.2020.07.012.

[16] Transportation Research Board, Pay and Working Conditions in the Long-Distance Truck and Bus Industries: Assessing for Effects on Driver Safety and Retention, 2024, https://nap.nationalacademies.org/catalog/27892/pay-and-working-conditions-in-the-long-distance-truck-and-bus-industries

[17] U.S. Department of Transportation, What Is a Safe System Approach?, accessed October 19, 2024, https://www.transportation.gov/NRSS/SafeSystem

[18] National Academies of Sciences, Engineering, and Medicine, Commercial Motor Vehicle Driver Fatigue, Long-Term Health, and Highway Safety: Research Needs, Washington, DC: The National Academies Press, 2016, doi: 10.17226/21921.

[19] J. Huting, Identifying Factors That Increase Bus Accident Risk by Using Random Forests and Trip-Level Data, *Transportation Research Record Journal of the Transportation Research Board*, no. 2539, pp. 149-158, 2016.

[20] https://www.researchgate.net/publication/303024391_Identifying_Factors_That_Increase_Bus_Accident_Risk_Using_Random_Forests_and_Trip-Level_Data

[21] Y. Hlotova, O. Cats, and S. Meijer, Measuring bus drivers' occupational stress under changing working conditions, *Transportation Research Record: Journal of the Transportation Research Board*, no. 2415, pp. 13–20, 2014.

[22] L. Staes, J. Godfrey, R. Saliceto, R. Yegidis, and D. Byrnes, FTA Standards Development Program: Medical Fitness for Duty and Fatigue Risk Management, Federal Transit Administration, June 2022, https://www.transit.dot.gov/sites/fta.dot.gov/files/2022-07/FTA-Report-No-0223.pdf

[23] National Transit Database, August 26, 2024.

[24] National Transit Database, April 2, 2024.

[25] H. Zhang, X. Yan, C. Wu, and T. Qiu, Effect of circadian rhythms and driving duration on fatigue level and driving performance of professional drivers, *Transportation Research Record: Journal of the Transportation Research Board*, no. 2402, pp. 19–27, 2014.

[26] FAA, Final Rule on Flight Crew Duty and Rest Requirements, 2012, https://www.faa.gov/sites/faa.gov/files/about/office_org/headquarters_offices/agc/Final%2520Flight%2520Duty%2520Rule.pdf

[27] J. Gertler S Popkin, D Nelson, K. O'Neil, Toolbox for Transit Operator Fatigue, Transit Cooperative Research Program Report 81, 2002, Transportation Research Board, https://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_81.pdf

Appendix A Additional Results

This appendix describes results for the hours-of-service elements for which we could not identify robust and meaningful operational interpretations, as discussed in Section 2.3. We provide these results for future work to build on.

A.1 Operator's Immediate Rest Duration

Figure A-1 captures the collision rate based on the operator's immediate rest duration in hours. It also does not include shifts with an immediate rest duration of one day or more because they are considered in the measure "immediate rest days and workdays." In total, this measure leverages 67 million hours worked in 7½ million shifts.

