MOUNTAIN-PLAINS CONSORTIUM

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PEDESTRIAN SAFETY AND TRAFFIC OPERATIONS NEAR TRANSIT STOPS

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16. Abstract

This research project's objective was to investigate the impacts of transit stop location (near-side versus far-side) on pedestrian safety and traffic operations at intersections. Three different video-based behavioral observation data collections at signals in Utah were utilized and studied: (1) transit stop events (interactions between transit vehicles and other vehicles) and transit rider crossing behaviors and vehicle conflicts; (2) pedestrian conflicts with right-turning vehicles (conflict severity, driver/pedestrian reactions); and (3) pedestrian crossing behaviors (crossing location, crossing behaviors). These outcomes were then statistically compared for near-side versus far-side transit stop locations.

From the results, far-side transit stops are better for general traffic operations. Although transit departure delays are more likely and impactful at far-side stops, actions can be taken to improve transit operations there. On the other hand, the evidence pointed toward far-side transit stops being worse for pedestrian safety. Specifically, conflicts at far-side stops were more severe, and drivers were less likely to slow/stop for pedestrians. This finding corroborates prior Utah-based research results that there were more pedestrian crashes at intersections with more far-side transit stops. Reconciling these differing findings likely requires improving pedestrian safety at some far-side transit stops, and prioritizing safety over operational efficiency at other near-side transit stops.

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Pedestrian Safety and Traffic Operations Near Transit Stops

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ABSTRACT

This research project's objective was to investigate the impacts of transit stop location (near-side versus far-side) on pedestrian safety and traffic operations at intersections. Three different video-based behavioral observation data collections at signals in Utah were utilized and studied: (1) transit stop events (interactions between transit vehicles and other vehicles) and transit rider crossing behaviors and vehicle conflicts; (2) pedestrian conflicts with right-turning vehicles (conflict severity, driver/pedestrian reactions); and (3) pedestrian crossing behaviors (crossing location, crossing behaviors). These outcomes were then statistically compared for near-side versus far-side transit stop locations.

From the results, far-side transit stops are better for general traffic operations. Although transit departure delays are more likely and impactful at far-side stops, actions can be taken to improve transit operations there. On the other hand, the evidence pointed toward far-side transit stops being worse for pedestrian safety. Specifically, conflicts at far-side stops were more severe, and drivers were less likely to slow/stop for pedestrians. This finding corroborates prior Utah-based research results that there were more pedestrian crashes at intersections with more far-side transit stops. Reconciling these differing findings likely requires improving pedestrian safety at some far-side transit stops, and prioritizing safety over operational efficiency at other near-side transit stops.

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EXECUTIVE SUMMARY

Pedestrian crashes are more frequent at intersections with transit stops. Recent research in Utah found that the association between pedestrian crashes and transit stops was stronger for far-side transit stops (where the transit vehicle stops after passing through the intersection), potentially suggesting that far-side stops are less safe for pedestrians. This was a surprising finding because transit agency experience and expectations are that near-side transit stops (where the transit vehicle stops before passing through the intersection) are less safe and less desirable because transit vehicles could block other vehicles from turning right, thus leading to more conflicts and delays while also obstructing the views of pedestrians crossing in front of the transit vehicle at the intersection. This suggests the need for more detailed analysis and study to better understand the impact of transit stop locations on pedestrian safety and traffic operations.

The objectives of this research project were to investigate the impacts of transit stop location (near-side versus far-side) on pedestrian safety and traffic operations at intersections, and to provide recommendations for improvements that consider both outcomes. To achieve this objective, three different data collections were utilized, all involving extracting information from videos recorded at several dozen signalized intersections in Utah. Data collection 1 was collected for this project, and it captured information about each transit stop event, each pedestrian who boarded or alighted, and each time they crossed the street or interacted with a vehicle while crossing. Data collections 2 and 3 were collected for prior projects: one about pedestrian conflicts with right-turning vehicles, and the other about pedestrian crossing behaviors at intersections. Across all data collections, several relevant outcomes were identified relating to traffic operations (traffic impacts on public transit operations, and transit vehicle impacts on other traffic) and pedestrian safety (pedestrian crossing location, pedestrian crossing behaviors, conflict severity, and driver/pedestrian reactions to conflicts). These outcomes were compared for near-side versus far-side transit stop locations using bivariate analysis methods, specifically Welch's t-test and Fisher's exact test.

For public transit operations, arrival delays and impacts were more likely and more severe at near-side stops, but departure delays were much more likely and impactful at far-side stops. For other traffic, transit vehicles delayed other vehicles much more often and more significantly at near-side stops, whereas somewhat more passing was observed at far-side stops. This suggests that far-side transit stops are certainly better for general traffic operations because fewer other vehicles are impacted by transit stop events. Results for public transit operations are more equivocal, but given the predominance of far-side transit stops at signalized intersections in Utah, actions can be taken to improve transit operations at far-side stops. Example actions include constructing curb extensions to make in-lane far-side stops, or enacting and enforcing laws requiring overtaking vehicles to yield to transit vehicles entering traffic while a yield sign on the transit vehicle is flashing.

For pedestrian safety, there were some contradictory or inconclusive findings regarding pedestrian crossing locations and pedestrian crossing behaviors; yet overall, the evidence pointed toward far-side transit stops being worse for pedestrian safety. Specifically, conflicts at far-side stops were more severe (as measured by a surrogate safety metric), with less time between when pedestrians and vehicles were at the same point. Also, drivers were less likely to slow down or stop for pedestrians at far-side stops. Also, there was slightly more evidence suggesting that more pedestrians cross mid-block near far-side transit stops than evidence that more pedestrians cross mid-block by near-side transit stops. These results suggest that adverse safety outcomes at far-side transit stops may be affected by both pedestrian and driver behaviors and actions. This conclusion also corroborates prior Utah-based research finding that there were more pedestrian crashes at signalized intersections, especially with far-side transit stops, since conflicts are precursors to crashes (and surrogate safety measures).

This raises a conundrum: What should be done if far-side transit stops are better (or can be made better) for traffic operations, but far-side stops are worse for pedestrian safety? Generally, there are two possible approaches. First, to make far-side transit stops safer for pedestrians, implement strategies such as using curb extensions and tighter corner radii to control vehicle speeds, or using traffic signal timing/phasing to provide more protected pedestrian crossing movements. Second, pedestrian safety could be prioritized over traffic operations, and near-side transit stops could be recommended in certain situations. This approach fits within the Vision Zero goals that many cities and states (Utah included) have adopted, prioritizing safety over efficient operations. A combination of both approaches, tailored to unique situations, may be the best ultimate recommendation for improving both traffic operations and pedestrian safety through transit stop placement.

1. INTRODUCTION

1.1 Background

Pedestrian injuries and fatalities continue to show a troubling and stubborn increase (in both number and share) nationally and in Utah. According to a recent report from the Governors Highway Safety Association (GHSA, 2024), pedestrian fatalities have increased by around 75% since 2010 (compared with 22% for other modes) and now represent almost 18% of all traffic deaths (up from 13% in 2010). The majority of pedestrian fatalities occur on non-freeway arterials that may be difficult to cross except at signalized intersections. In 2022, 52 fatal and 819 injury crashes involving pedestrians were reported on Utah streets and highways (UDPS, 2024a). As vulnerable road users, pedestrians are much more likely than vehicle occupants to be injured or killed when involved in a collision.

Past research has shown that pedestrian crashes are more frequent at intersections with transit stops. Recently completed research projects for the Utah Department of Transportation (UDOT) found that pedestrian crashes at signalized intersections were more frequent when there were more transit stops nearby (Singleton et al., 2021; Singleton et al., 2022). The association was stronger for **far-side transit *stops*** (where the transit vehicle stops after passing through the intersection) (Islam et al., 2022), potentially suggesting that far-side transit stops are less safe for pedestrians. This is surprising because transit agency experience and expectations are that **near-side transit stops** (where the transit vehicle stops before passing through the intersection) are less safe and less desirable because side-running transit vehicles could block other vehicles from turning right, thus lead to more conflicts and delays while also obstructing views of pedestrians crossing in front of the transit vehicle at the intersection. As a result, more detailed analysis and study is required to fully understand the impact of transit stop locations on pedestrian safety. This project attempts to add insights into potential causes of adverse pedestrian safety outcomes at intersections with transit stops.

Understanding pedestrian behaviors can be essential to gaining some insights about crash causes. Based on Utah crash reports, pedestrian behaviors play a role in around 50% of pedestrian crashes, including contributing factors such as improper crossing, darting, not visible, inattentive, failure to obey traffic signs/signals, in roadway improperly, and failure to yield right of way (UDPS, 2020). Many of these behaviors and violations are particularly relevant at intersection transit stops. These behaviors may be more common in certain locations (e.g., at far-side transit stops) or under certain conditions (e.g., nighttime, low traffic volumes), but there is limited research documenting these locations and conditions. Recent research for UDOT has studied some of these pedestrian behaviors when crossing streets (Singleton et al., 2023a) and interacting with right-turning motor vehicles (Singleton et al., 2023b). However, this past work did not focus on locations with transit stops. The current project intends to help fill this gap by studying pedestrian behaviors near transit stops, thus informing potential design and operational treatments (and educational or enforcement initiatives) to improve pedestrian safety while mitigating negative operational impacts.

Finally, these previous Utah-based studies and research in other states have not comprehensively considered or balanced the impacts of transit stop location at intersections on pedestrian safety with the impacts on transit and other vehicle operations in a meaningful way. There is often a tradeoff between operational efficiency and safety regarding the placement of transit stops. For example, if a transit stop is on the near-side of an intersection, it tends to promote pedestrian use of marked crosswalks but may increase delay if buses often arrive on green instead of red. This project takes steps to better understand both the safety and operational implications of transit stop locations on near-side versus far-side of intersections.

1.2 Literature Review

Mirroring the research already mentioned in Utah (Singleton et al., 2021; Singleton et al., 2022), many other studies have found that intersections and other places with more nearby transit stops tend to experience more pedestrian crashes. These studies have been conducted throughout the United States—California (Singh et al., 2022), Florida (Lin et al., 2019), Maryland (Clifton & Kreamer-Fults, 2007), New York (Ashraf et al., 2022), North Carolina (Pulugurtha & Penkey, 2010; Pulugurtha & Srirangam, 2022), Texas (Geedipally, 2023), and Washington (Hess et al., 2004)—and in other countries—Canada (Osama & Sayed, 2017; Shahla et al., 2009) and Peru (Quistberg et al., 2015) —among other examples. While there is a logical explanation for these findings—more transit stops implies more pedestrian transit riders, which increases pedestrian exposure to motor vehicle traffic at intersections, and exposure is a strong predictor of crash frequencies—these relationships have held even when controlling for pedestrian exposure (Islam et al., 2022).

