

**PEDESTRIAN CROSSING SAFETY AND ACCOMMODATION AT SIGNALIZED
INTERSECTIONS IN SAN JOSE, COSTA RICA**

By

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ABSTRACT

This research is an empirical analysis of pedestrian safety in San Jose, Costa Rica. The purpose of this research is to evaluate pedestrian accommodation and analyze pedestrian safety performance at signalized intersections. Pedestrian accommodation is defined by the documented and applied practices for designing and operating pedestrian facilities at signalized intersections. Pedestrian safety performance is defined by pedestrian compliance and conflicts. This research: (1) reviews and compares documented practices in Costa Rica regarding pedestrian accommodation at signalized intersections with best practices from North America; (2) develops and applies a data collection program for evaluating pedestrian accommodation and safety at 20 signalized intersections on an urban-arterial study corridor; (3) evaluates the study corridor's physical and operational site conditions; and (4) analyzes pedestrian compliance and conflicts on the study corridor. Transport policy revisions and engineering measures to improve pedestrian accommodation and safety at signalized intersections in Costa Rica are recommended.

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ACRONYMS

APS	Accessible pedestrian signal
FHWA	U.S. Federal Highway Administration
MUTCD	Manual of Uniform Traffic Control Devices
MUTCDC	Manual of Uniform Traffic Control Devices for Canada
MUTCDCA	Manual of Uniform Traffic Control Devices for Central America
MOPT	Ministry of Public Works and Transportation of Costa Rica
PCS	Pedestrian countdown signal
TAC	Transportation Association of Canada
TTC	Time-to-collision

1.0. INTRODUCTION

1.1. PURPOSE

This research is an empirical analysis of pedestrian safety in San Jose, Costa Rica. The purpose of this research is to evaluate pedestrian accommodation and analyze pedestrian safety performance at signalized intersections. Pedestrian accommodation is defined in terms of the documented and applied practices for designing and operating pedestrian crossing facilities at signalized intersections. Pedestrian safety performance is defined in terms of pedestrian compliance and conflicts. This research investigates practices in Costa Rica and utilizes an urban portion of the Pan American Highway in San Jose to develop and apply the study methodology.

1.2. BACKGROUND AND NEED

Walking is a key component of sustainable transportation systems. Regardless of whether an individual's primary mode of transportation is by automobile, public transportation, or cycling, all road users are pedestrians at some point in their trip; like when they walk to and from the parking lot, bus station, or bicycle rack. The provision of pedestrian infrastructure is also an equitable practice, as people unable to own or operate a vehicle because of financial constraints or personal impairments often travel by foot.

Stefanov (2011) captured the public perception of pedestrians in Costa Rica in a study on the socio-cultural dynamics that influence the behaviours associated with road safety, road infrastructure, the motorized fleet, and urbanism in San Jose:

Road education for pedestrians in Costa Rica is basic or minimal. Interviews and focus group meetings that were conducted with pedestrians in this study revealed that pedestrians are not viewed as part of the road network; nor are they viewed as road users. Rather, pedestrians are viewed as a present entity that must face the limitations of urban space and the consequences of competing with the motorized fleet, other pedestrians, and other obstacles on the roads and sidewalks. Pedestrians have a passive and victim-type role and are in constant interaction with multiple variables on the road network (Stefanov, 2011, p. 117).

High proportions of pedestrian fatalities are observed throughout Latin America and much of the developing world. This trend can be attributed to high proportions of vulnerable road users, a lack of accommodating infrastructure, inadequate safety-focused legislation, poor enforcement of existing laws, insufficient road user education, and public and professional opinion that places motorized traffic at the top of the road user hierarchy. Costa Rica is one of the more developed countries in Latin America and one of the first in the region to establish a nationally funded road safety agency. However, pedestrian safety is still a significant issue. Pedestrians constitute the highest proportion of fatal collisions in Costa Rica (World Health Organization, 2013). Collisions involving pedestrians along the study corridor constitute about 40 percent of total road collisions on the study corridor, which is the highest proportion of pedestrian collisions reported for any road in San Jose (Barrantes & Delgado, 2012).

Pedestrians face safety risks each time they cross a road. Pedestrian crossing control aims to manage road user safety by reducing conflicts and separating the times when vehicles and pedestrians have the right-of-way. Traffic signals are the most common type of pedestrian crossing control used in urban areas of Costa Rica. The safety of these crosswalks is hindered by deteriorating and absent infrastructure, signal timing

plans which give motor vehicles priority over pedestrians, and crossing control devices which do not convey a clear meaning or command the respect of road users. Pedestrian and driver behaviour can be unpredictable and dangerous at crosswalks in San Jose. Understanding road user behaviour and the current operational and physical site characteristics at signalized crosswalks can assist civil engineers in making more informed decisions on how to better design, operate, and maintain these facilities.

Safety performance is commonly measured using collision data; however, pedestrian collisions are relatively rare events and many locations and years of data must be available to obtain a sufficient sample for evaluation. The quality of collision data is questionable in Costa Rica, and reports often fail to include attributes necessary for completing a detailed analysis and obtaining a sufficient understanding of the problem. A methodology which employs surrogate safety measures is required to understand the characteristics of the pedestrian safety problem at signalized intersections. Understanding the characteristics of the problem is critical for selecting mitigation measures.

Surrogate safety measures can be used in conjunction with or in the absence of quality collision data to evaluate road safety. Obtaining sufficient samples of surrogate road safety data is often more timely and less resource-intensive than obtaining collision data. Pedestrian conflicts and pedestrian compliance are two surrogate safety measures. Pedestrian conflicts indicate the type and severity of unsafe interactions between vehicles and pedestrians. Pedestrian compliance with the traffic signal measures the effectiveness of traffic controls and the risk-taking tendencies of crossing pedestrians.

This research develops and applies a methodology for using pedestrian compliance and conflicts to evaluate safety at signalized intersections. This methodology can be

implemented in other jurisdictions to conduct similar studies. Documented and applied practices in Costa Rica for designing and operating pedestrian crossing facilities at signalized intersections are compared with North American best practices to identify gaps and directions for improvement. Operational and physical site conditions associated with poor pedestrian accommodation on the study corridor are discussed. This research proposes recommendations for improving pedestrian accommodation and safety performance at signalized intersections in Costa Rica through transportation policy revisions and operational and physical engineering measures.

1.3. OBJECTIVES AND SCOPE

The objectives of this research are to:

1. Understand and compare documented practices (i.e. policies, guidelines, and standards) in Costa Rica that inform how pedestrian facilities are designed and operated with best practices from North America.
2. Develop and apply a data collection program for evaluating pedestrian safety performance at signalized intersections using pedestrian compliance and conflicts.
3. Evaluate existing physical and operational site conditions which influence pedestrian accommodation at signalized intersections on the study corridor.
4. Analyze pedestrian compliance and conflict characteristics at signalized intersections on the study corridor.
5. Recommend suitable measures to improve pedestrian crossing safety.

The scope of this research was constrained by the following factors:

- The provision of pedestrian crossing control at signalized intersections. Pedestrian accommodation on grade-separated structures was not analyzed.
- The study corridor spanned the portion of the Pan American Highway through the urban municipality of San Jose, Costa Rica.
- Pedestrian compliance and conflict studies were carried out at all signalized intersections on the study corridor that operated a pedestrian crossing phase.

1.4. RESEARCH APPROACH

This research employed the following approach:

Literature review and expert consultation on pedestrian accommodation practices and crossing safety at signalized intersections:

- Standards, policies, legislation, guidelines, and manuals that inform how pedestrian crossing facilities are designed and operated in North America and Costa Rica were reviewed and compared to identify gaps in the documented practices in Costa Rica. Informal interviews were conducted with local experts in Costa Rica to understand certain contexts that may not be found in written sources. Revisions to the documented practices in Costa Rica were recommended to address gaps and move towards best practice approaches from North America.
- Guidelines, recommended practices and academic research was reviewed to understand the use of surrogate safety measures for evaluating pedestrian safety, as well as procedures for manually conducting pedestrian compliance and conflict studies.

Site visits for data collection on the study corridor in San Jose, Costa Rica:

- Pedestrian compliance and conflict studies were manually conducted at all signalized intersections on the study corridor. A written and photo inventory of operational and physical conditions at each intersection was recorded.

Analysis of collected data:

- The inventory of operational and physical site conditions was synthesized and compared with documented practices in Costa Rica and North American best practices for accommodating pedestrians crossing at signalized intersections.
- The collected pedestrian compliance and conflict data was analyzed to determine the safety performance characteristics of each intersection and of the entire study corridor.
- Engineering measures for improving the safety and accessibility of existing pedestrian infrastructure at signalized intersections were developed based on the site condition and safety performance data analysis.

1.5. THESIS ORGANIZATION

The thesis is organized in six chapters and three appendices:

Chapter 2 – Pedestrian Accommodation Practices at Signalized Intersections: This chapter compares North American best practices for accommodating pedestrians crossing at signalized intersections with documented practices in Costa Rica to identify gaps and area for potential revision. Appendix A contains a complete summary of the practices, while this chapter discusses the key documents that were reviewed and provides a high-level comparison between practices in North America and Costa Rica.

Chapter 3 – Research Methodology: This chapter presents the research methodology through: (1) an overview of the study corridor, (2) the guiding principles used to design the data collection program; and (3) the data collection program that was applied to every signalized intersection on the study corridor. The data collection program involved an inventory of physical and operational site conditions, pedestrian compliance studies, and pedestrian conflict studies.

Chapter 4 – Physical and Operational Site Condition Evaluation: This chapter evaluates the physical and operational conditions at all 20 sites on the study corridor. The chapter includes the evaluation approach and results for: (1) general site characteristics; (2) pedestrian-related signage and pavement markings; (3) pedestrian signal design and timing; and (4) accessible features.