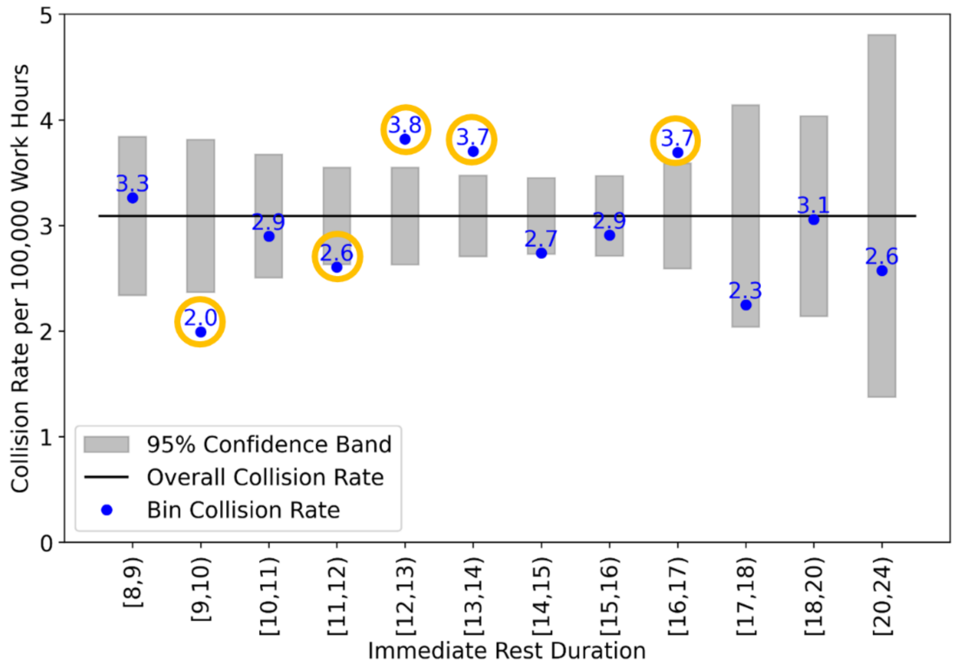

Figure A-1. Bus Collision Rate by Operator's Immediate Rest Duration

Figure A-1 does not capture an obvious trend in collision rate. Transit agencies could not identify operational reasons for the statistically significant differences in collision rates. Considering transit agencies modified operations during and after the COVID-19 pandemic, we evaluated the collision rate by pre-, during, and post-pandemic periods. Results remained unclear.

Based on this inconclusive result, we recommend evaluating validity of the assumptions (e.g., distribution of split shifts among the increments) and accounting for such factors in future analysis. Transit agencies suggested that the time of day might impact the collision rate, and we recommend this topic for future analysis. Also, we recommend analysis with more collisions and operator shifts to potentially generate clearer results.

A.2 Operator's Work Hours on the Previous Day

Figure A-2 highlights the collision rate based on the operator's work hours on the previous day in hours. The figure does not include shifts with no work hours in the previous day because they are considered in the measure “immediate rest days and workdays.” In total, this measure leverages 67 million hours worked in 7½ million shifts.