Several studies related to the built environment provide further insights into the relationship between transit stops and pedestrian safety, highlighting the significant influences of location. Land use factors, such as the presence of discount stores, convenience stores, and fast-food restaurants, significantly influence pedestrian crash rates (Lin et al., 2019). Transit stops along street segments near parks (Yu & Woo, 2022) and in areas with more big box stores and gas stations (Yu, 2022) have been found to have a higher number of pedestrian crashes. However, having more pedestrian connectivity and more pedestrian volumes in an area has been found to reduce the severity of pedestrian crashes (Clifton et al., 2009; Hu et al., 2024). These results highlight the importance of strategic planning and design in enhancing pedestrian safety around transit stops.

Few studies have investigated differences in pedestrian safety for transit stops placed on the near-side versus the far-side of the intersection. As previously mentioned, prior research in Utah (Islam et al., 2022) found that the number of far-side transit stops at an intersection increased the predicted number of pedestrian crashes much more than the number of near-side transit stops. Alternatively, Campbell et al. (2003) and Nabors et al. (2008) suggest that far-side transit stops have safety advantages because they encourage pedestrians to cross behind the transit vehicle, thereby increasing their visibility to drivers.

More research and guidance exist regarding the impacts of transit stop placement (i.e., near-side versus far-side locations) on public transit and traffic operations. Generally, far-side transit stops have been identified as more favorable than near-side or mid-block stops (Tirachini, 2014). Near-side transit stops are slower to serve (by several seconds, on average) as compared with far-side stops (Diab & El-Geneidy, 2015). Far-side stops reduce other vehicle queuing, provide more maneuvering space for non-transit vehicles, and minimize delays caused by passenger boarding for right-turning vehicles (Terry & Thomas, 1971). Far-side stops are also particularly beneficial at complex intersections with heavy turning volumes (TriMet, 2010). Among far-side stop designs, in-lane stops prioritize transit operations by eliminating pull-out and re-entry times, but they can cause traffic spillbacks on single-lane streets. Far-side pull-out stops efficiently use intersection space and have minimal effects on general traffic, although transit vehicles may be delayed when trying to re-enter the travel lane (Nabors et al., 2008; NACTO, 2016).

In summary, while transit stops significantly impact pedestrian safety, particularly in terms of crash frequency and severity, the operational design, predictability, and strategic placement of these stops are crucial in mitigating risks and operational impacts. Therefore, careful planning of transit stop locations is essential to ensure that the benefits to traffic operations do not come at the expense of pedestrian safety.

1.3 Research Objectives

The objectives of this research project are to:

1. Investigate the impacts of transit stop location (near-side versus far-side) on pedestrian safety and traffic operations at intersections
2. Provide recommendations for improving both pedestrian safety and traffic operations at intersections with transit stops

The remainder of this report is structured as follows. Chapter 2 describes the study area in Utah, the three data collections utilized in this work, and the analysis methods that were applied. Chapter 3 presents results for the analyses regarding traffic operations and pedestrian safety, including insights from interactions between transit vehicles and other vehicles, pedestrian crossing behaviors, and interactions between pedestrians and turning vehicles. The concluding Chapter 4 discusses the key findings in relation to objective 1, offers recommendations in relation to objective 2, and describes study limitations and opportunities for future research.

2. DATA AND METHODS

2.1 Study Area: Utah

This project's study area included intersections with transit stops in Utah. A medium-sized state located in the Intermountain West, Utah was the 31st-most populous state in 2020, but it had the fastest percentage growth (18%) of any U.S. state between 2010 and 2020 (U.S. Census Bureau, 2021). Although Utah ranks 40th among states by statewide population density, it is actually one of the most urbanized states, with nearly 90% of the population living within an urbanized area (U.S. Census Bureau, 2024). Around 75% of the population lives in four counties along what is called the Wasatch Front region, which is also where the majority of the public transit service in the state is provided by the Utah Transit Authority (UTA). UTA operates one regional rail line, three light rail lines, one streetcar line, two bus rapid transit lines, and several dozen bus lines. In 2022, UTA had an annual ridership of over 31 million unlinked passenger trips, with an average weekday ridership of over 100,000 (FTA, 2023). A few other agencies operate transit services in smaller regions and cities throughout Utah.

Pedestrian safety trends in Utah (UDPS, 2024b) mirror those seen nationally. Except for a COVID-induced decline in 2020 and part of 2021, pedestrian crashes and fatalities have continued to increase in recent years. In 2010, there were 716 pedestrian-involved crashes, of which 27 were fatal (4%) and 104 were suspected serious injuries (15%). In 2023, there were 931 pedestrian-involved crashes, of which 40 were fatal (4%) and 172 were suspected serious injuries (18%). That is a 30% increase in the number of pedestrian crashes, and a 62% increase in the number of fatal or suspected serious injury crashes involving pedestrians. Statistics are not publicly available about how many of these crashes involved public transit riders or occurred at or near transit stops.

Figure 2.1 shows the study locations within the context of the state of Utah (left) and the Wasatch Front region (right). As described in the following sections, the analysis in this report utilized three different data collection efforts, so the sites from each data collection effort are shown in different colors on the maps.

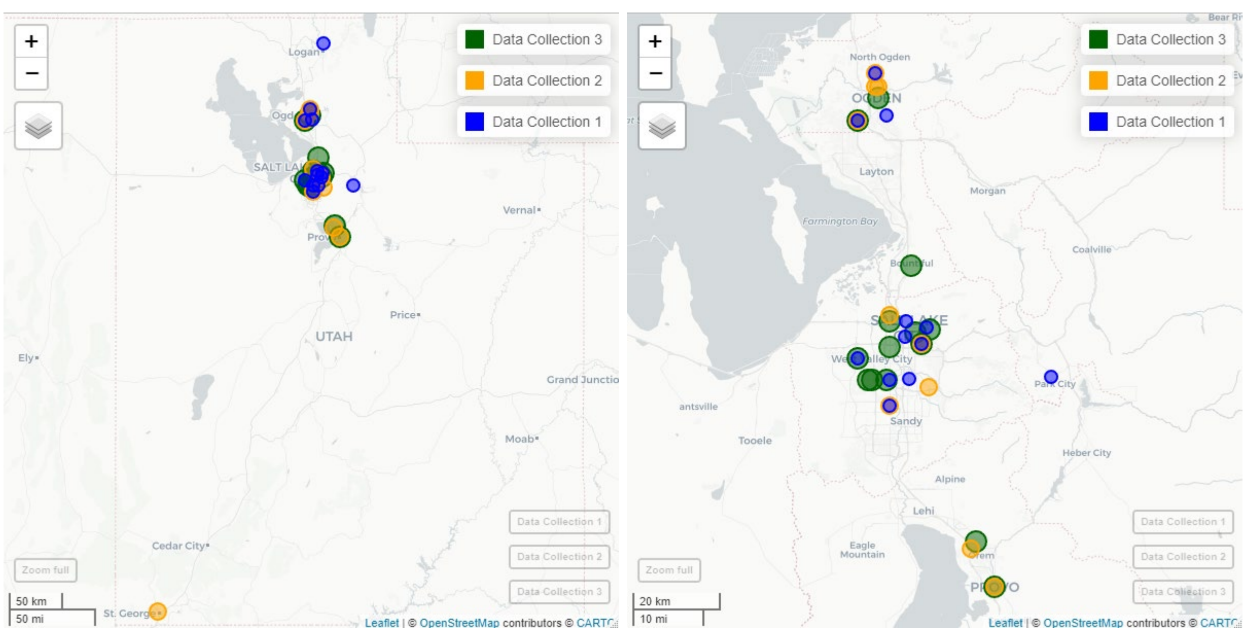

Figure 2.1 Maps of Utah (left) and the Wasatch Front (right), showing study locations

2.2 Data Collection 1: Transit, Pedestrian, and Vehicle Interactions

Original data were collected for this project to identify the impacts of near-side versus far-side transit stop locations on pedestrian safety and traffic operations at intersections. The first step was to identify potential study locations from a population of signalized intersections in Utah with nearby transit stops. Various stop, schedule, and ridership datasets from most Utah transit agencies—including the Utah Transit Authority (UTA), the Cache Valley Transit District (CVTD), and Park City Transit—were assembled, merged, and processed to obtain a spatial database of transit stops, their average daily trip frequency, and (when available) their average daily ridership. These transit data were then merged with traffic signal information to create another spatial database of signals that tabulated the number of near-side, far-side, and total transit stops (along with average daily trip frequency and ridership) at each location. Consistent with previous research in Utah (Singleton et al., 2021), a 300-ft buffer from the center of each intersection was used to determine if a transit stop was "near" an intersection. Near-side stops were on the "inbound" side of the intersection, while far-side stops were on the "outbound" side of the intersection.

In the second step, specific study locations were selected from this list. The research team considered multiple factors when selecting study locations. First, locations had to have an existing overhead traffic camera (operated by UDOT) nearby, since this was planned to be the primary method for collecting data on traffic operations and pedestrian safety. Second, they needed to have a sufficient level of ridership and/or trip frequency in order to make it feasible to collect a sufficient quantity of data, given limited resources. Third, the research team relied upon expert knowledge and advice from members of a technical advisory committee (including transit agency staff members) for recommendations on locations to study. Fourth, this study's authors also tried to balance sites within the region and to obtain data from places with different operational contexts, design features, and surrounding environments. In the end, 15 transit stops at 13 intersections were selected for this data collection effort.

Third, at each of these study locations, the research team recorded around two days of transit stop video using overhead traffic cameras operated by UDOT. The video views captured the transit stop itself, but not all of the cameras were positioned in such a way as to also capture the adjacent intersection crosswalks. Therefore, at some sites, it was not possible to observe pedestrian crossing behaviors or potential conflicts between pedestrians and vehicles. Most of the videos (for eight transit stops) were recorded on weekdays in June 2023. However, at some locations, similar videos recorded by the authors for previous research projects (Singleton et al., 2020; Singleton et al., 2023a; Singleton et al., 2023b) could also to be used: August 2019 (three), June 2020 (one), November 2021 (one), and late May/early June 2022 (two).