Chapter 5 – Pedestrian Compliance and Conflict Analysis: This chapter presents an overview of: (1) the analysis approach including determination of minimum sample size for the compliance and conflict studies; (2) pedestrian compliance characteristics and analysis results; and (3) pedestrian conflict characteristics and analysis results. Conflict studies evaluated the severity and type of unsafe interactions between motor vehicles and pedestrians that crossed at sites on the study corridor. Compliance studies evaluated pedestrian compliance with the signal by examining the interval that was active at the time pedestrians crossed the study corridor.

Chapter 6 – Conclusions and Recommendations: This chapter summarizes key findings of the research and recommends revisions to the documented practices in Costa Rica and well as engineering treatments to improve pedestrian accommodation and safety at signalized intersections. Opportunities for future research are discussed.

Appendix A – Summary of Pedestrian Accommodation Practices at Signalized

Intersections: Appendix A is related to Chapter 2. This appendix summarizes the results of the literature review on practices regarding pedestrian accommodation at signalized intersections. The appendix summarizes best practices from North America and documented practices from Costa Rica for the operational design of pedestrian signals and the geometric design of pedestrian infrastructure at signalized intersections.

Appendix B – Physical and Operational Site Conditions: Appendix B is related to Chapter 4. This appendix contains the complete inventory of physical and operational site characteristics at all signalized intersections on the study corridor.

Appendix C – Site Safety Profiles: Appendix C is related to Chapter 5. This appendix contains the pedestrian compliance and pedestrian conflict data collection forms, and summarizes the pedestrian safety performance results for each site on the study corridor.

2.0. PEDESTRIAN ACCOMMODATION PRACTICES AT SIGNALIZED INTERSECTIONS

This chapter compares North American best practices for accommodating pedestrians crossing at signalized intersections with documented practices in Costa Rica to identify gaps and area for potential revision. Appendix A contains a complete summary of the practices, while this chapter discusses the key documents that were reviewed and provides a high-level comparison between practices in North America and Costa Rica.

2.1. BEST PRACTICES FROM NORTH AMERICA

The key documents consulted on best practices from North America for accommodating pedestrians crossing at signalized intersections were:

- Transportation Association of Canada's (TAC) *Manual of Uniform Traffic Control Devices for Canada (MUTCDC)* (1998) and the U.S. Federal Highway Administration's (FHWA) *Manual of Uniform Traffic Control Devices (MUTCD)* (2009), provided information on signal installation justification and on signage, pavement markings, pedestrian signal displays, and signal phasing.
- *Canadian Capacity Guide for Signalized Intersections* (2007) provided information on signal phasing.
- TAC's *Pedestrian Crossing Control Guide* (2012) and the *Pedestrian Crossing Control Guide Technical Knowledge Base* (2012) provided information on accessible pedestrian signals and pedestrian countdown signals. These documents provide guidance on the use of devices for pedestrian crossing control and provide a comprehensive technical knowledge base of pedestrian crossing control that was obtained through a broad literature review and

international jurisdictional survey (Montufar, et al., 2012a; Montufar, et al., 2012b).

- FHWA's *Designing Sidewalks and Trails for Access: Part II of II: Best Practices Design Guide* from McMillen et al. (2001) provided information on the geometric design of crosswalks at signalized intersections and on the use of tactile markings. This guidebook is the result of data collection, literature reviews, and site visits conducted across the United States on best practices for designing sidewalks and trails that promote access and the inclusion of pedestrians with impairments (McMillen, et al., 2001).

2.2. DOCUMENTED PRACTICES IN COSTA RICA

The key documents consulted from Costa Rica on practices for accommodating pedestrians crossing at signalized intersections were:

- *Law 7600 for the Equal Opportunities for Persons with Disabilities* (1996) gives equal rights to Costa Ricans with disabilities to access social, economic, political, and cultural development opportunities. Information on the design of pedestrian crosswalks and sidewalks was obtained from Chapter 4 of Law 7600, which discusses the provision of access to public spaces for people with disabilities (Centro Nacional de Recursos para la Inclusion Educativa, 1996).
- The *Urban Design Regulations for San Jose* (2014) outline constructability, zoning and land use classification, public space, outdoor advertising, land use operation, road network, traffic control, environmental quality, landscaping, and urban beautification regulations (Gobierno de Costa Rica, 2014).

- The *Manual of Highway Geometric Design Standards for Central America* specifies geometric design requirements for roadways in Central America (CEPRENAC and SIECA, 2011).
- The *Manual of Uniform Traffic Control Devices for Central America (MUTCDCA)* (2000) establishes standards, criteria, and recommendations to facilitate and ensure the orderly, safe, and predictable movement of all road users across the entire road network in Central America (SIECA, 2000). The MUTCDCA includes standards and guidelines on the installation of all traffic control devices, including pavement markings, highway signs, and traffic signals. It is equivalent to the MUTCD and MUTCDC, and was heavily based on information contained in the MUTCD.
- The National Standard in Costa Rica for *Signage on Horizontal Surfaces* (2008) provided information on the design and application of tactile pavement markings (INTECO, 2008). This standard was developed based on Argentina's national standard for accessibility in the physical environment, specifically for signing the physical environment for people with vision impairments.
- Personal correspondence with transportation engineers from the Ministry of Public Works and Transportation of Costa Rica (MOPT) and from the Road Safety Unit at the National Laboratory of Materials and Structural Models at the University of Costa Rica (LanammeUCR) provided supplementary information on practices where documentation was not readily available, including information on signal phasing, pedestrian signal displays, and the application of accessible pedestrian signals in Costa Rica.

2.3. PRACTICE COMPARISON

Two categories of practices for accommodating pedestrians crossing at signalized intersections were compared for North America and Costa Rica: (1) operational design of pedestrian signals, and (2) geometric design of pedestrian infrastructure at signalized intersections.

2.3.1. Operational Design of Pedestrian Signals

Practices for the operation of pedestrian signals consider the design and application of:

- Signage related to pedestrians
- Pavement markings related to the crosswalk
- Tactile markings
- Signal installation justification
- Pedestrian signal phasing
- Pedestrian signal heads
- Pedestrian clearance intervals
- Leading pedestrian intervals
- Accessible pedestrian signals
- Pedestrian countdown signals

Table 1 summarizes key practices for the operations of pedestrian signals in North America and Costa Rica. An asterisk beside the parameter indicates that documented practices in Costa Rica do not contain sufficient content outlined by best practices in North America.

Table 1: Practices for the Operational Design of Pedestrian Signals

* indicates Costa Rica practices not consistent with North America

Parameter	Practices from North America	Practices Documented in Costa Rica
Signage	Standardized design and application of signage. Regulatory pedestrian signs provide information on how to cross.	Standardized design and application of signage. Regulatory pedestrian signs provide information on how to cross.
Pavement markings	Standardized design and application of pavement markings. Crosswalk pavement markings include crosswalk lines and zebra markings. The minimum zebra marking stripe width is 30 cm. Pavement markings extend full length of crosswalk.	Standardized design and application of pavement markings. Crosswalk pavement markings include crosswalk lines and zebra markings. The minimum zebra marking stripe width is 40 cm. Pavement markings extend full length of crosswalk.
Tactile markings*	Includes detectable warnings and directional surfaces which assist pedestrians with vision impairments. Tiles have distinct texture and contrasting colour (yellow). Detectable warnings consist of truncated domes and are used to indicate hazards, at the base of curb ramps, and on depressed corners. Directional surfaces convey wayfinding information along sidewalks, but are not widely used in North America.	Standardized design and application of tactile markings for detectable warnings and directional surfaces. Tiles have distinct texture and contrasting colour (yellow). Detectable warnings consist of truncated domes and are used to indicate hazards, change in direction, and to cover entire curb ramps. Directional surfaces consist of textured bars which convey wayfinding information along sidewalks. The standard does not dictate when directional surfaces are warranted and does not give specific guidance on the application of detectable warnings on perpendicular curb ramps.
Signal installation justification	Requires comprehensive engineering studies and satisfaction of warrants. Pedestrian signal heads recommended on all crossing directions.	Requires comprehensive engineering studies and satisfaction of warrants.
Pedestrian signal intervals	Pedestrian phase operates three intervals: WALK: pedestrians may begin crossing. Flashing DON'T WALK: pedestrians are not allowed to begin crossing. Pedestrians who began crossing during the WALK interval are allowed to complete their crossing. DON'T WALK: pedestrians are not allowed to enter the intersection.	Pedestrian phase operates three intervals: WALK: pedestrians may begin crossing. Flashing WALK: pedestrians are not allowed to begin crossing. Pedestrians who began crossing during the WALK interval are allowed to complete their crossing. DON'T WALK: pedestrians are not allowed to enter the intersection.
Pedestrian signal heads	Standardized displays, configuration, mounting, location, and directionality of signal head to provide greatest visibility to pedestrians. All symbols displayed on a square lens with 30 cm sides on a black background: WALK symbol: solid white walking pedestrian Flashing DON'T WALK symbol: flashing orange hand DON'T WALK symbol: solid orange hand	Standardized displays, configuration, mounting, location, and directionality of signal head to provide greatest visibility to pedestrians. All symbols displayed on circular or square lenses with 30 cm diameter/sides: WALK symbol: solid green walking pedestrian Flashing WALK symbol: flashing green walking pedestrian DON'T WALK symbol: solid red standing pedestrian

Table 1 continued...