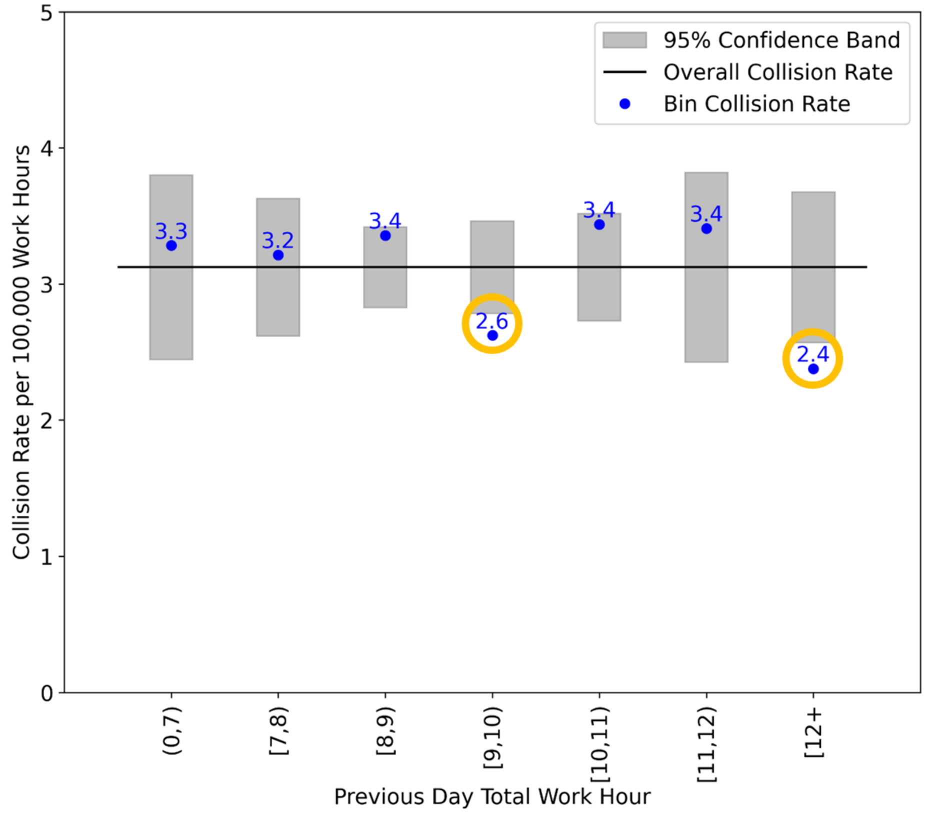

Figure A-2. Bus Collision Rate by Operator’s Work Hours on the Previous Day

Figure A-2 shows that the collision rate is lower on the day following a 9- to-10-hour shift and a shift of 12+ hours. Transit agencies interpreted that such long shifts are unusual and may indicate experienced operators, who typically have fewer collisions, working overtime. These shifts may also have short durations as a scheduling practice to minimize operator fatigue on the day after a long shift; collision rates in short shifts appear slightly lower than long shifts, per Figure 1. We recommend additional analysis of operator experience and unusually long and short shifts to assess how much these factors influence collision rates.

A.3 Operator’s Work Hours in the Previous Week

Figure A-3 describes the bus collision rates by the operator’s work hours in the previous week in hours. The figure does not include shifts with no work hours in the previous week because they are considered in the measure “immediate rest days and workdays.” In total, this measure leverages 89 million hours worked in 9.8 million shifts.

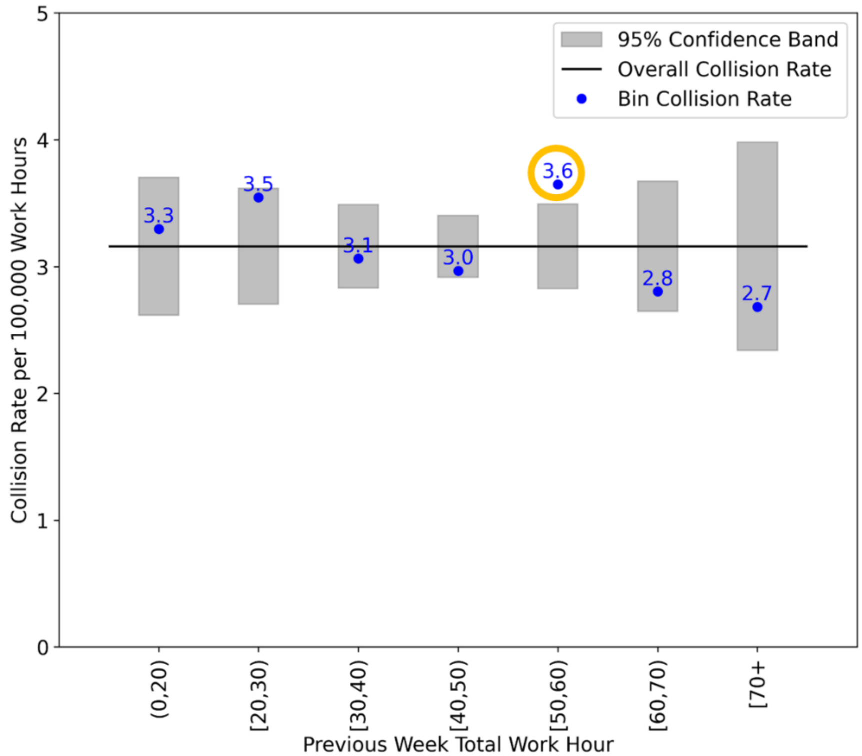

Figure A-3. Bus Collision Rate by Operator's Work Hours in the Previous Week

Figure A-3 shows that the collision rate is different for shifts after an operator works 50–60 hours in the previous week. Like the operator's work hours on the previous day, transit agencies interpreted that a 50- to 60-hour work week may represent less-experienced operators and therefore a higher collision rate. We recommend additional analysis of operator experience and unusually long and short shifts to assess how much these factors influence collision rates.