Fourth, once videos were recorded, data extraction could begin in earnest. For this step, trained observers (undergraduate students) watched the videos and recorded information about every transit stop event and every person who boarded or alighted the transit vehicle. To ensure consistent data collection across multiple observers, a detailed data collection form was created (along with a comprehensive training document) to walk video observers through a series of questions, split into multiple sections:

- **Section 1, General information**: This section had basic information about who was filling out the form, the specific location being studied, whether the transit stop was a near-side or far-side stop, and the data shown in the video.
- **Section 2, Transit stop event information**: This section contained information specific to the transit stop event itself. Information included the time the transit vehicle arrived at the stop, the number of people who alighted (got off from) or boarded (got on to) the transit vehicle, and the time the transit vehicle left the stop. To help understand traffic operations, information was also

obtained about whether the transit vehicle was delayed by traffic when arriving at or leaving the stop, whether other traffic was delayed (or opted to change lanes) by the transit vehicle while it was stopped, and some other information about interactions between the transit vehicle and other traffic.

- **Section 3, Pedestrian information**: This section was filled out for every person (up to a maximum of 10) who boarded or alighted the transit vehicle during that stop event. Pedestrian-specific information included: whether the person was boarding or alighting; the person's age and gender (as best could be seen from the videos); and whether the person was traveling with others, carrying a load, appeared distracted, or was using a mobility device (stroller, wheelchair, skateboard, scooter, or bicycle). For people who were boarding, the form collected information about where they came from (if it could be seen, and if they crossed the street and where), when they arrived at the transit stop, and when they stepped on to the transit vehicle. For people who were alighting, the form recorded when they stepped off from the transit vehicle, when they left the transit stop, and where they went to (if it could be seen, and if they crossed the street and where).
    - **Subsection A, Crossing behaviors**: Only for transit riders who could be observed crossing at the intersection, a subsection of the form collected follow-up information about their crossing behaviors. This included which street was crossed (main or side), when they started and finished crossing the street, what behaviors they did while crossing (e.g., outside of the crosswalk markings, changing speed, paused, were distracted, or crossed in front of or behind the transit vehicle). In addition, the form collected information about whether the pedestrian "interacted" with a motor vehicle while crossing, which was defined to be whether the pedestrian and the vehicle passed the same point within three seconds of each other. This was used to define a "conflict" for the purposes of this study.
    - **Subsection B, Vehicle conflicts**: If a short-duration interaction or conflict was noted, a second subsection of the form collected details about the pedestrian–vehicle conflict. Information was collected about the pedestrian movement (entering, exiting, in the middle of the crosswalk), the driver movement (turning right, turning left, driving straight), the vehicle type (large, medium, small), the times when the pedestrian and the vehicle passed the "conflict point," any pedestrian reactions to the conflict, and any driver reactions to the conflict. (These reactions are described in a later section.)

Following data collection, a quality control process was used to check the data and fix any errors identified. This process involved spot checking a sample of observations at each location against the original videos; if systematic issues were found for a site or for an observer, they were fixed for those data and the issue was communicated to the observer to be addressed in future data collection. The team also performed several automated checks of the data for missing, illogical, or extreme responses on key variables, such as negative or unexpectedly long transit vehicle dwell times or pedestrian waiting or crossing times.

2.2.1 Descriptive Statistics

Finally, after the data from each study location were collected and checked, they were combined and processed into the final datasets to be used for analysis. Two different datasets were constructed, given the nature of the data collected from the videos: (a) data about each transit stop event, and (b) data about each pedestrian transit rider. In the end, from the videos recorded at 13 intersections (six with a near-side transit stop, six with a far-side transit stop, and one with both a far-side and near-side stop), there were 1,592 observations about transit stop events and 2,582 observations about pedestrian transit riders, of which 1,115 had an observed crossing and 60 had an observed conflict with a motor vehicle. For the purposes of this study, several dependent variables were considered.

- ***Traffic operations***
    - **Transit vehicle was delayed**: For each transit stop event, the form recorded whether the transit vehicle was delayed by traffic when arriving at the stop, and when leaving the stop. If either were true, a follow-up question asked how many vehicles were blocking the transit vehicle (when it was arriving) or who passed the transit vehicle (while it was delayed when leaving). These questions were used to understand ways in which other traffic negatively affected the operation of the transit vehicle during the stop event.
    - **Other traffic was delayed**: The form also recorded whether other traffic was delayed by the transit vehicle while it was stopped (and, if so, how many vehicles were delayed), and whether other vehicles changed lanes (and, if so, how many) in order to pass the stopped transit vehicle. These questions were used to understand ways in which the transit stop event negatively affected the operation of other traffic.
    - **Stopping location**: Finally, the data collection answered two additional questions. The first question was whether the transit vehicle stopped for passengers but not at the stop location, which could have happened because other vehicles were blocking access to the stop. The second question was whether the transit vehicle was blocking a driveway or intersection while it was stopped, which could have negatively affected the operation of other traffic.
- ***Pedestrian safety***
    - **Pedestrian crossing location**: If the transit rider crossed the street (before boarding or after alighting) and the intersection was visible from the view of the video, the crossing location was recorded. This was a binary variable with two options: crossed at an intersection or a marked crossing or crossed mid-block away from an intersection or marked crossing. Crossing away from a legal crossing location is considered an unsafe pedestrian behavior.
    - **Pedestrian crossing behaviors**: Also, the form recorded if the pedestrian did any of the following while crossing: was outside of the crosswalk markings for most if not all of the crossing, changed speed (e.g., walk to run, or run to walk), paused in the middle of the street, seemed distracted by phone or something else, crossed just in front of the transit vehicle (if present), or crossed just behind the transit vehicle (if present). All of these were assumed to be potentially hazardous pedestrian crossing behaviors because they implied crossing in an unexpected location, at an unexpected rate of speed, or not observing the surroundings while crossing.
    - **Conflict severity**: For each instance of a pedestrian–vehicle conflict, this was measured using the time difference between when the pedestrian and the vehicle were at the conflict point. The absolute value of this time difference is sometimes termed the encroachment time (ET). In this situation, smaller values (less ET) imply more severe conflicts that were almost a crash.
    - **Pedestrian reaction to the conflict**: Several possible reactions were noted: stopped and waited for the vehicle, slowed down to avoid a collision, sped up or ran to avoid a collision, changed direction, and no obvious reaction. These were grouped into two pedestrian reaction categories: no obvious reaction, and other.
    - **Driver reaction to the conflict**: Several possible reactions were noted: driver fully stopped, driver slowed down, driver sped up, driver swerved, and no obvious reaction. These were grouped into two driver reaction categories: no obvious reaction, and others.

Table 2.1 reports descriptive statistics for the variables contained within the dataset that was originally collected for this study.

Table 2.1 Descriptive statistics for data collection 1: Transit, pedestrian, and vehicle interactions

Variable	*#*	*%*	*Mean*	*SD*
Transit stop event information (*N* = 1,592)				
Transit stop location: Far-side	1,249	78.45		
Near-side	343	21.55		
Number of people: Boarded (got on to) the transit vehicle			0.68	1.03
Alighted (got off of) the transit vehicle			0.74	1.10
The transit vehicle was delayed by traffic when arriving at the stop	22	1.38		
The transit vehicle was delayed by traffic when leaving the stop	227	14.26		
Other traffic was delayed by the transit vehicle while it was stopped	82	5.15		
Some other vehicles changed lanes in order to pass the stopped transit vehicle	138	8.67		
The transit vehicle stopped to pick up/drop off passengers, but not at or near the stop location	22	1.38		
The transit vehicle was blocking a driveway or intersection while it was stopped	3	0.19		
Number of vehicles: Between the transit vehicle and the stop location, while it was delayed by traffic when arriving at the stop			0.03	0.30
Delayed by the transit vehicle, while it was stopped			0.10	0.57
Changed lanes in order to pass the stopped transit vehicle, while it was stopped			0.17	0.68
Passed the transit vehicle, while it was delayed by traffic when leaving the stop			0.33	1.06
Dwell time (sec) (vehicle departure time − vehicle arrival time)			32.69	34.64
Pedestrian information (*N* = 2,582)				
Transit stop location: Far-side	2,110	81.72		
Near-side	472	18.28		
Pedestrian action: Alighting	1,525	59.06		
Boarding	1,057	40.94		
Age: Adult of unknown age	996	38.59		
Child	31	1.20		
Teenager	326	12.63		
Young adult	1,010	39.13		
Middle-aged adult	175	6.78		
Older adult	43	1.67		
Gender: Unknown gender	2,366	91.63		
Female	69	2.67		
Male	147	5.69		
Other characteristics: Traveling with 1+ other person(s)	401	15.53		
Carrying load (larger than small purse or backpack)	58	2.25		
Stroller	13	0.50		
Wheelchair	14	0.54		
Skateboard	11	0.43		
Scooter	4	0.15		
Bicycle	11	0.43		
Distracted (by phone, headphones, conversation, etc.)	39	1.51		
Other	441	17.08		
Alighting person (*N* = 1,525): Crossed at an intersection or a marked crossing	684	44.85		
Crossed mid-block, away from an intersection or a marked crossing	19	1.25		
Did not cross a street; turned a corner instead	25	1.64		
Did not cross a street; walked away from the transit stop along the street	190	12.46		
Did not cross a street; went to an adjacent land use (business, home, etc.)	128	8.39		
Did not leave; stayed at the transit stop to board another transit vehicle	15	0.98		
Cannot see from the view of the video	396	25.97		
Other	68	4.46		
Boarding person (*N* = 1,057): Crossed at an intersection or a marked crossing	395	37.37		
Crossed mid-block, away from an intersection or a marked crossing	17	1.61		
Did not cross a street; turned a corner instead	22	2.08		
Did not cross a street; walked toward the transit stop along the street	151	14.29		
Did not cross a street; came from an adjacent land use (business, home, etc.)	255	24.12		

Did not arrive; was already at the transit stop after alighting another transit vehicle	45	4.26		
Cannot see from the view of the video	149	14.10		
Other	23	2.18		
Pedestrian crossing information (*N* = 1,115)				
Transit stop location: Far-side	907	81.35		
Near-side	208	18.65		
Street crossed: The main street	896	80.72		
A side street	213	19.19		
Other	1	0.09		
Pedestrian behavior: Was outside of the crosswalk markings for most if not all of the crossing	45	4.04		
Changed speed (e.g., walk to run, or run to walk)	25	2.24		
Paused in the middle of the street	9	0.81		
Seemed distracted by phone or something else	8	0.72		
Crossed just in front of the transit vehicle (if present)	5	0.45		
Crossed just behind the transit vehicle (if present)	10	0.90		
Pedestrian–vehicle conflict information (*N* = 60)				
Transit stop location: Far-side	37	61.67		
Near-side	23	38.33		
Conflict location: When the person was entering (or starting to cross) the street	28	46.67		
When the person was in the middle of the street	22	36.67		
When the person was exiting (or finishing crossing) the street	10	16.67		
Other	0	0.00		
Vehicle movement: Driving straight	32	55.17		
Turning right	17	29.31		
Turning left	9	15.52		
Other	0	0.00		
Driver reaction: No obvious reaction	38	63.33		
Driver fully stopped	10	16.67		
Driver slowed down	11	18.33		
Driver sped up	0	0.00		
Driver swerved	0	0.00		
Cannot see from the view of the video	1	1.67		
Pedestrian reaction: No obvious reaction	26	43.33		
Stopped and waited for the vehicle	27	45.00		
Slowed down to avoid collision	0	0.00		
Sped up or ran to avoid collision	3	5.00		
Changed direction	1	1.67		
Cannot see from the view of the video	3	5.00		
Encroachment time (sec): abs (vehicle time − pedestrian time at the conflict point)			1.89	0.93

2.3 Data Collection 2: Pedestrian–Right-Turning Vehicle Conflicts

A second set of data was collected for a different research project (Singleton et al., 2023b), but a subset of them is relevant for this project. The objective of that project was to understand factors affecting pedestrian safety at intersections by studying conflicts involving right-turning vehicles. The researchers recorded videos, identified conflicts between pedestrians and right-turning vehicles, measured both the severity of the conflicts and any resulting pedestrian or driver behavioral reactions to the conflict, and analyzed the data. This section describes the data collection in sufficient detail to understand how the data were collected and how they are being used in the present study. For more details, see the published report (Singleton et al., 2023b).