Parameter	Practices from North America	Practices Documented in Costa Rica Green = consistent with North America Red = not consistent with North America
Design walking speed*	0.8 m/s to 1.0 m/s	1.2 m/s
Pedestrian clearance interval*	Includes the Flashing DON'T WALK interval and a portion of the DON'T WALK interval that immediately follows, prior to the release of conflicting traffic. Timed for a pedestrian travelling at the design walking speed to travel the full crossing distance before conflict traffic is released.	Includes the Flashing WALK interval. Timed for a pedestrian travelling at the design walking speed to reach the centre of the furthest lane before conflicting traffic is released.
Leading pedestrian interval*	Can be applied at intersections with high pedestrian activity and high volumes of turning vehicles. Lead time duration should allow pedestrians to establish themselves within the intersection before concurrent traffic is released and allowed to turn across the crosswalk.	No documented practices.
Accessible pedestrian signals (APS)*	Provide APS following a comprehensive engineering study. APS provide redundant information to pedestrians using different forms of communication (e.g., audible, raised surfaces, or vibrating surfaces) to assist pedestrians with impairments. One audible signal should be provided on each terminal. Separate tones should be used for north-south crossings and east-west crossings. The tone should indicate the start of the WALK interval. When signals are actuated using pedestrian pushbuttons: • One pushbutton per pole • Mounted parallel with crossing direction • Maximum mount height of 1.25 m • Operable by people with limited mobility	APS are used in Costa Rica however documented practices for their design and application were not identified in this research. Pushbuttons should be mounted at a height of 1 m to 1.2 m.
Pedestrian countdown signals (PCS)*	Provide PCS following a comprehensive engineering study. PCS provide information to pedestrians regarding the time (in seconds) remaining to safely complete their crossing. Display the countdown during the pedestrian clearance interval in conjunction with the Flashing DON'T WALK interval. Rest the countdown in dark mode during all other pedestrian intervals. Information panels explaining how to interpret the countdown can be provided adjacent to pedestrian pushbuttons.	PCS are not currently used in Costa Rica. Documented practices for their design and application were not identified in this research.

The following points are concluded by comparing practices in Table 1:

Signage: The standardization of signage in Costa Rica is equivalent to practices in North America. Signage is installed in a consistent and uniform format when the regulations are followed.

Pavement markings: The standardization of pavement markings in Costa Rica is equivalent to practices in North America. Pavement markings are installed in a consistent and uniform format when the regulations are followed. Larger zebra marking stripes in Costa Rica provide greater visibility.

Tactile markings: Pedestrians with vision impairments rely on the consistent application of tactile markings, which is provided in Costa Rica when the National Standard is followed. The tactile marking standard in Costa Rica differs from practices in North America. For example, detectable warnings on curb ramps cover the entire ramp in the Costa Rica standard, while practices from North America recommend a single strip of markings at the base of the curb ramp. Traversing over a curb ramp that is covered in detectable warnings can be difficult for pedestrians with mobility impairments, such as people in wheelchairs.

Signal installation justification: The warrant systems differ between North America and Costa Rica, but both provide a standardized process to ensure traffic signals are installed under consistent conditions.

Pedestrian signal intervals: The meanings of the Flashing DON'T WALK interval used in North America and the Flashing WALK interval used in Costa Rica are equivalent. Pedestrian crossing behaviour may be influenced differently by displaying the WALK symbol versus the DON'T WALK symbol during this intermittent interval.

Pedestrian signal heads: The standardization of pedestrian signal heads in Costa Rica is equivalent to practices in North America. Although the symbols displayed differ between North America and Costa Rica, the important practice is that they are standardized and consistently applied within each jurisdiction. Better visibility is provided with larger pedestrian signal lenses.

Design walking speed: The design walking speed used in Costa Rica does not accommodate pedestrians that travel at slower speeds, such as people with impairments and older adults. This has road safety implications because these pedestrians may not be able to cross the street during the time provided by the traffic signal and could be left within the street when conflicting traffic is released.

Pedestrian clearance interval: The documented practice for timing the pedestrian clearance interval in Costa Rica releases conflicting traffic while pedestrians are still within the crosswalk – when they are at the centre of the furthest lane. This practice places pedestrians at risk of conflict or collision.

Leading pedestrian interval: Pedestrians are more visible to drivers when they establish themselves within the intersection during a leading pedestrian interval. Having a policy in Costa Rica on the application of leading pedestrian intervals is important so that they are applied under consistent conditions.

Accessible pedestrian signals: Documented practices for the design and application of APS helps to ensure they are consistently and uniformly applied at traffic signals. Variability in the design and application of any traffic control device can confuse road users, particularly those with impairments, on the intended meaning and direction provided by the device.

Pedestrian countdown signals: Documented practices for the design and application of PCS in Costa Rica are not required because the devices are not currently used.

2.3.2. Geometric Design of Pedestrian Infrastructure at Signalized Intersections

Practices for the geometric design of pedestrian infrastructure at signalized intersections consider pedestrian facilities connecting to the crosswalk terminal (e.g., sidewalks), at the crosswalk terminal (e.g., curb ramps), and within the crossing zone over the roadway. Table 2 summarizes key practices for the geometric design of pedestrian infrastructure at signalized intersections in North America and Costa Rica.

Table 2: Practices for the Geometric Design of Pedestrian Infrastructure at Signalized Intersections

* indicates Costa Rica practices not consistent with North America

Parameter	Practices from North America	Practices Documented in Costa Rica
Connecting to the crosswalk terminal*	Follow universal design principles for the design and maintenance of sidewalks. Provide good sidewalk infrastructure connecting to crosswalk terminals with: • Clearly defined pedestrian, furniture, and frontage zones • Wide pathways (minimum 1.5 m width) • Minimal obstacles/ protruding objects • Maximum longitudinal grade 5 percent • Maximum cross slope 2 percent • Rest areas and good lighting • Minimal changes in level • Firm, stable, and slip-resistant surfaces	Sidewalks are recommended on roads with high pedestrian volumes and with posted speeds in excess of 60 km/hr. Property owners, rather than the municipality, are responsible for constructing and maintaining sidewalks in front of their properties. Sidewalk design specifications are: • Minimum 1.2 m width • Clear of obstacles • Concrete construction for slip-resistance • Cross-slope between 2 and 3 percent • Stairs not permitted unless accompanied by ramps
At the crosswalk terminal*	Follow universal design principles for the design and maintenance of curb ramps and manoeuvring space. Well-designed curb ramps are/have: • Placed wholly within the crosswalk • Aligned with the crosswalk/ far terminal • Perpendicular to the curb • Distinguishable from surrounding terrain • Indicated with detectable warnings • Adequate landing space • Longitudinal grades of 7.1 ± 1.2 percent • Minimal grade changes • Flush transitions to the street • Maximum cross slope of two percent • Adequate drainage	Curb ramps are required to provide access for pedestrians with impairments at sidewalks, parks, streets, pedestrian overpasses, and places. Design specifications are: • Minimum 1.2 m width • Maximum 10 percent longitudinal gradient • Constructed of same material as sidewalk

Table 2 continued...

Parameter	Practices from North America	Practices Documented in Costa Rica
Within the crossing zone over the roadway	Provide medians for refuge at crosswalks with large crossing distances where pedestrians may be unable to complete their crossing within a single cycle. Medians should be accessible via curb ramps with detectable surfaces. Right-angle intersections are ideal for sightlines and provide the shortest crossing distance. Raised pedestrian crosswalks improve pedestrian visibility. Curb extensions improve pedestrian visibility and reduce crossing distance. Provide small turning radii to slow speeds of turning vehicles, decrease pedestrian crossing distance, and improve navigational ease for pedestrians with vision impairments.	Crosswalk width is typically governed by sidewalk width, but should not be less than 1.8 m. Provide medians for refuge at crosswalks where pedestrians may be unable to complete their crossing within a single cycle. Driver sightlines should be clear and free of obstructions. Streets should ideally intersect at right-angles.

The following points are concluded by comparing practices in Table 2:

Connecting to the crosswalk terminal: Sidewalk connectivity is compromised by the sidewalk ownership policy in Costa Rica. Property owners do not place the same level of effort into constructing and maintaining sidewalks in front of their properties, leading to facilities that are poorly accessible. Additionally, standards in Costa Rica need additional content to follow universal design principles for sidewalk design.

At the crosswalk terminal: Standards in Costa Rica need additional content to follow universal design principles for curb ramp design. Current curb ramp design specifications do not adequately address the needs of pedestrians with mobility impairments.

Within the crossing zone: Practices in Costa Rica for the geometric design of pedestrian facilities within the crossing zone over the road way are consistent with best practices from North America.

3.0. RESEARCH METHODOLOGY

This chapter presents the research methodology through: (1) an overview of the study corridor, (2) the guiding principles used to design the data collection program; and (3) the data collection program that was applied to every signalized intersection on the study corridor. The data collection program involved an inventory of physical and operational site conditions, pedestrian compliance studies, and pedestrian conflict studies.

3.1. OVERVIEW OF STUDY CORRIDOR

The study corridor is a 2.4 km section of the Pan-American Highway that passes through downtown San Jose, Costa Rica (Figure 1). The Pan-American Highway is a corridor with international significance: it links the northern and southern points of the Americas by travelling through 18 countries. As part of Costa Rica's National Road Network, the Pan-American Highway provides linkage between major urban centres and land-uses with national significance. The downtown region is surrounded on three sides by a perimeter highway. The study corridor is the only National Primary Highway to pass through the centre of downtown San Jose and is the main east-west route in the region. The study corridor is locally named Paseo Colon and Avenida Segunda.

Downtown land-use is predominantly commercial and institutional, including hospitals, churches, cultural centres, and theatres. Two of Costa Rica's major hospitals are located on the study corridor: Hospital Nacional de Ninos (National Children's Hospital) and Hospital San Juan de Dios. Figure 2 shows the study corridor and the 20 signalized intersections on the corridor that were investigated in this research. Commercial land-use is predominantly low- to mid-quality retail shops and street vendors. The concentration of commercial, political, institutional, and governmental land-uses along

with urban sprawl has led to depopulation of the downtown region over the last 40 years (Stefanov, 2011).

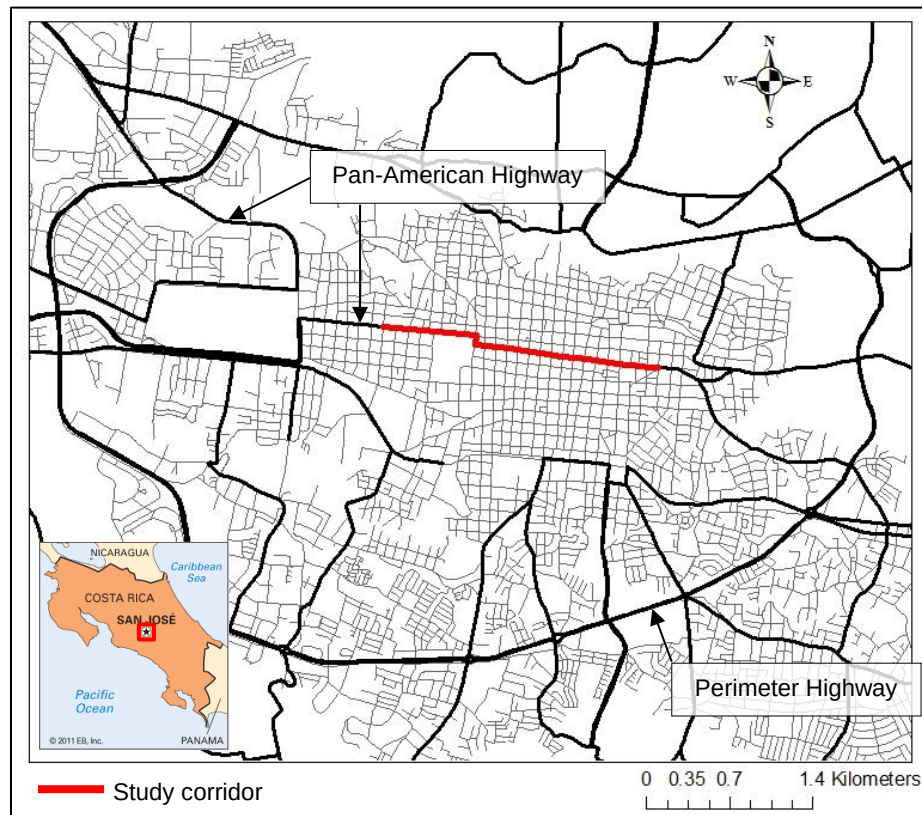


Figure 1: Downtown San Jose road map illustrating study corridor

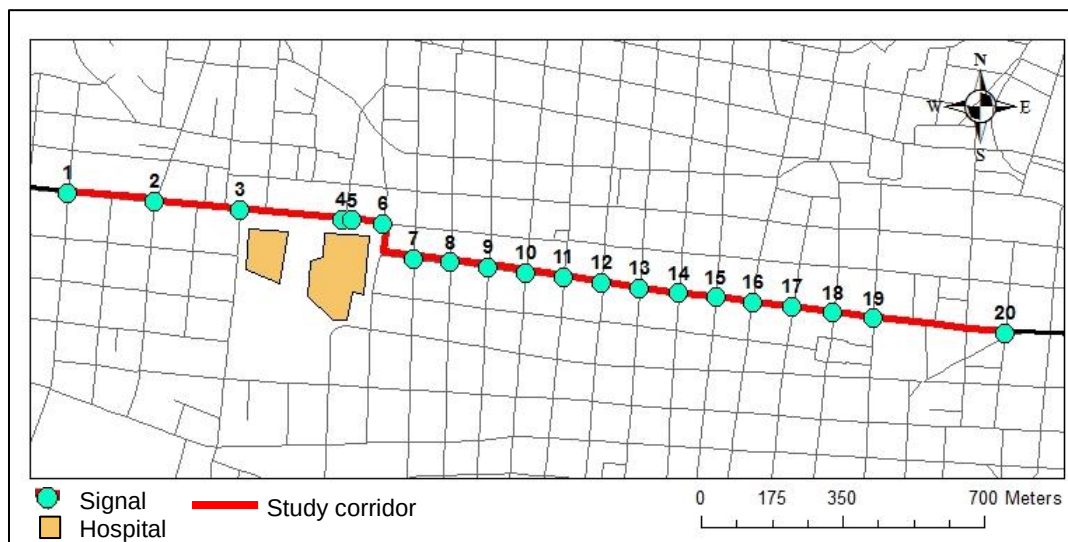


Figure 2: Study corridor

Pedestrian crossing control on the study corridor is provided at signalized intersections and pedestrian overpasses. The study corridor incorporates 20 signalized intersections (all except one operate a pedestrian phase) and two pedestrian overpasses. The signals operate on fixed-time timing plans, with different plans operating during the peak and off-peak periods.

Downtown San Jose accommodates a high level of pedestrian activity and acts as a large transit hub, with practically all national and local bus terminals located on or in close proximity to the study corridor (Stefanov, 2011). Pedestrians travel between transit terminals and stops to transfer routes, and come to the downtown for employment, to shop in the retail facilities, socialize in parks, conduct business, and visit churches, hospitals, museums, and other venues. Given the lower quality retail establishments in the downtown, including many street vendors, people visiting and working in the area are generally from lower-income classes. Petty crimes are common and there is a high police presence to monitor public safety.

Pedestrian malls (i.e., streets restricted for pedestrian use which contain commercial and retail space) intersect the study corridor at four signalized intersections and vehicular streets intersect at 17 signalized intersections. Intersecting vehicular streets are two- to three-lane facilities that accommodate lower traffic volumes than the study corridor and typically operate one-way traffic. Pedestrian malls exist throughout the downtown and link transit stops and terminals, accommodate a great volume of pedestrian trips, hold local markets, and serve as destinations for people to shop, dine, and socialize. These streets occasionally accommodate some motorized traffic for loading and police enforcement purposes. Some of the pedestrian malls and intersecting vehicular streets on the study corridor are illustrated in Figure 3.

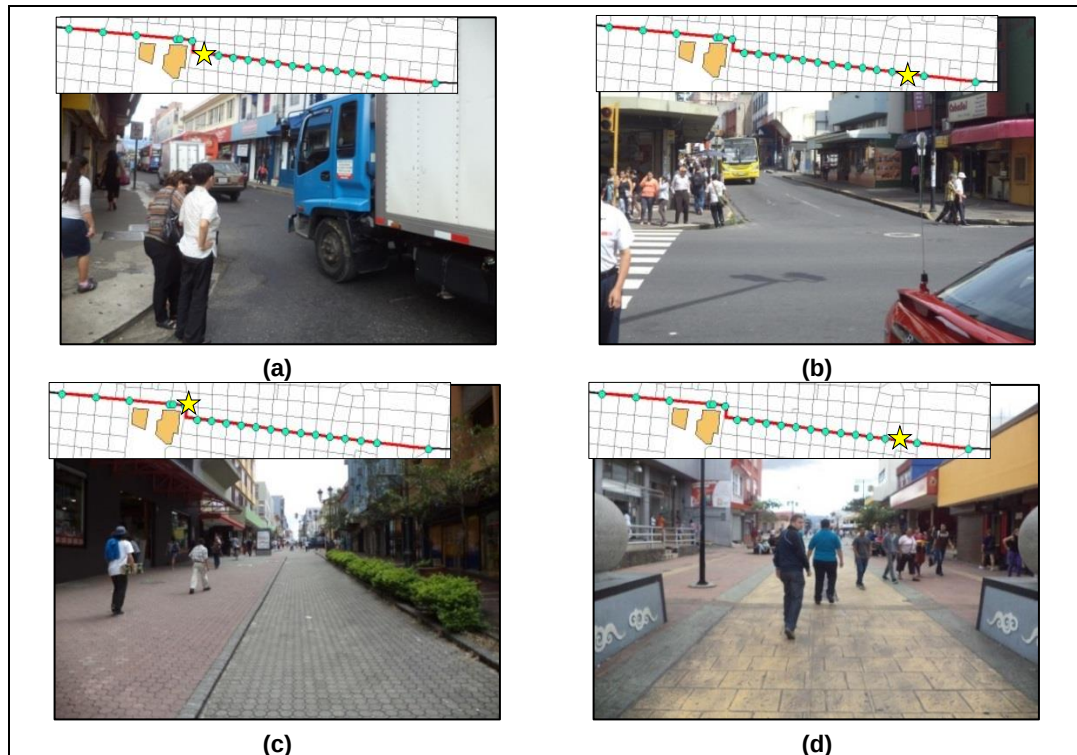


Figure 3: Intersecting streets: (a) vehicular street site 7; (b) Vehicular street at Site 18; (c) Pedestrian mall at Site 6; (d) Pedestrian mall at Site 18

Figure 4 illustrates a pedestrian overpass on the study corridor. Both overpasses are equivalent in design and appearance and are located near the hospitals. The pedestrian overpasses are infrequently maintained and less convenient and comfortable to use than adjacent at-grade crosswalks at signalized intersection. Stairs are provided for pedestrian access onto the overpasses (Figure 5). However, the absence of ramps makes their design inaccessible for many users with mobility impairments, of which there are many, given the close proximity to the hospitals. Pedestrian overpasses are seen to be dangerous because of a high perceived risk of personal crime. Although significant volumes of pedestrians use the overpasses on the study corridor, 98 percent or more of crossing pedestrians prefer to cross at-grade at nearby signalized intersections (Stefanov, 2011, p.119).



Figure 4: Pedestrian overpass



Figure 5: Stair access onto pedestrian overpass

3.2. GUIDING PRINCIPLES FOR THE PROVISION OF PEDESTRIAN CROSSING CONTROL

The seven guiding principles for the provision of pedestrian crossing control developed by Montufar et al. (2012a) served as the framework for developing the methodology applied in this research. Although safety is paramount, it is important to balance the guiding principles when providing pedestrian crossing control.

- **Safety** is the key objective in the provision of pedestrian crossing control and was the focus of this research. Pedestrian safety at signalized intersections is managed by separating the times that vehicles and pedestrians have the right-of-way.