First, the authors selected 34 intersections with traffic signals in Utah as study locations, ensuring that a variety of intersection and roadway design and operational characteristics were included. Most of the locations were along the urbanized Wasatch Front corridor, from Ogden through Salt Lake City to Provo, although intersections (one each) in Logan, Moab, and St. George were also included. Second, at each of these intersections, the research team recorded one to two days of video of one corner at each intersection (two corners were recorded at two intersections) using overhead traffic cameras operated by UDOT. Videos were recorded on weekdays, mostly in fall 2021 and early summer 2022.

Third, trained observers watched the videos and recorded information about conflicts between pedestrians and right-turning vehicles, as well as behaviors of the pedestrians and drivers involved. A conflict was defined as an interaction in which a pedestrian and a right-turning vehicle passed the same point (termed the "conflict point") within 10 seconds of each other. Once a conflict was determined to have occurred, several pieces of information were collected, about the pedestrian—group size, age if it could be determined, gender if it could be determined, mode if not walking (e.g., bicycle, scooter), crossing location (at the intersection versus mid-block), crossing direction (approaching or leaving the curb), pedestrian reaction to the conflict; the vehicle—size (large, medium, small), stopping location (did not stop, before versus between versus after the crosswalks), driver reaction to the conflict; and the situation—right-turn queue lengths, times when the pedestrian and the vehicle were at the conflict point. The video-based data were checked as part of a quality control process. To these data, the researchers added additional information from other, non-video sources such as weather (temperature, precipitation), temporal factors (time-of-day, day-of-week), traffic signal statuses (pedestrian signal status, vehicle signal status), corner and intersection attributes (e.g., corner radius, lanes, crosswalk types, traffic volumes), and neighborhood attributes (e.g., built environment, land uses, neighborhood demographics). The authors then conducted bivariate and multivariate analyses on the data to understand factors associated with a variety of outcomes related to the severity of the conflict and both pedestrian and driver behaviors (Singleton et al., 2023b).

2.3.1 Descriptive Statistics

For the purposes of this project, the right-turn project dataset (Singleton et al., 2023b) was borrowed but filtered to include only study locations with either a near-side or a far-side transit stop on the corner that was filmed (within 300 ft of the intersection). This was done in an attempt to provide as much consistency as possible between the two datasets: both datasets include pedestrians (in some or all cases) interacting with vehicles at intersections with near-side and/or far-side transit stops. Nevertheless, some key differences remain. The right-turn dataset included all pedestrians interacting with right-turning vehicles at corners with transit stops. In contrast, the newly collected data for this project included only transit riders (not all pedestrians), but did count pedestrians crossing the street even if they did not interact with a right-turning vehicle.

After filtering the right-turn dataset, information about 807 conflicts between pedestrians and right-turning vehicles at 11 signalized intersection corners in Utah (three with a near-side transit stop, seven with a far-side transit stop, and one with both a far-side and near-side stop) remained. For the purposes of this study, several dependent variables were considered, all related to pedestrian safety:

- **Crossing location**: The location where the pedestrian crossed the street was recorded, with three options: in the crosswalk or the crosswalk area, mid-block away from the crosswalk, and in the middle of the intersection. The latter two options were recoded into one category: away from the crosswalk.
- **Conflict severity**: This was measured using the time difference between when the pedestrian and the vehicle were at the conflict point; therefore, smaller values (less ET) imply more severe conflicts that were almost a crash. To aid in interpretation, ET was split into three groups, representing the severity of conflicts as being low (6–10 sec.), mild (4–5 sec.), or high (0–3 sec.).
- **Pedestrian reaction to the conflict**: Several possible reactions were noted: no obvious reaction, pedestrian stopped and waited for the vehicle, pedestrian ran to avoid a collision, pedestrian slowed down to avoid a collision, pedestrian changed direction, and others. These were grouped into two pedestrian reaction categories: no obvious reaction, and other.
- **Driver reaction to the conflict**: Several possible reactions were noted: no obvious reaction, driver fully stopped, driver slowed down, driver sped up, driver swerved, and others. Similarly, these were grouped into two driver reaction categories: no obvious reaction, and other.

Table 2.2 reports descriptive statistics for the variables contained within the filtered version of the right-turn dataset used in this study.

Table 2.2 Descriptive statistics for data collection 2: Pedestrian–right-turning vehicle conflicts

Variable	*#*	*%*	*Mean*	*SD*
Pedestrian–right-turning vehicle conflict information (*N* = 807)				
Transit stop location: Far-side	661	81.91		
Near-side	146	18.09		
Group size (# people)			1.20	0.62
Age: Child	21	2.60		
Teenager	68	8.43		
Young adult	323	40.02		
Middle-aged adult	328	40.64		
Older adult	24	2.97		
Adult of unknown age	84	10.41		
Gender: Male	537	66.54		
Female	234	29.00		
Unknown gender	89	11.03		
Other characteristics: Carrying load	33	4.09		
Stroller	7	0.87		
Wheelchair	4	0.50		
Skateboard	20	2.48		
Scooter	21	2.60		
Bicycle	135	16.73		
Distracted (phone, headphones, conversation, etc.)	9	1.12		
Crosswalk: First crosswalk	122	15.12		
Second crosswalk	685	84.88		
Crossing location: In the crosswalk or the crosswalk area	790	97.89		
Mid-block, away from the crosswalk	13	1.61		
In the middle of the intersection	4	0.50		
Crossing direction: Leaving curb	536	66.42		
Approaching curb	271	33.58		
Pedestrian reaction: No obvious reaction	725	89.84		
Stopped and waited for the vehicle	36	4.46		
Slowed down to avoid collision	8	0.99		
Sped up to avoid collision	18	2.23		
Ran to avoid collision	10	1.24		
Changed direction	10	1.24		
Right-turn queue length (# vehicles)			1.91	1.69
Stopping location: Did not stop	489	60.59		
Before the first crosswalk	112	13.88		
Inside the first crosswalk	145	17.97		
Between the first and second crosswalks	61	7.56		
Inside the second crosswalk	0	0.00		
Driver reaction: No obvious reaction	415	51.43		
Driver fully stopped	167	20.69		
Driver slowed down	208	25.77		
Driver sped up	15	1.86		
Driver swerved	2	0.25		
Vehicle type: Small (sedan, motorcycle)	333	41.26		
Medium (SUV, pickup truck, van)	451	55.89		
Large (large truck, vehicle pulling a trailer, bus)	23	2.85		
Encroachment time (sec): abs (vehicle time − pedestrian time at the conflict point)			5.58	2.30
Conflict severity: Low (5−10 sec)	409	50.68		
Mild (4−5 sec)	242	29.99		
High (0−3 sec)	156	19.33		

2.4 Data Collection 3: Pedestrian Crossing Behaviors

A subset of a third dataset, also collected for a different research project (Singleton et al., 2023a), is also relevant for this work. The objective of that project was to understand factors affecting pedestrian crossing behaviors at signalized intersections in order to inform efforts to improve pedestrian safety. The researchers recorded videos, identified pedestrian crossing events, measured various elements of pedestrian behavior related to the crossing event, and analyzed the data. This section describes the data collection in sufficient detail to understand how the data were collected and how they are being used in the present study. For more details, see the published report (Singleton et al., 2023a).

First, the authors selected 47 crosswalks at 39 intersections with traffic signals in Utah as study locations. Most of the locations were along the urbanized Wasatch Front corridor, from Ogden through Salt Lake City to Provo, although several locations were in other cities throughout the state (near or in Logan, St. George, Cedar City, and Moab). Second, at each intersection, the research team recorded usually one to two days of videos of each crosswalk being studied, using overhead traffic cameras operated by UDOT. Videos were mostly recorded throughout 2019, but three locations were studied in September 2021.

Third, trained observers watched the videos and recorded information about the crossing events and pedestrian behaviors. Several data were collected, including information about the pedestrian(s)—group size, age if it could be determined, gender if it could be determined, mode if not walking (e.g., bicycle, scooter); waiting information—number of other people waiting, number of vehicles passing in the 10 seconds prior and 10 seconds following arrival at the corner, waiting behaviors (pressed the push-button, paced, left without crossing), and wait time; and information about the crossing event itself—crossing location (at the intersection versus mid-block), number of other people crossing (in the same and the opposite direction), behavior in relation to the crosswalk markings (e.g., inside versus outside), crossing behaviors (changed speed, paused, distracted), crossing obstacles (car blocking the crosswalk, snow or puddle), and crossing time. To these data, the researchers added additional information from other, non-video sources: weather (temperature, precipitation), temporal factors (time-of-day, day-of-week), traffic signal statuses (pedestrian signal status when started/finished crossing, time spent crossing against a conflicting protected vehicle movement showing green), crossing and intersection attributes (e.g., crosswalk markings, crosswalk length, traffic volumes, median presence), and neighborhood attributes (e.g., built environment, land uses, neighborhood sociodemographic). The authors then conducted bivariate and multivariate analyses on the data to understand factors associated with a variety of outcomes related to safety-related pedestrian crossing behaviors (Singleton et al., 2023a).

2.4.1 Descriptive Statistics

In relation to this project, the pedestrian crossing behavior dataset (Singleton et al., 2023a) was borrowed but filtered to include only study locations with either a near-side or a far-side transit stop (within 300 ft of the intersection) on one of the two corners connecting to the crosswalk that was filmed. This was done in an attempt to provide as much consistency as possible with data collection 1. Both datasets include pedestrians (in some or all cases) crossing at intersections from or to corners with near-side and/or far-side transit stops. Nevertheless, some key differences remain. The pedestrian crossing behavior dataset included all pedestrians crossing to/from at corners with transit stops. In contrast, the newly collected data for this project included only transit riders (not all pedestrians).

After filtering the pedestrian crossing behavior dataset, information about 2,611 pedestrian crossing events at 14 signalized intersections in Utah (two connecting corners with a near-side transit stop, 11 with a far-side transit stop, and one with both a far-side and near-side stop) remained. For this study, several dependent variables were considered, all related to pedestrian safety:

- **Crossing location**: The location where the pedestrian crossed the street was recorded, with three options: in the crosswalk or the crosswalk area, mid-block away from the crosswalk, and in the middle of the intersection. The latter two options were recoded into one category: away from the crosswalk.
- **Crosswalk marking adherence**: The study also recorded whether the pedestrian stayed within the crosswalk markings for all or almost the entire crossing, stepped outside of the crosswalk markings for part of the crossing, or was outside of the crosswalk markings for most if not all of the crossing.
- **Crossing behaviors**: Several pedestrian behaviors were tallied, if observed: changed speed (e.g., walk to run, or run to walk), paused in the middle of the street, or seemed distracted by phone or something else.
- **Crossing obstacles**: Related to pedestrian behavior, it was also recorded whether there was a car blocking the crosswalk while the pedestrian was crossing.

Table 2.3 reports descriptive statistics for the variables contained within the filtered version of the pedestrian crossing behaviors dataset used in this study.

Table 2.3 Descriptive statistics for data collection 3: Pedestrian crossing behaviors

Variable	*#*	*%*	*Mean*	*SD*
Pedestrian crossing information (*N* = 2,611)				
Transit stop location: Far-side	2,172	83.19		
Near-side	439	16.81		
Group size (# people)			1.24	0.66
Age: Child	40	1.53		
Teenager	106	4.06		
Young adult	951	36.42		
Middle-aged adult	941	36.04		
Older adult	30	1.15		
Adult of unknown age	630	24.13		
Gender: Male	1,563	59.86		
Female	674	25.81		
Unknown gender	605	23.17		
Other characteristics: Carrying load	29	1.11		
Stroller	16	0.61		
Wheelchair	19	0.73		
Skateboard	36	1.38		
Scooter	51	1.95		
Bicycle	359	13.75		
Other	77	2.95		
# other people waiting			0.17	0.55
# vehicles passing (past 10 sec)			4.12	4.65
# vehicles passing (next 10 sec)			3.57	4.28
Waiting behaviors: Pressed pedestrian push-button	1,380	52.85		
Paced or otherwise seemed impatient	135	5.17		
Left waiting area without crossing street	39	1.49		
Other	72	2.76		
Waiting time (sec)			30.04	31.25
Crossing location: In the crosswalk or the crosswalk area	2,488	95.29		
Mid-block, away from the crosswalk	82	3.14		
In the middle of the intersection	2	0.08		
Other	39	1.49		
# other people crossing (same direction)			0.24	0.63
# other people crossing (opposite direction)			0.20	0.55
Crosswalk markings: Stayed within the crosswalk markings for all or almost the whole crossing	2,216	84.87		
Stepped outside of the crosswalk markings for part of the crossing	220	8.43		
Was outside of the crosswalk markings for most if not all of the crossing	165	6.32		
Other	2	0.08		
Crossing behaviors: Changed speed (e.g., walk to run, or run to walk)	153	5.86		
Paused in the middle of the street	59	2.26		
Seemed distracted by phone or something else	10	0.38		
Other	50	1.91		
Crossing obstacles: Car blocking the crosswalk	121	4.63		
Snow pile, water puddle, or debris	0	0.00		
Other	4	0.15		
Crossing time (sec)			17.07	7.21

2.5 Analysis Methods

Recall the ultimate goal of this study's first objective: to investigate the impact of transit stop locations (near-side vs. far-side) on pedestrian safety and traffic operations. This was accomplished by comparing the various dependent variables—related to traffic operations and pedestrian safety—for near-side versus far-side transit stops. Two different statistical tests were performed, depending on the structure of the dependent variable.

For continuous dependent variables—those measured as integers or other real numbers—the statistical test was the Welch's t-test. This tests the null hypothesis that the mean (dependent variable) values of two populations (near-side and far-side) are equal. Adapted from the well-known student's t-test, Welch's t-test is more appropriate when the two samples have unequal variances and are of unequal sizes, as is the case for the data in this project. The calculations involved are as follows:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{s_{\bar{X}_1}^2 + s_{\bar{X}_2}^2}} \quad \text{and} \quad s_{\bar{X}_i} = \frac{s_i}{\sqrt{N_i}} \quad \text{and} \quad \nu = \left(\frac{s_1^2}{N_1} + \frac{s_2^2}{N_2}\right)^2 \Bigg/ \left(\frac{s_1^4}{N_1^2 \nu_1} + \frac{s_2^4}{N_2^2 \nu_2}\right)$$

where $\bar{X}_i$ is the sample mean, s_i is the sample standard deviation, N_i is the sample size, and $\nu_i = N_i - 1$ is the degree of freedom for group i. Test statistic t is then compared against the t-distribution with degree of freedom ν to determine the statistical significance of the mean difference $(\bar{X}_1 - \bar{X}_2)$.

For binary dependent variables—those containing two categories, or true/false—the statistical test was Fisher's exact test. This tests the null hypothesis that the proportions (of one category of the dependent variable) of two populations (near-side and far-side) are equal. Similar to the chi-squared test, Fisher's exact test is more appropriate when the sample sizes are small, as is the case for the data in this project. The calculations involved are quite complicated to represent mathematically. Suffice it to say that the test produces a test statistic—representing the odds ratio, i.e., the ratio of the two proportions—and a p-value or probability of seeing the sample ratio of proportions if they were in fact equal in the population (i.e., a ratio of 1). From this, the statistical significance of the ratio difference in the proportions can be determined.

3. RESULTS

Results of the bivariate analyses of key outcomes related to traffic operations and pedestrian safety, compared for near-side and far-side transit stops, are presented and described in the following sections. The sections are organized according to each of the three data collections.

3.1 Data Collection 1: Transit, Pedestrian, and Vehicle Interactions

3.1.1 Traffic Operations

Recall the three types of dependent variables (from data collection 1) considered for understanding traffic operations and interactions between transit vehicles and other traffic:

- Whether the **transit vehicle was delayed** by other traffic, and by how much, measured in number of vehicles
- Whether **other traffic was delayed** by the transit vehicle, and by how much, measured in number of vehicles
- Whether the **stopping location** of the transit vehicle (away from the stop location, or blocking a driveway or intersection) implied potential adverse operational impacts

To analyze the impacts of near-side versus far-side transit stops on traffic operations, bivariate analyses were conducted. The questions related to numbers of vehicles were analyzed using Welch's t-tests, comparing the mean number of vehicles per transit stop event for near-side versus far-side locations. The questions that were true/false were analyzed using Fisher's exact tests, comparing the proportion of transit stop events when each statement was true for near-side versus far-side locations. Results are shown in Table 3.1.

There were statistically significant differences in other **traffic's impacts on transit operations** for near-side versus far-side stops. Transit vehicles were delayed by traffic when arriving at the stop more often for near-side stops (2.9%) than for far-side stops (1.0%). On average, more vehicles were blocking the transit vehicle from arriving at the stop for near-side stops (0.09) than for far-side stops (0.01). It was more likely for the transit vehicle to stop to pick up/drop off passengers but not at the actual stop location for near-side stops (3.2%) than for far-side stops (0.9%). Conversely, traffic delays to transit vehicles when leaving the stop were much more likely for far-side stops (17.6%) than for near-side stops (2.0%) (excluding delays due to the traffic signal). Many more vehicles tended to pass the transit vehicle delaying it from leaving far-side stops (0.42) than near-side stops (0.02). To summarize, for transit vehicles, arrival delays and impacts were more likely and more severe at near-side stops, but departure delays were much more likely and impactful at far-side stops.

There were also some statistically significant differences in **transit vehicles' impacts on other traffic** for near-side versus far-side stops. Other traffic was delayed by the transit vehicle while it was stopped much more often for near-side stops (14.0%) than for far-side stops (2.7%). This was also reflected in the much higher number of average vehicles that were delayed by the transit vehicle while it was at near-side stops (0.34) than at far-side stops (0.04). Other vehicles were equally likely to change lanes to pass a transit vehicle stopped at a near-side stop (8.8% of the time) as they were at a far-side stop (8.7% of the time); however, a larger number of vehicles tended to change lanes to pass transit vehicles at far-side stops (0.19 vehicles per stop event) than at near-side stops (0.12 vehicles). Transit stop events where the transit vehicle was blocking a driveway or intersection was more common at near-side stops (0.6%) than at far-side stops (0.1%), but the difference was not marginally significant (likely due to the small occurrence frequency). To summarize, for other traffic, transit vehicles delayed other vehicles much more often and more significantly at near-side stops, whereas somewhat more passing was observed at far-side stops.

Table 3.1 Results for data collection 1, traffic operations

Traffic operations	*Far-Side*	*Near-Side*	*Far-Side*	*Near-Side*	*Statistic*	*df*	*p-value*
Dependent variable	*Sample size*		*Proportion (true)*		*Fisher's exact test*		
The transit vehicle was delayed by traffic when arriving at the stop	1,249	343	0.0096	0.0292	3.09	--	0.015
The transit vehicle was delayed by traffic when leaving the stop	1,249	343	0.1761	0.0204	0.10	--	0.000
Other traffic was delayed by the transit vehicle while it was stopped	1,249	343	0.0272	0.1399	5.81	--	0.000
Some other vehicles changed lanes in order to pass the stopped transit vehicle	1,249	343	0.0865	0.0875	1.01	--	0.914
The transit vehicle stopped to pick up/drop off passengers, but not at or near the stop location	1,249	343	0.0088	0.0321	3.73	--	0.003
The transit vehicle was blocking a driveway or intersection while it was stopped	1,249	343	0.0008	0.0058	7.31	--	0.119
Dependent variable	*Sample size*		*Mean (#)*		*Welch's t-test*		
Number of vehicles between the transit vehicle and the stop location, while it was delayed by traffic when arriving at the stop	1,249	343	0.0128	0.0875	-2.48	363	0.014
Number of vehicles passed the transit vehicle, while it was delayed by traffic when leaving the stop	1,249	343	0.4171	0.0233	11.27	1440	0.000
Number of vehicles delayed by the transit vehicle, while it was stopped	1,249	343	0.0392	0.3411	-5.06	352	0.000
Number of vehicles changed lanes in order to pass the stopped transit vehicle, while it was stopped	1,249	343	0.1857	0.1224	1.98	897	0.048

3.1.2 Pedestrian Safety: Pedestrian Crossing Behaviors

From data collection 1, there were two sets of dependent variables related to events when pedestrians (transit riders) were crossing the street:

- Whether the **pedestrian crossing location** was at an intersection or a marked crossing, or if it was mid-block (i.e., not at an intersection or a marked crossing)
- Multiple **pedestrian crossing behaviors** observed while crossing, such as, was outside of the crosswalk markings, changed speed, paused in the middle of the street, seemed distracted, and crossed just in front of or behind the transit vehicle (if present).