- **Delay:** pedestrian delay should be managed in balance with vehicular delay so that travel convenience is equivalent between modes. At signalized intersections, delay is reflected in the length of time road users wait to receive the right-of-way.
- **Equity:** pedestrian crossing control should follow universal design standards and be accessible for all users, including those with impairments. At signalized intersections, equity can be evaluated by the existence of accessible signals and by the pedestrian walking speed used in signal timing.
- **Expectancy:** pedestrian crossing control should not violate driver expectancy. Drivers will more often respond correctly and quickly when their expectations are met. Using the positive guidance approach at signalized intersections can help meet driver expectation. The positive guidance approach includes “primacy (signs are placed according to the importance of their information, and in such a way as to present the driver with information when and where it is essential); spreading (information is given in small amounts to reduce the information load on the driver); coding (colour and shape coding of traffic signs); and redundancy (information is repeated)” Montufar et al. (2012a).
- **Consistency:** consistent use of traffic control devices helps ensure road users recognize, understand, respect, and respond appropriately to their given direction. At signalized intersections, consistency should be provided in the application and condition of signals, signs, pavement markings, and signal timing.
- **Connectivity:** connectivity can be considered on a macro scale (system-wide connectivity through a connected path of crossing opportunities and

infrastructure along pedestrian desire lines) and on a micro scale (curb-to-curb connectivity at a single crosswalk with accessible infrastructure).

- ***Pragmatism*** considers the practical issues and consequences associated with the pedestrian crossing control, such as costs, ease of installation and maintenance, as well as local device effectiveness.

3.3. DATA COLLECTION PROGRAM

There were three components to the data collection program:

- An inventory of physical and operational site characteristics
- Pedestrian compliance studies
- Pedestrian conflict studies

3.3.1. Inventory of Physical and Operational Characteristics

Pedestrian activity and safety performance are influenced by the surrounding built environment and transportation system. An inventory of physical and operational conditions was manually collected at each of the 20 study sites to identify factors contributing to poor pedestrian compliance and high conflict severity and frequency, and to assess overall pedestrian accommodation. The inventory included qualitative and quantitative data, as well as a photo catalogue of general site characteristics, pedestrian-related signage and pavement markings, pedestrian signal design and timing, and accessible features.

3.3.1.1. General Site Characteristics

Table 3 summarizes general characteristics of the study corridor and Figure 6 illustrates sample conditions of the corridor's alignment and cross-section.

Table 3: Study Corridor Characteristics

Classification	National primary highway (part of the Pan-American Highway)
Local name	Paseo Colon at Sites 1 to 6, Avenida Segunda at Sites 6 to 20
Length	2.4 km
Surrounding land-use	Commercial, institutional and some parks
Average daily traffic	30 000 vehicles
Posted speed	40 km/hr
Horizontal alignment	Straight east-west roadway shifted one block on north/south plane at Site 11 (Figure 6a)
Vertical alignment	Relatively flat with some minor variations throughout the corridor. Maximum longitudinal gradient of 3 to 5 percent at eastern edge of study corridor (Figure 6b).
Cross-section 1 (site 1 to 3)	Five lanes of two-way traffic (3 eastbound and 2 westbound lanes) present on 17 percent of study corridor. Changes to five lanes of one way traffic (5 eastbound lanes) during AM peak period between 6:00 AM and 8:30 AM (Figure 6c). Lane reversal is controlled with stationary roadside signage and with traffic signals.
Cross-section 2 (site 3 to 20)	Five lanes of one-way traffic (5 eastbound lanes) present on 83 percent of study corridor (Figure 6d).

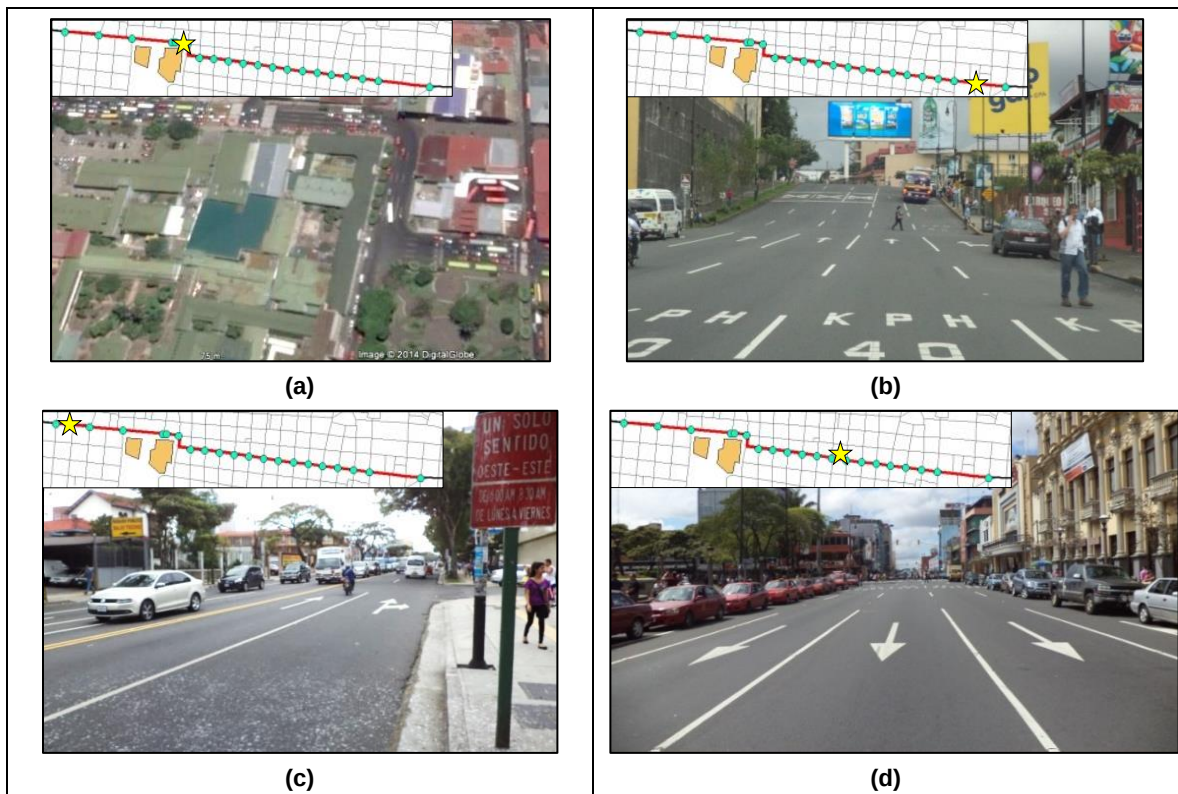


Figure 6: Illustrative examples of the study corridor's: (a) Vertical alignment; (b) Horizontal alignment; and (c)-(d) Cross-section

Table 4 summarizes the general site characteristics that were collected at each of the 20 signalized intersections on the study corridor.

Table 4: General Intersection Characteristics Collected in the Inventory

Site diagram	Intersection configuration, location and direction of lanes, crosswalks, signals, obstructions, and other data collected in the inventory
Intersection layout and configuration	Number and direction of intersection approaches and lanes on each approach Movements permitted on each lane Number, location, and intersecting angle of all crosswalks
Grade and cross-slope	Longitudinal grade and cross-slope of crosswalk qualitatively evaluated as level, minor, medium, or steep.
Surface condition	Qualitatively evaluated based on the presence of cracking, pavement deterioration, rutting, and unevenness as: 1. Poor surface condition 2. Acceptable surface condition with some damage 3. Good surface condition with negligible or no damage
Illumination	Presence of illumination on each terminal
Obstructions	Presence and type of objects at each terminal obstructing pedestrian movement (e.g., trees, poles, vendors, etc.) Obstruction dimensions and observations of pedestrians interacting with obstructions
Sightline obstructions	Presence and type of sightline obstructions blocking drivers' views of pedestrians waiting at either terminal to cross (e.g., trees, fences, taxis, etc.)
Use of outer lanes	Presence and type of activity in the outer lanes adjacent to the crosswalk (e.g., parked cars, loading, bus stops, taxis stands, etc.)

3.3.1.2. Pedestrian-related Signage and Pavement Markings

Pedestrian crosswalks are marked with zebra pavement markings at each of the 19 signalized intersections that operate a pedestrian phase. The pedestrian phase is provided for pedestrians crossing the study corridor, and not for pedestrians crossing the intersecting minor street. Pedestrian crossing control is typically not provided on intersecting minor streets: only six intersections have zebra pavement markings on one of the minor street approaches, and the quality of the markings is poor (Figure 7).



Figure 7: Zebra markings on the minor street approach at Site 7

Table 5 summarizes the pedestrian-related signage and pavement marking characteristics that were collected at each of the 20 signalized intersections on the study corridor.

Table 5: Pedestrian-related Signage and Pavement Marking Characteristics Collected in the Inventory

Sign type and application	Presence of signs related to the pedestrian crosswalk and colour, symbol, shape, dimensions, mounted height, and direction of signs (i.e., directed or not directed towards traffic), and distance between the crosswalk and sign
Sign condition	1. Poor: Sign is severely bent and not directed towards traffic Sign has severe graffiti that blocks the meaning of the sign Retro-reflectivity properties are severely compromised and the sign is not likely visible during the night 2. Okay: Sign is bent but still directed towards traffic Sign has graffiti but the meaning of the sign is still clear Retro-reflectivity properties compromised, but the sign is still likely visible during the night 3. Good: Sign is not bent and is directed towards traffic Sign has no graffiti Retro-reflectivity properties of the sign are in good condition
Street recognition	Presence, type, and general location of street recognition signs at each terminal (i.e., post mounted or mounted on corner building)
Sightline obstructions	Presence and type of sightline obstructions for drivers to pedestrian-related signage
Marking type and application	Stop lines: paint colour, width, distance between the stop line and crosswalk, extends full length of crosswalk paint colour, width, distance between the stop line and crosswalk, extends full length of crosswalk Zebra markings: paint colour, stripe width and length, extends full length of crosswalk
Pavement marking condition	1. Poor: Markings present but extremely worn and barely visible Underlying pavement more visible than pavement markings Pavement markings likely not visible during the night 2. Okay: Moderate wearing of pavement markings Some underlying pavement is visible Pavement markings likely visible during the night 3. Good: Pavement markings in perfect condition No underlying pavement is visible No wearing

3.3.1.3. Pedestrian Signal Design and Timing

Table 6 summarizes the pedestrian signal design and timing characteristics that were collected at each signalized intersection on the study corridor.