To analyze the impacts of near-side versus far-side transit stops on pedestrian crossing behaviors, bivariate analyses were conducted. The pedestrian crossing location question was analyzed using Fisher's exact test, comparing the proportion of pedestrian crossing events that happened at mid-block locations (instead of at an intersection or a marked crossing) for near-side versus far-side locations. The true/false questions about pedestrian crossing behaviors were also analyzed using Fisher's exact tests, comparing the proportion of pedestrian crossing events when each statement was true for near-side versus far-side locations. Results are shown in Table 3.2.

There were some modest differences in **pedestrian crossing locations** observed for near-side versus far-side stops, although the differences were not statistically significant. Slightly more pedestrian crossings happened mid-block at far-side stops (3.4%) than at near-side stops (2.4%), but the analysis could not conclude definitively that one was more likely than the other when extrapolated to the population.

Similarly, of the relatively small differences in pedestrian crossing behaviors observed for near-side versus far-side stops, most were not statistically significant and could not be distinguished from random chance. Slightly more pedestrians were outside of the crosswalk markings for most if not all of the crossing at locations with near-side stops (4.3%) than those with far-side stops (4.0%). Similar trends were observed for pedestrians pausing in the middle of the street (1.0% for near-side stops versus 0.8% for far-side stops) and for pedestrians seeming to be distracted (1.0% for near-side stops versus 0.7% for far-side stops). Conversely, certain pedestrian behaviors were slightly more common for far-side stops than for near-side stops: pedestrians changing speed (2.3% for far-side stops versus 1.9% for near-side stops) and pedestrians crossing just behind the transit vehicle (1.0% for far-side stops versus 0.5% for near-side stops). The only behavior with a significant difference based on transit stop location was for pedestrians crossing just in front of the transit vehicle. This was much more common for near-side stops (1.9%) than for far-side stops (0.1%).

Table 3.2 Results for data collection 1, pedestrian crossing behaviors

Pedestrian crossing behaviors	*Far-Side*	*Near-Side*	*Far-Side*	*Near-Side*	*Statistic*	*df*	*p-value*
Dependent variable	*Sample size*		*Proportion (mid-block)*		*Fisher's exact test*		
Crossing location: Mid-block (versus at an intersection or a marked crossing)	907	208	0.0342	0.0240	0.70	--	0.663
Dependent variable	*Sample size*		*Proportion (true)*		*Fisher's exact test*		
Pedestrian behavior: Was outside of the crosswalk markings for most if not all of the crossing	907	208	0.0397	0.0433	1.09	--	0.845
Pedestrian behavior: Changed speed (e.g., walk to run, or run to walk)	907	208	0.0232	0.0192	0.83	--	1.000
Pedestrian behavior: Paused in the middle of the street	907	208	0.0077	0.0096	1.25	--	0.678
Pedestrian behavior: Seemed distracted by phone or something else	907	208	0.0066	0.0096	1.46	--	0.648
Pedestrian behavior: Crossed just in front of the transit vehicle (if present)	907	208	0.0011	0.0192	17.70	--	0.005
Pedestrian behavior: Crossed just behind the transit vehicle (if present)	907	208	0.0099	0.0048	0.48	--	0.698

3.1.3 Pedestrian Safety: Pedestrian–Vehicle Conflicts

There were three additional dependent variables from data collection 1 that are relevant for studying pedestrian safety, specifically in relation to events with conflicts between pedestrians and vehicles:

- There were several possible **driver reactions** to the conflict, which were categorized into no obvious reaction versus some other reaction (driver fully stopped, driver slowed down, driver sped up, driver swerved).
- There were also several **pedestrian reactions** to the conflict, which were similarly categorized into no obvious reaction versus some other reaction (stopped and waited for the vehicle, slowed down to avoid a collision, sped up or ran to avoid a collision, changed direction).

- A measure of **conflict severity** was also calculated as the encroachment time: the absolute value of difference between when the pedestrian and the vehicle were at the conflict point. Note that smaller values (less time) imply more severe conflicts.

To analyze the impacts of near-side versus far-side transit stops on pedestrian–vehicle conflict outcomes, bivariate analyses were conducted. The driver and pedestrian reaction questions were analyzed using Fisher's exact tests, comparing the proportion of conflicts with some other driver/pedestrian reaction (instead of no obvious reaction) for near-side versus far-side locations. Since the encroachment time variable was a continuous variable (ranging from 0 to 3 seconds), it was analyzed using Welch's t-test, comparing the mean ET (a measure of conflict severity) for near-side versus far-side locations. Results are shown in Table 3.3.

There were some measurable and significant differences in **driver and pedestrian reactions** to conflicts based on transit stop location. Specifically, drivers were more likely to have some other reaction (than no obvious reaction) when involved in conflicts at near-side stops (52%) than at far-side stops (25%). Conversely, more conflicts with some other pedestrian reactions (than no obvious reaction) were observed for far-side stops (62%) than for near-side stops (43%), although the difference was not statistically significant. Recall (from Table 2.1) that most "other" driver reactions were slowing down or stopping fully, and most "other" pedestrian reactions were stopping and waiting for the vehicle. In summary, drivers stopped/slowed for pedestrians more often during conflicts at near-side stops; whereas it appears that pedestrians stopped/slowed more often for drivers during conflicts at far-side stops, but the low sample size (number of conflicts) is limiting an ability to come to a definitive conclusion.

A minor difference in **conflict severity** was observed for near-side versus far-side stops, but the difference was modest and not statistically significant. Specifically, conflicts were slightly more severe at far-side stops (ET of 1.81 sec) than at near-side stops (ET of 2.00 sec), but again there was not enough confidence (small difference and small sample size) to determine if this difference was due to random chance or not.

Table 3.3 Results for data collection 1, pedestrian–vehicle conflicts

Pedestrian–vehicle conflicts	*Far-Side*	*Near-Side*	*Far-Side*	*Near-Side*	*Statistic*	*df*	*p-value*
Dependent variable	*Sample size*		*Proportion (other)*		*Fisher's exact test*		
Driver reaction: Other (versus no obvious reaction)	36	23	0.2500	0.5217	3.20	--	0.051
Pedestrian reaction: Other (versus no obvious reaction)	34	23	0.6176	0.4348	0.48	--	0.190
Dependent variable	*Sample size*		*Mean (#)*		*Welch's t-test*		
Encroachment time (sec): abs(vehicle time – pedestrian time at the conflict point)	32	21	1.8125	2.0000	-0.71	42	0.482

3.2 Data Collection 2: Pedestrian–Right-Turning Vehicle Conflicts

3.2.1 Pedestrian Safety: Pedestrian–Right-Turning Vehicle Conflicts

Data collection 2 contained several additional dependent variables related to pedestrian safety for observed conflicts between pedestrians (not necessarily transit riders) and right-turning motor vehicles occurring at signalized intersection corners containing near-side and/or far-side transit stops:

- Whether the **pedestrian crossing location** was at an intersection or away from the crosswalk (i.e., mid-block or through the middle of the intersection);
- The **driver's reaction** to the conflict, which was categorized into no obvious reaction versus some other reaction (fully stopped, slowed down, sped up, swerved);
- The **pedestrian's reaction** to the conflict, which was categorized into no obvious reaction versus some other reaction (stopped at waited for the vehicle, slowed down to avoid collision, sped up to avoid collision, ran to avoid collision, changed direction); and
- **Conflict severity**, measured as encroachment time: the absolute value of difference between when the pedestrian and the vehicle were at the conflict point. Again, smaller values (less time) imply more severe conflicts.

To analyze the impacts of near-side versus far-side transit stops on pedestrian crossing locations and pedestrian–right-turning vehicle conflict outcomes, bivariate analyses were conducted. The questions about crossing location, driver and pedestrian reactions, and conflict severity categories were analyzed using Fisher's exact tests, comparing the proportion of conflicts with crossing locations away from the crosswalk (instead of in the crosswalk or the crosswalk area), some other driver/pedestrian reaction (instead of no obvious reaction), and each category of conflict severity for near-side versus far-side locations. Since the encroachment time variable was a continuous variable (ranging from 0 to 10 seconds), it was analyzed using Welch's t-test, comparing the mean ET (a measure of conflict severity) for near-side versus far-side locations. Results are shown in Table 3.4.

Because the threshold for a conflict was greater in data collection 2 (10 sec) than in data collection 1 (3 sec), another set of bivariate analyses were conducted containing only those 156 high severity conflicts of three seconds or less. Results for this second analysis are shown in Table 3.5.

There were noticeable differences in **pedestrian crossing locations** observed for near-side versus far-side stops. When studying all potential conflicts (Table 3.4), more pedestrian crossings happened away from the crosswalk at near-side stops (5.5%) than at far-side stops (1.4%); this difference was statistically significant. For high-severity conflicts (Table 3.5), the results were of a similar magnitude and direction—6.1% at near-side stops versus 2.4% at far-side stops—although the difference was no longer statistically significant (likely due to the smaller sample size). In summary, it appears that pedestrians were more likely to cross away from the crosswalk at corners with near-side transit stops.

Results of transit stop location differences for **driver and pedestrian reactions** to right-turn conflicts depended somewhat upon whether the analysis used all potential conflicts (Table 3.4) or only high severity conflicts (Table 3.5). For driver reactions, when considering all potential conflicts, there was effectively no difference in whether drivers were more likely to have some other reaction (than no obvious reaction) when involved in conflicts for near-side stops (45%) than for far-side stops (49%). However, when looking just at the most severe conflicts, drivers were much more likely to have some other reaction for conflicts at near-side stops (82%) than for far-side stops (59%). For pedestrian reactions, although the data showed slightly more "other" pedestrian reactions for conflicts at far-side stops than those at near-side stops—11% versus 8% for all potential conflicts, 19% vs 15% for high severity conflicts—the differences were not statistically significant. Recall (from Table 2.2) that most "other" driver reactions were slowing down or stopping fully, whereas "other" pedestrian reactions were much more varied. In summary, it appears that right-turning drivers stopped/slowed for pedestrians more often during high severity conflicts at near-side stops, whereas there was some (albeit not convincing) evidence that pedestrians were less likely to have no reaction during conflicts at far-side stops.

Similarly, the differences in **conflict severity and encroachment time** for near-side versus far-side stops seemed to change depending on the threshold for a conflict. When looking at all potential conflicts (Table

3.4), high and mild severity conflicts were slightly more likely for near-side stops (23% and 33%) than for far-side stops (19% and 29%), whereas the opposite was true for low severity conflicts: they were slightly more likely at far-side stops (52%) than near-side stops (45%). Yet, none of these differences were statistically significant; although the difference for low severity conflicts was approaching marginal significance. Similarly, for all potential conflicts, there was no difference in average encroachment time for near-side stops (5.56 sec) compared to far-side stops (5.59 sec). On the other hand, when looking just at high severity conflicts (Table 3.5), the encroachment time was significantly shorter (the conflict was more severe) for those taking place on corners with far-side stops (2.31 sec) as compared to near-side stops (2.61 sec). In summary, this suggests that high-severity conflicts tend to be more severe at far-side stops than at near-side stops.

Table 3.4 Results for data collection 2, pedestrian–right-turning vehicle conflicts (max 10 sec)

Pedestrian–vehicle conflicts (max 10 sec)	*Far-Side*	*Near-Side*	*Far-Side*	*Near-Side*	*Statistic*	*df*	*p-value*
Dependent variable	*Sample size*		*Proportion (away)*		*Fisher's exact test*		
Crossing location: Away from the crosswalk (mid-block or middle of the intersection) (versus in the crosswalk or the crosswalk area)	661	146	0.0136	0.0548	4.19	--	0.005
Dependent variable	*Sample size*		*Proportion (other)*		*Fisher's exact test*		
Driver reaction: Other (versus no obvious reaction)	661	146	0.4932	0.4521	0.85	--	0.410
Pedestrian reaction: Other (versus no obvious reaction)	661	146	0.1074	0.0753	0.68	--	0.291
Dependent variable	*Sample size*		*Proportion (true)*		*Fisher's exact test*		
Conflict severity: High (0-3 sec)	661	146	0.1861	0.2260	1.28	--	0.297
Conflict severity: Mild (4-5 sec)	661	146	0.2935	0.3288	1.18	--	0.425
Conflict severity: Low (6-10 sec)	661	146	0.5204	0.4452	0.74	--	0.120
Dependent variable	*Sample size*		*Mean (#)*		*Welch's t-test*		
Encroachment time (sec): abs(vehicle time − pedestrian time at the conflict point)	661	146	5.5900	5.5616	0.13	207	0.896

Table 3.5 Results for data collection 2, pedestrian–right-turning vehicle conflicts (max 3 sec)

Pedestrian–vehicle conflicts (max 3 sec)	*Far-Side*	*Near-Side*	*Far-Side*	*Near-Side*	*Statistic*	*df*	*p-value*
Dependent variable	*Sample size*		*Proportion (away)*		*Fisher's exact test*		
Crossing location: Away from the crosswalk (mid-block or middle of the intersection) (versus in the crosswalk or the crosswalk area)	123	33	0.0244	0.0606	2.56	--	0.285
Dependent variable	*Sample size*		*Proportion (other)*		*Fisher's exact test*		
Driver reaction: Other (versus no obvious reaction)	123	33	0.5935	0.8182	3.06	--	0.024
Pedestrian reaction: Other (versus no obvious reaction)	123	33	0.1870	0.1515	0.78	--	0.800
Dependent variable	*Sample size*		*Mean (#)*		*Welch's t-test*		
Encroachment time (sec): abs(vehicle time − pedestrian time at the conflict point)	123	33	2.3089	2.6061	-2.42	76	0.018

3.3 Data Collection 3: Pedestrian Crossing Behaviors

3.3.1 Pedestrian Safety: Pedestrian Crossing Behaviors

Data collection 3 included information on several additional pedestrian safety-related dependent variables about pedestrian crossing behaviors for crosswalks linking signalized intersection corners with near-side and/or far-side transit stops:

- Whether the **pedestrian crossing location** was at an intersection or away from the crosswalk (i.e., mid-block or through the middle of the intersection)
- Whether the pedestrian stayed within the **crosswalk markings** for most or all of the crossing, whether they were outside of the crosswalk markings for most or all of the crossing, or whether they were both inside and outside for part of the crossing
- Multiple observations related to **pedestrian crossing behaviors and obstacles**, such as, changed speed, paused in the middle of the street, seemed distracted, or encountered a car blocking the crosswalk

To analyze the impacts of near-side versus far-side transit stops on pedestrian crossing behaviors, bivariate analyses were conducted. The questions about crossing location, crosswalk marking adherence, and pedestrian crossing behaviors were analyzed using Fisher's exact tests, comparing the proportion of conflicts with crossing locations away from the crosswalk (instead of in the crosswalk or the crosswalk area) and each observed behavior/obstacle for crossings leading to corners with near-side versus far-side transit stops. Results are shown in Table 3.6.

The analysis found statistically significant differences in **pedestrian crossing locations** for crossings leading to/from corners with near-side versus far-side stops. Many more pedestrian crossings happened away from the crosswalk at locations with far-side stops (3.8%) than those with near-side stops (0.7%). In summary, it appears that pedestrians were more likely to cross away from the crosswalk when crossing to/from a corner with a far-side transit stop.

Analysis of **pedestrian crossing behaviors** and situations found only a few statistically significant differences regarding near-side versus far-side transit stops. Most small differences in adherence to the crosswalk markings could not be distinguished from random chance when comparing near-side and far-side stop locations: 85% versus 85% of pedestrians stayed within the crosswalk markings, and 9.1% versus 8.3% were outside of the markings for part of the time. One exception was that more pedestrians crossed while mostly outside of the crosswalk markings at near-side stops (8.4%) versus far-side stops (5.9%). There were also no statistically significant differences observed for situations when the pedestrian seemed distracted (0.2% for near-side versus 0.4% for far-side), when a car was blocking the crosswalk (3.9% for near-side versus 4.8% for far-side), or when pedestrians were observed to change their speed (walk to run, or run to walk) (7.3% for near-side versus 5.6% for far-side). The only statistically significant difference in pedestrian behaviors was that it was somewhat more common to observe pedestrians pausing in the middle of the street for crossings linked to corners with far-side stops (2.5%) than for near-side stops (0.9%). In summary, crossings with near-side stops were more likely to observe pedestrians crossing mostly outside the crosswalk markings, while crossings with far-side stops were more likely to observe pedestrians pausing in the middle of the street.

Table 3.6 Results for data collection 3, pedestrian crossing behaviors

Pedestrian crossing behaviors	*Far-Side*	*Near-Side*	*Far-Side*	*Near-Side*	*Statistic*	*df*	*p-value*
Dependent variable	*Sample size*		*Proportion (mid-block)*		*Fisher's exact test*		
Crossing location: Away from the crosswalk (mid-block or middle of the intersection) (versus in the crosswalk or the crosswalk area)	2,133	439	0.0380	0.0068	0.17	--	0.000
Dependent variable	*Sample size*		*Proportion (true)*		*Fisher's exact test*		
Crosswalk markings: Stayed within the crosswalk markings for all or almost the whole crossing	2,172	439	0.8476	0.8542	1.05	--	0.770
Crosswalk markings: Stepped outside of the crosswalk markings for part of the crossing	2,172	439	0.0829	0.0911	1.11	--	0.572
Crosswalk markings: Was outside of the crosswalk markings for most if not all of the crossing	2,172	439	0.0589	0.0843	1.47	--	0.053
Pedestrian behavior: Changed speed (e.g., walk to run, or run to walk)	2,172	439	0.0557	0.0729	1.33	--	0.180
Pedestrian behavior: Paused in the middle of the street	2,172	439	0.0253	0.0091	0.35	--	0.034
Pedestrian behavior: Seemed distracted by phone or something else	2,172	439	0.0041	0.0023	0.55	--	1.000
Crossing obstacle: Car blocking the crosswalk	2,172	439	0.0479	0.0387	0.80	--	0.457

4. DISCUSSION

4.1 Objective 1: Key findings

The primary objective of this research project was to investigate the impacts of near-side versus far-side transit stop location on pedestrian safety and traffic operations at signalized intersections. To achieve this, three different datasets were collected, assembled, and analyzed. This section summarizes and discusses the key findings and their implications. In reviewing the results, it is important to note the slightly different populations studied: data collection 1 followed transit passengers before/after boarding; data collection 2 studied pedestrians involved in conflicts with right-turning vehicles, and data collection 3 observed all pedestrians crossing the street.

Effects of transit stop location on **traffic operations** were measured in data collection 1 through traffic impacts on public transit operations and transit vehicle impacts on traffic operations. For public transit operations, arrival delays and impacts were more likely and more severe at near-side stops, but departure delays were much more likely and impactful at far-side stops. For other traffic, transit vehicles delayed other vehicles much more often and more significantly at near-side stops, whereas somewhat more passing was observed at far-side stops. These results make sense and match findings from the literature and expectations from transit agencies. At traffic signals on minor and major arterials (streets where transit lines are more common), there is often more delay and vehicle occupancy—and a need for more lanes—on the intersection approaches. Thus, near-side transit stops are more likely to be placed in a travel lane—or block access to a right-turn lane—rather than in a pull-off, as this may be more common for far-side stops. As a result, it makes sense that near-side stops have more (and more severe) delays for transit vehicles' arrival and delays to other traffic during the stop event. This is likely why many more transit stops in Utah are placed on the far-side of intersections (see sample sizes in Table 2.1, Table 2.2, and Table 2.3). However, there is an operational tradeoff with placing transit stops on the far side of intersections: transit vehicles are often delayed (17% of the time) when trying to leave the stop and rejoin traffic. This is important to consider when siting transit stops.

Evidence about the role of transit stop locations on **pedestrian crossing behaviors** (as an indicator of pedestrian safety) were obtained from all three data collections, and results were somewhat contradictory or inconclusive. First, consider **pedestrian crossing location**. Transit riders (data collection 1) were slightly more likely to cross mid-block at far-side stops than at near-side stops, although the difference was slight. Similarly, pedestrians crossing the street (data collection 3) were more likely to cross away from the crosswalk to/from corners with far-side transit stops. However, more pedestrians involved in a right-turn conflict (data collection 2) were crossing away from the crosswalk at corners with near-side transit stops. The authors are inclined to defer somewhat to the far-side results due to the larger sample sizes (and more general populations) used in data collections 1 and 3, which could lead to a conclusion that far-side stops are more likely to induce transit riders or pedestrians to cross mid-block, away from the crosswalk. Perhaps far-side stops are placed farther from the intersection than near-side stops so pedestrians would have to walk farther and have more incentive to cross mid-block. There could be a perceptual impact when getting off the bus because riders have already waited on the bus to cross the intersection; they would rather not spend more time backtracking to walk back to the intersection and wait to cross. Perhaps there are other factors that were not considered in this analysis (i.e., roadway width, traffic volumes, land uses) that are correlated with transit stop locations and may cause this result. Nevertheless, one should also not completely discount the possibility that some near-side stops may also see elevated numbers of pedestrians crossing mid-block, away from the crosswalk.