Table 6: Pedestrian Signal Design and Timing Characteristics Collected in the Inventory

Signal type	Full (at intersections with vehicular streets) or half (at intersections with pedestrian malls)
Pedestrian signal location	Bottom mount height of pedestrian signal head Offset between the centre of the pedestrian signal pole and the edge of crosswalk
Pedestrian signal visibility	Visibility of the pedestrian signal (i.e., visible for entire length of crosswalk) Direction of the pedestrian signal head (i.e., perpendicularly facing crossing pedestrians)
Pedestrian signal configuration	Position of the signal head displays (i.e., vertically positioned or tilted/not vertically positioned) Configuration of the signal head displays (i.e., DON'T WALK display above or below WALK display) Presence of signal visors Reflectivity and colour of signal head backboard
Pedestrian signal display type	Lens shape and dimensions Display shown for WALK, flashing WALK, and DON'T WALK intervals
Pedestrian signal condition	1. Poor: Lens is old (possibly incandescent display) Image is foggy Lens is partially burnt out Lens is dirty and indication is obstructed 2. Good: Lens is new and possible an LED display Image is clear Lens is not burnt out Lens is clean and indication is unobstructed
Signal timing and phase composition	Signal timing plans and phase composition recorded using a stopwatch Duration of each interval recorded for every phase
Signal timing and phase composition continued...	Timing plans recorded while the signals operated the same plan that was active when the conflict and compliance studies were conducted. Collected signal timing plans were compared to written signal timing plans obtained from the Costa Rican Ministry of Public Works and Transportation for conformity
Presence of conflicting phases	Phases in conflict with the pedestrian movements at the crosswalk

3.3.1.4. Accessible Features

Sidewalks exist on both sides of the study corridor and are constructed from concrete, asphalt, or brick paving stones. Sidewalk width was not consistently measured; however from general observations and occasional measurements it can be stated that sidewalk widths range from less than 1 meter to about 2.5 metres. The minimum legal requirement for sidewalk width in Costa Rica is 1.2 metres (Centro Nacional de Recursos para la Inclusion Educativa, 1996). Sidewalk obstructions, including poles, vendors, trees, garbage disposal bins, and degraded pavement are frequently present

and restrict the effective sidewalk width to below the minimum 1.2 metre requirement (Figure 8). Narrow sidewalk widths do not allow for the unobstructed passage of pedestrians and are not passable for people in wheelchairs.



Figure 8: Sidewalks on study corridor: (a) Wider sidewalk; (b) Narrower and obstructed sidewalk

Tactile pavement markings run along sidewalks for the first 0.8 km of the study corridor. Two types of tactile markings are used: (1) longitudinal markings along the sidewalk with grooves to indicate direction of travel (Figure 9a); and (2) transverse markings at terminals with raised bumps to indicate the presence of intersections (Figure 9b). All tactile markings are yellow.

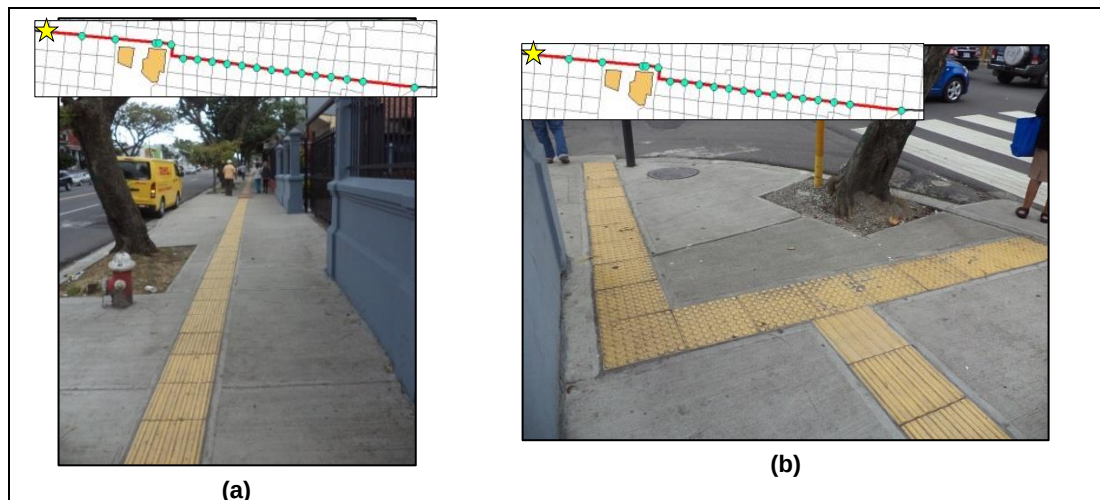


Figure 9: Tactile pavement markings: (a) Longitudinal grooved markings on sidewalk, (b) Transverse markings with raised bumps at terminal

Table 7 summarizes the accessible feature characteristics that were collected at each signalized intersection on the study corridor.

Table 7: Accessible Feature Characteristics Collected in the Inventory

Application of curb ramps	Presence, alignment, location (i.e., within or outside crosswalk), direction (i.e., along crosswalk, into centre of intersection, into lanes of traffic) of curb ramps
Grade and dimensions of curb ramps	Longitudinal grade qualitatively assessed as level, minor, medium, or steep Ramp width and gap width between the end of the ramp and roadway Presence and extent of upward grades (i.e., grades between the road level and the bottom of the curb ramp) When no ramp was present, dimensions measured for the height of the curb, gap between the curb and the roadway, and height of the roadway
Application of tactile pavement markings	Presence and purpose of tactile markings (i.e., indicate the presence of an intersection, lead to the crossing terminal from the sidewalk, lead to the curb ramp) Colour, dimensions, and type of tactile markings (i.e., tiles with raised bumps or elongated grooves)
Condition of tactile pavement markings	Tactile marking condition recorded as comments (i.e., extent of wear and presence of damage)
Method of pedestrian signal actuation	Presence of a pedestrian pushbutton and mount height, side of the pole mounted on, and whether mounted parallel or perpendicular to the crosswalk If pushbutton not present, pedestrian signal operated on fixed-time without actuation
Application of audible signals	Presence, mounting location, and direction of audible signals (i.e., along crosswalk, to centre of intersection, down to terminal) Presence of audible indication for the start of the WALK, flashing WALK, and DON'T WALK intervals
Condition of audible signals	Obstructions to the audible signal and general comments on the volume and carrying capacity of the emitted tone

3.3.2. Data Collection Process

All data was manually collected at all 20 signalized intersections on the study corridor. The studies were conducted Mondays through Fridays during the months of October and November 2013, between 9:30 a.m. and 11:30 a.m. These months correspond to the rainy season in Costa Rica, which is characterized by sun and clear skies in the morning followed by heavy rainfall in the afternoon. The data collection time period was selected to avoid the lane reversal during the AM peak period (as discussed in Table 3) and to capture pedestrian activity during clear and consistent weather conditions.

It was not necessary to collect the inventory of site conditions at consistent times because the attributes collected do not vary temporally: physical and operational

conditions are consistent throughout the day. Therefore, the inventory of site characteristics was taken at times convenient to the researchers, during the same months that the studies were conducted. Three observers conducted the compliance and conflict studies at each intersection: two observers recorded pedestrian compliance and one observer recorded conflicts. Pedestrian compliance and conflict occurrence was recorded for every pedestrian that crossed within the crossing zone during the data collection period.

Pedestrians crossing outside of the crossing zone were not recorded in the compliance and conflict studies. The crossing zone was defined depending on the type of intersecting street. At intersections with vehicular streets, the crosswalk was on one intersection leg and the crossing zone was defined as the distance between the stop line and the edge of the intersecting street curb, where the zebra markings terminated (Figure 10a). At intersections with pedestrian malls, the crosswalk was in the centre of the intersection and the crossing zone was defined as the distance between the stop line and two metres past the far edge of the zebra markings (Figure 10b). A two-metre distance was selected to mirror the distance typically observed between the stop line and the near edge of the zebra markings. This size of crossing zone was also used in previous pedestrian signal compliance studies (King, Soole, & Ghafourian, 2009).

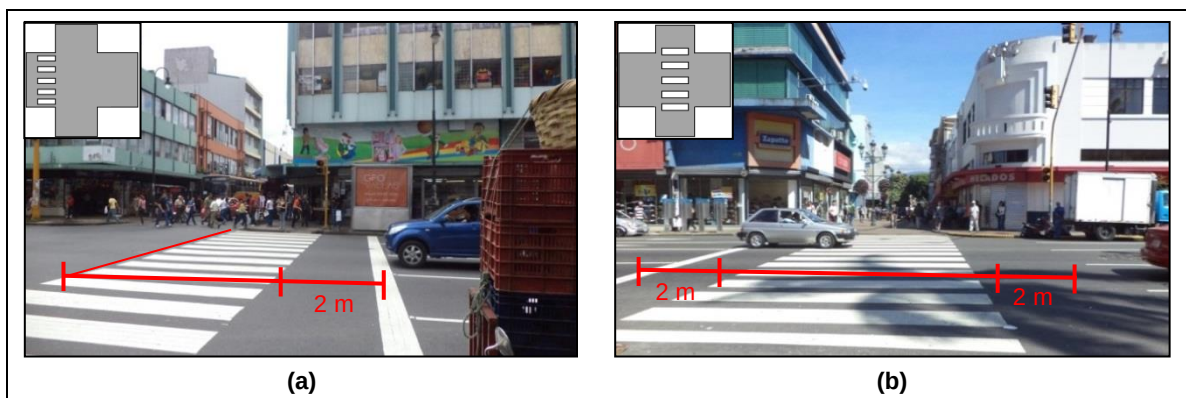


Figure 10: Crossing zones: (a) At signalized intersection with vehicular street; (b) At signalized intersection with pedestrian mall

Pedestrians were considered to be people walking, travelling in wheelchairs, motorized scooters, or with the use of other assistive devices. Bicyclists, children being carried, pushed in a stroller, or pulled in a wagon were not recorded.