Next, consider **pedestrian crossing behaviors**. Very few pedestrian behaviors while crossing had significant differences in occurrence at near-side versus far-side transit stops. In data collection 1, transit riders were observed to cross in front of the transit vehicle more often at near-side stops than at-far side stops. This is intuitive, and perhaps not indicative of a safety issue, because near-side stops are located on the approach to the intersection and sometimes close to the stop bar, so pedestrians may just be crossing legally in the crosswalk while the transit vehicle is stopped waiting for the signal to change. In data collection 3, near-side stops had more pedestrians crossing mostly outside of the crosswalk markings, while far-side stops had more pedestrians pausing in the middle of the street. The authors are uncertain about the causes of these results. One possible explanation is that, for near-side stops, the transit stop event may be more likely to coincide with a red light for the street along which the transit vehicle is traveling, and thus a walk indication for crossing that street. After alighting, transit passengers may hurry—i.e., cut the corner and cross between the stopped transit vehicle and other stopped vehicles, outside of the crosswalk markings—in order to cross the street and not have to wait for the next traffic signal cycle. On the other hand, for far-side stops, the transit stop event may be more likely to coincide with a green light for the street along which the transit vehicle is traveling, and thus a steady *DON'T WALK* indication for crossing the street. After alighting, transit passengers may try to cross against the transit signal, thus pausing in the middle of the street to wait for a gap in traffic. More detailed observations of pedestrian trajectories and traffic signal timing would be necessary to substantiate these potential explanations.

Results from the analyses of **pedestrian–driver conflicts** using the first two data collections also offer insights regarding pedestrian safety in proximity to near-side and far-side transit stops despite the small sample sizes. When considering **driver reactions** to conflicts with pedestrians, drivers slowed down or stopped for pedestrians much more often at locations with near-side stops, in both datasets, which means that drivers were less likely to stop or slow down during conflicts with pedestrians at far-side stops. While transit stop locational differences for **pedestrian reactions** to conflicts with vehicles were not statistically significant, the evidence leaned toward pedestrians slowing/stopping more often at locations with far-side stops, in both datasets. When considering **encroachment time** (as an inverse measure of conflict severity), conflicts or near-misses were slightly more severe (less time between road users) at far-side stops. Altogether, these findings indicate potential pedestrian safety concerns associated with far-side transit stops. Because conflicts are considered a precursor to crashes (a surrogate safety measure), it is troubling that far-side stops had more severe pedestrian–vehicle conflicts, implying closer near-misses. This conclusion is also potentially supported by the results for driver/pedestrian reactions. At far-side stops, drivers are not slowing or stopping for pedestrians as much, and pedestrians are having to take more evasive actions to avoid a collision. The authors are unsure what could be causing these findings. One possible explanation is that, if transit lines are more likely to run on the main street of an intersection, then it could be that vehicles are traveling faster at (or turning right more quickly onto) the far-side leg of the main street (where pedestrians are crossing on their way to/from a far-side transit stop), but traveling slower when approaching (or turning right off of) the near-side leg of the main street (where pedestrians are crossing on their way to/from a near-side transit stop). Again, this hypothesis would need to be corroborated through more detailed observations of pedestrian and vehicle speeds, trajectories, and interactions.

4.2 Objective 2: Recommendations

The secondary objective of this research project was to use the insights gained through data collection and analysis to make recommendations about improving both pedestrian safety and traffic operations at signalized intersections with near-side and/or far-side transit stops.

Given the key findings summarized and discussed in the previous section, are near-side or far-side transit stops better when considering both traffic operations and pedestrian safety? Unfortunately, implications differ. First, consider **traffic operations**. It appears that far-side transit stops are certainly better for general traffic operations because fewer other vehicles are impacted by transit stop events. For public transit operations, near-side stops delay transit vehicles when approaching the stop, but far-side stops delay transit vehicles when departing the stop. Which situation is worse for transit operations would depend on a more detailed analysis (and possible simulation) of intersection operations and impacts on transit speed and reliability. NACTO's *Transit Street Design Guide* (2016) offers useful insights into the operational tradeoffs and potential design/operational solutions to make near-side and far-side transit stops function better, including differences for in-lane versus pull-out stops.

Given the predominance of far-side transit stops at signalized intersections in Utah (see sample sizes in Table 2.1, Table 2.2, and Table 2.3) and their benefits for general traffic operations, there are some actions that could be taken to improve far-side transit stops for public transit operations. Given the frequent occurrence and high number of other vehicles passing and delaying transit vehicles when they were trying to depart a far-side stop, this suggests a need to changes laws and/or increase yielding to transit vehicles when they are trying to leave a stop and re-enter traffic. Many buses have or can be equipped to have a rear yield sign that turns on when the bus operator signals a left turn or pulls away from a stop. Some states—including Oregon (ORS, 2024)—have laws requiring overtaking vehicles to yield the right-of-way to transit buses entering traffic while the yield sign is flashing. Such laws (and education and enforcement actions to increase compliance) can reduce the amount of delay transit vehicles experience when trying to depart a stop, which this research has found to be especially important at far-side transit stops. Alternatively, a more intensive infrastructure solution would be to construct curb extensions to house in-lane, far-side stops, which would reduce the significant delay experienced by transit vehicles when trying to depart a stop. Of course, such an installation should also consider strategies to avoid queued vehicles backing up into the intersection, and to shift any bicycle lanes behind the stop (NACTO, 2016).

Second, consider **pedestrian safety**. Although there were some contradictory or inconclusive findings regarding pedestrian crossing locations and pedestrian crossing behaviors, overall, the evidence pointed toward far-side transit stops being worse for pedestrian safety. Specifically, there was slightly more evidence suggesting that more pedestrians cross mid-block near far-side transit stops than evidence that more pedestrians cross mid-block close to near-side transit stops. As discussed above, this finding could be due to complex interactions between the distance far-side transit stops are from the intersection and transit riders' desires to not backtrack when traveling to/from transit stops. The most convincing evidence for the adverse safety conclusion for far-side transit stops comes from analyses of pedestrian–vehicle conflicts, driver/pedestrian reactions, and encroachment time. Specifically, conflicts at far-side stops were more severe, with less time between when pedestrians and vehicles were at the same point. Also, drivers were less likely to slow down or stop for pedestrians at far-side stops. As discussed above, these findings could be related to higher speeds at which vehicles may be traveling/turning in proximity to far-side stops (as compared with near-side stops). These results suggest that adverse safety outcomes at far-side transit stops may be affected by both pedestrian and driver behaviors and actions.

This conclusion about far-side transit stops being potentially worse for pedestrian safety (based on observations of behaviors and, especially, conflicts) corroborates the prior Utah-based research results finding that there were more pedestrian crashes at signalized intersections, especially those with far-side transit stops (Islam et al., 2022; Singleton et al., 2021; Singleton et al., 2022). It also raises a conundrum: what should be done when far-side transit stops are better (or can be made better) for traffic operations, but far-side transit stops are also worse for pedestrian safety? Generally, there are two possible approaches. First, strategies could be implemented to make far-side transit stops safer for pedestrians. A variety of options may be considered, including but not limited to the following: curb extensions and tighter corner radii to reduce pedestrian crossing times and slow the speeds of turning motor vehicles; traffic signal timing and phasing to provide more protected pedestrian crossing movements (i.e., no right on red for vehicles, leading pedestrian intervals, leading through/pedestrian intervals with delayed signalized right turns, protected-only left turns); and other intersection traffic calming strategies

(NACTO, 2013). However, some of these may have adverse impacts on traffic and/or transit operations. Second, pedestrian safety could be prioritized over traffic operations, and near-side transit stops could be recommended in certain situations. Many cities and states—including Utah (UDOT, 2024)—have adopted Vision Zero plans and policies to achieve the goal of eliminating traffic fatalities and severe injuries among all road users, including pedestrians. If this is truly an agency's goal, then safety must be a higher priority than efficient operations in some if not many situations, including when choosing where to locate transit stops at signalized intersections. In general, a combination of both approaches (make far-side transit stops safer for pedestrians, accept adverse traffic operations in exchange for enhanced pedestrian safety), tailored to unique situations, may be the best ultimate recommendation.

4.3 Limitations & Future Work

This research project was not without limitations that could be addressed through future work. Notably, the research only studied a few dozen locations in one state (Utah), the sample sizes were small for some of the analyses, and the analyses relied on data collected in slightly different ways (i.e., transit riders versus pedestrians involved in a conflict versus all pedestrians). Studying more locations over longer time periods in a more consistent manner would not only help to collect more data—thus increasing the power to detect statistically significant small differences in outcomes between near-side and far-side transit stops—but it would also help the findings be applicable to more situations and contexts.

Speaking of context, this research conducted fairly simple bivariate analyses, comparing outcomes related to traffic operations and pedestrian safety for instances with near-side versus far-side transit stops. While generating useful insights that were easy to interpret, many other factors potentially affecting these outcomes were not accounted for in the analysis. It may be useful to control for the influences of situational and locational factors such as time-of-day, weather, adjacent land uses, neighborhood sociodemographic characteristics, traffic volumes and speeds, and other design or operational features of the intersection. One important characteristic that should be studied in future work is the distance from the transit stop to the intersection; this could be particularly influential in pedestrian behaviors and might help to explain some of the findings from this study.

Another useful avenue for future research is a more detailed study (and/or simulation) of the trajectories, speeds, actions, and interactions among individual road users, including transit vehicles, transit riders, all pedestrians, and other vehicles. For instance, using computer vision algorithms to extract precise information about the speeds and paths that vehicles were traveling when they conflicted with crossing pedestrians could help to explain why pedestrian–vehicle conflicts were more severe in proximity to far-side transit stops. Such an analysis could help to corroborate or disprove some of the hypothesized explanations described in this study's key findings discussion. Also, microsimulations of traffic and public transit operations for a variety of near-side and far-side transit stop placement scenarios would help to understand which situations have fewer negative impacts on corridor-level measures of transit speeds and reliability. Altogether, future research can help shed additional light on the implications of near-side and far-side transit stops for traffic operations and pedestrian safety.

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