3.3.3. Pedestrian Conflict Studies

This research adopted the U.S. FHWA traffic conflict definition, which states:

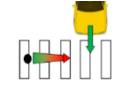
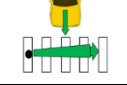
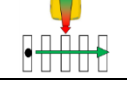
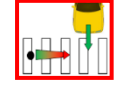
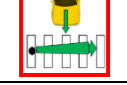
A traffic conflict is an event involving two or more road users, in which the action of one user causes the other user to make an evasive manoeuvre to avoid a collision (Parker & Zegeer, 1989).

The U.S. FHWA definition considers conflicts as evasive and atypical actions that are not necessarily extreme or infrequent (Lord, 1996). Other conflict definitions only record real near-misses and are based on the time-to-collision (TTC) parameter, which is computed by dividing the distance between two conflicting parties by their speeds at the time of the evasive action. A conflict is identified if the computed TTC is within a predefined minimum value (Lord, 1996). Methods that adopt the TTC conflict definition require video recordings and conflict detection software. The U.S. FHWA conflict definition was adopted in this research because it is more general and allows conflicts to be identified manually and in real-time onsite. The U.S. FHWA definition also allows for less extreme and atypical actions to be captured onsite, in addition to real near-misses.

Conflicts can be categorized by severity and type. Conflict severity is subjectively judged by the observer based on a predetermined severity scale. The severity scale can be set by TTC thresholds, the complexity of evasive manoeuvres, and the proximity of conflicting parties. This research categorized conflict severity as minor and severe. Minor conflicts were considered events where there was casual and less threatening interaction between pedestrians and vehicles. Minor conflicts were considered

inconveniences to road users and disruptions to their natural movements, such as unforeseen stops or accelerated walking in response to an approaching vehicle or changing signal interval. Severe conflicts were considered events where the interactions between pedestrians and vehicles posed a great risk of collision. In severe conflicts, pedestrians or drivers were observed taking drastically evasive manoeuvres to avoid a collision, such as sudden stops, swerving, running, or jumping to avoid an approaching vehicle. Conflict type was broken into nine different events that were either taken from previous research or observed in the field on initial site visits. Table 8 illustrates the types of minor and severe pedestrian conflicts used in this research.

Table 8: Types of Pedestrian Conflicts

Type		Diagram	Description
Minor	MA		A pedestrian stepped onto the roadway and then casually stepped back onto the curb to let a vehicle pass or because they felt there was not enough time remaining in the active phase to complete a crossing.
	MB		A pedestrian went around a vehicle that was stopped and blocking the crosswalk.
	MC		A pedestrian noticeably slowed mid-crossing to let a vehicle pass.
	MD		A pedestrian slightly increased their apparent natural traveling speed to avoid an oncoming vehicle or to reach the end of the crosswalk before the signal changed.
	ME		A driver gradually decreased their speed to let a crossing pedestrian pass.
Severe	SA		A pedestrian drastically increased their traveling speed by sprinting, running, or jumping back to the original curb to avoid an oncoming motorist.
	SB		A pedestrian abruptly stopped while crossing to avoid an oncoming motorist.
	SC		A pedestrian drastically increased their traveling speed by sprinting, running, or jumping forward to avoid an oncoming motorist.
	SD		A driver abruptly braked or swerved to avoid a crossing pedestrian.
Note: The red boxes around the severe conflict diagrams reflect that the movements taken by both parties were more abrupt, rapid, and drastic than their minor conflict counterpart.			

One observer recorded pedestrian conflicts for both directions of travel at all 20 intersections. Conflict type, severity, pedestrian gender, and the active pedestrian signal interval at the time of the conflict were recorded for each pedestrian conflict observed during the study period. Because the conflict studies were carried out simultaneously with the pedestrian compliance studies, which recorded total crossing pedestrians during the study period, it was possible to determine the proportion of conflicts for total crossing pedestrians. Some conflicts involved more than one of the interactions shown in Table 8. For example, a pedestrian could hurry across the road (type MA) while a vehicle slowed (type ME). In these cases, the event which appeared more pronounced to the observer was recorded as the conflict type. If the interactions appeared to have the same severity, the interaction which occurred first was recorded as the conflict type. The pedestrian conflict data collection form is shown in Appendix C.

3.3.4. Pedestrian Compliance Studies

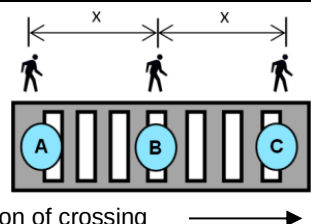
Pedestrian compliance with signals was evaluated temporally (i.e., crossing during the WALK, Flashing WALK, or DON'T WALK interval) and not spatially (i.e., crossing at designated crosswalks or jaywalking). Pedestrian compliance was recorded as green-walking, amber-walking, or red-walking, as defined by 10 crossing scenarios developed in the research and illustrated in Table 9. The scenarios were used as a guideline for observers conducting the studies, who recorded compliance for every pedestrian that crossed during the study period. The crossing scenarios determine compliance based on the interval displayed at the beginning, midpoint, and end of the pedestrian's journey across the street. For example, a type 1 green-walker begins, reaches the midpoint, and finishes crossing during the WALK interval. A type 9 red-walker begins, reaches the midpoint, and finishes crossing during the DON'T WALK interval.

Table 9: Pedestrian Signal Compliance Determination

Compliance	Type	Pedestrian location in crosswalk*	Active signal phase
Green-walker	1	A	 Solid WALK
		B	
		C	
	2	A	 Solid WALK
		B	
		C	 Flashing WALK
	3	A	 Solid WALK
		B	
		C	 Flashing WALK
	4	A	 Solid WALK
		B	
		C	 DON'T WALK
	5	A	 DON'T WALK
		B	
		C	 Solid WALK
Amber-walker	6	A	 Flashing WALK
		B	
		C	
	7	A	 Flashing WALK
		B	
		C	 DON'T WALK
Red-walker	8	A	 Flashing WALK
		B	
		C	 DON'T WALK
	9	A	 DON'T WALK
		B	
		C	
	10	A	 DON'T WALK
		B	
		C	 Solid WALK

**Pedestrian location in crosswalk*

A: Pedestrian begins crossing at start of crosswalk
B: Pedestrian reaches midpoint of crosswalk
C: Pedestrian finishes crossing at end of crosswalk



Direction of crossing →

Two observers recorded compliance by pedestrian gender and travel direction for each signal cycle. The observers stood at opposing crossing terminals and recorded compliance for pedestrians travelling away from them, towards the far side of the intersection. Two observers were necessary because pedestrian volumes were too high to be recorded by one observer. Observers recorded compliance of total pedestrians and total female pedestrians. Male pedestrian compliance was calculated in the office. The observers received pedestrian compliance identification training in the office and onsite before conducting the studies. Manual data collection in real-time onsite is subject to human error: it is possible that the compliance of some pedestrians were missed or wrongly recorded.

Pedestrian signal compliance is a measure of road user behaviour and has been linked to road safety performance. Research conducted at signalized intersections in a central business district with high vehicular and pedestrian volumes found that red-walking has a collision risk factor eight times greater than green-walking (King, Soole, & Ghafourian, 2009). Illegal crossing behaviour, including red-walking and jaywalking, were involved in 58 percent of collisions in this study. In a collision analysis by Garder (1989), red-walking pedestrians were found to be one of the most frequent types of collisions. Although not proven, there is a higher collision risk associated with crossing against the solid DON'T WALK interval as opposed to the Flashing DON'T WALK interval. Allowing pedestrians to cross against the signal and yield to oncoming vehicles is undesirable because of safety concerns (Zegeer, Opiela, & Cynecki, 1985). The data collection form used to collect compliance data is shown in Appendix C.

3.4. SUMMARY OF RESEARCH METHODOLOGY

The research methodology was applied to a 2.4 km study corridor on the Pan-American Highway that passes through downtown San Jose, Costa Rica. Downtown San Jose accommodates a high level of pedestrian activity. Pedestrian crossing control is primarily provided at signalized intersections. The study corridor incorporates 20 signalized intersections (all except one operate a pedestrian phase).

Seven guiding principles for the provision of pedestrian crossing control served as the framework for developing the methodology applied in this research: safety, delay, equity, expectancy, consistency, connectivity, and pragmatism.

The data collection program included an inventory of physical and operational site conditions, pedestrian conflict studies, and pedestrian compliance studies at all 20 signalized intersections on the study corridor. All data was manually collected. The studies were conducted on weekdays in October and November 2013, between 9:30 a.m. and 11:30 a.m. Every pedestrian that crossed the study corridor at a signalized intersection during the study period was included in the conflict and compliance studies. Pedestrians crossing outside of a predefined crossing zone were not recorded. Motor vehicle volume was not recorded during the studies, however is believed to be consistent across all 20 sites during the study time period. The average daily traffic is 30,000 vehicles.

The purpose of the inventory of physical and operational site characteristics was to identify factors contributing to poor pedestrian compliance, high conflict severity and frequency, and to assess overall pedestrian accommodation. The inventory included qualitative and quantitative data, as well as a photo catalogue of general site characteristics, pedestrian-related signage and pavement markings, pedestrian signal design and timing, and accessible features.

Conflict type, severity, pedestrian gender, and the active pedestrian interval displayed at the time of the conflict were recorded for each pedestrian conflict observed during the study period. The research defined nine different conflict types based on previous studies and initial field observations. Pedestrian compliance was recorded by gender. Pedestrian compliance was recorded as green-walking, amber-walking, or red-walking, as defined by 10 crossing scenarios developed in this research. The crossing scenarios determine compliance based on the phase displayed at the beginning, midpoint, and end of the pedestrian's journey across the street.

4.0. PHYSICAL AND OPERATIONAL SITE CONDITION EVALUATION

This chapter evaluates the physical and operational conditions at all 20 sites on the study corridor. The chapter includes the evaluation approach and results for: (1) general site characteristics; (2) pedestrian-related signage and pavement markings; (3) pedestrian signal design and timing; and (4) accessible features.

4.1. EVALUATION APPROACH

An inventory of physical and operational conditions was manually collected at each of the 20 sites on the study corridor to assess pedestrian accommodation. The inventory was of qualitative and quantitative data and also included a photo catalogue for four different categories of site conditions:

- General site characteristics
- Pedestrian-related signage and pavement markings
- Pedestrian signal design and timing
- Accessible features

The findings from the inventory were summarized and broadly compared to the documented practices in Costa Rica and best practices from North America for accommodating pedestrians crossing at signalized intersections. Appendix B summarizes all physical and operational site conditions collected in the inventory for each site on the study corridor. This chapter presents the collective inventory results and discusses pedestrian safety implications

4.2. GENERAL SITE CHARACTERISTICS

The evaluation of general site characteristics is presented in Table 10 and Figure 11 through Figure 14.

Table 10: Evaluation of General Site Characteristics

Parameter	Observations	Best Practice
Crosswalk angle	Crosswalks intersect the study corridor at 90 degrees at 18 of the 20 sites. One site has a 70 degree crosswalk intersection angle and one site does not have a marked crosswalk.	90 degree intersections are ideal for sightlines and for minimizing pedestrian crossing distance.
Grade and cross-slope	All crosswalks were level, with negligible longitudinal grades. Cross-slope varied from level (nine sites), minor (eight sites), medium (two sites), and steep (one site).	Longitudinal grades should not exceed five percent and cross-slopes should not exceed two percent. Steep grades and cross-slopes are difficult to traverse for pedestrians with mobility impairments.
Surface condition	Surface condition was acceptable at eight sites and good at 12 sites (Figure 11). None of the sites had poor surface condition.	Provide good surface condition that is smooth and slip-resistant.
Illumination	All sites were well illuminated.	Provide good illumination for nighttime visibility and to help deter crime.
Sightline obstructions	Sightline obstructions were present on at least one terminal at all 20 sites. Obstructions included taxi stands, bus stops, buses, vendor tables and umbrellas, poles, garbage cans, trees, building column supports extending onto the sidewalk, phone booths, loading zones, and parked vehicles. Figure 12 illustrates buses entering a terminal from the outer lanes at one site. These buses obstructed driver sightlines of the terminal and obstructed pedestrian views to signal heads.	Provide clear sightlines at intersections so drivers and crossing pedestrians can see each other, and so pedestrians can see the signal.
Outer lanes	Activity including parking, loading, bus stops, and taxi stands were present on at least one terminal at 19 sites. Parking and taxi stands are not allowed in outer lanes within marked crosswalks. Figure 13 illustrates activity in the outer lanes that is blocking pedestrian access to curb ramps.	Keep outer lanes within marked crosswalks clear of motor vehicle traffic. Do not allow vehicles to block access to curb ramps.
Obstacles	Obstacles were present on at least one terminal at 17 sites. Obstacles included trees, vendors and their structures, poles, grates, chains, handrail, fire hydrants, and train tracks (Figure 14). The chain was not flush with the ground and would be undetectable and a tripping hazard for pedestrians with vision impairments.	Remove obstacles that are impassable for pedestrians traveling with mobility devices, such as wheelchairs, and that may be undetectable for pedestrians with vision impairments.



Figure 11: Surface condition: (a) Acceptable; (b) Good

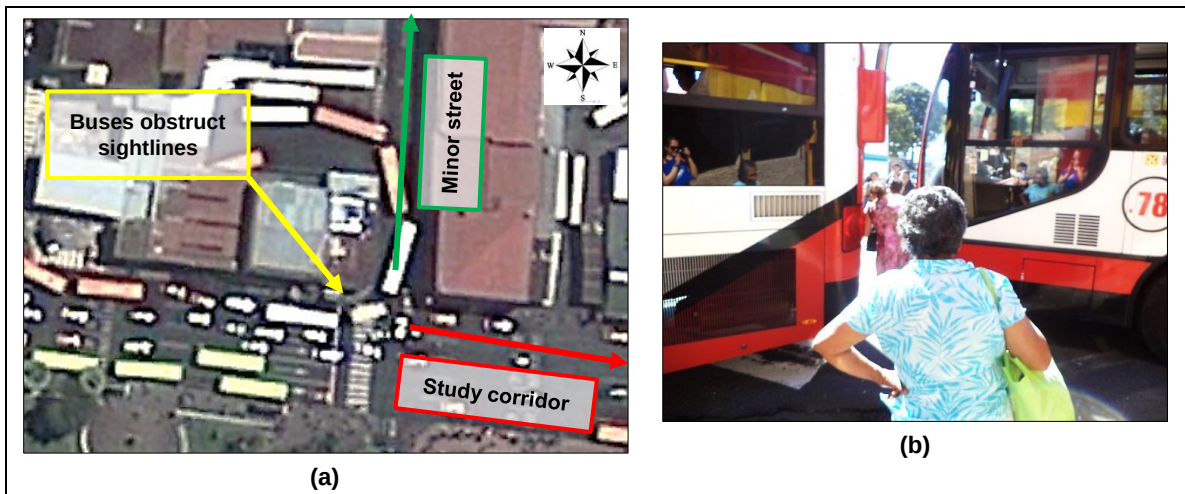


Figure 12: Buses entering terminal at Site 7 obstruct sightlines: (a) Aerial view of buses entering terminal Source: Adapted from Google Earth; (b) Pedestrian view of signal obstructed by turning buses



Figure 13: Activity in outer lanes blocks curb ramps at crosswalks: (a) Parked vehicle; (b) Taxi stand



Figure 14: Obstructions at terminals: (a) Tree and poles; (b) Poles and parked vehicles; (c) Vendor; (d) Train tracks; (e) Chain

4.3. PEDESTRIAN-RELATED SIGNAGE AND PAVEMENT MARKINGS

The evaluation of pedestrian-related signage and pavement markings is presented in Table 11 and Figure 15.

Table 11: Evaluation of Signage and Pavement Markings

Parameter	Observations	Best Practice
Crosswalk warning signs	A Zona de Seguridad (Safety Zone) sign was present at one terminal in front of the hospital. It is consistent with sign P-9-3 from the MUTCDCA (SIECA, 2000, p. 2.95). The sign has graffiti but the words are relatively clear. It is placed within the zebra markings of the crosswalk, facing westbound traffic. The study corridor operates one-way eastbound traffic; however, the northern lane in front of the hospital can be used by ambulances travelling westbound to the hospital. The sign only serves these drivers, who are likely familiar with the area and crosswalks.	The Zona de Seguridad (Safety Zone) sign is intended to warn drivers of an upcoming crosswalk. Warning signs should be set back from crosswalks, as opposed to being within the markings, so that drivers can react before reaching the site. Crosswalk warning signs are not typically required at signalized intersections.
Street recognition	Street recognition signs were present on at least one terminal at 19 sites. Signs were post-mounted at the terminal or mounted on a wall of an adjacent corner building. Street recognition information was never provided in alternative communication methods, such as Braille.	Provide street recognition signage at each terminal for way-finding. Provide information in alternative forms of communication for pedestrians with vision impairments.
Zebra markings	White zebra markings were present at 19 sites on the study corridor. Zebra markings extended across all lanes of traffic, except at one site where one lane had recently been repaved and the pavement markings were not redone. Zebra marking condition varied: • Good at nine sites (i.e., no underlying pavement was visible through the markings and there was no wearing). • Okay at nine sites (i.e., moderate wearing and some underlying pavement visible through the paint). • Poor at one site (i.e., markings worn and barely visible, underlying pavement more visible than paint, and the markings likely not visible at night). Stripe width ranged from 44 cm to 80 cm, with 70 cm as the average. Stripe length ranged from 3.6 metres to seven metres, with 4.0 metres as the average.	The application of zebra markings provides excellent crosswalk visibility for approaching drivers and pedestrians. Zebra markings should span the full width of the crosswalk. Pavement marking condition should be maintained to ensure nighttime visibility. The MUTCDCA specifies that zebra marking stripe width should be between 40 cm and 60 cm. Larger zebra markings provide greater visibility.
Stop line markings	White stop lines were present and in good condition at all sites. Stop lines extended across all necessary lanes of traffic, except at one site where one lane had been recently repaved and the pavement markings were not redone. Stop line width ranged from 37 cm to 50 cm, with 40 cm as the average. The distance between the stop line and the onset of zebra markings was two metres at most sites. At intersections with pedestrian malls, the stop line was often set further back, at approximately three metres. The closest distance that between the stop line and the onset of zebra markings was 1 metre. Special cases, such as the presence of train tracks which restricted traveled lanes and an ambulance entrance in front of the hospital, required the stop line to be set even further back.	Provide stop lines to indicate the proper location for drivers to stop during the <i>red</i> interval and to ensure drivers don't enter and block crosswalks. Pavement marking condition should be maintained to ensure nighttime visibility. Stop lines should extend across all necessary lanes of traffic. The MUTCDCA specifies that stop line width should be between 30 cm and 45 cm. Stop lines should typically be set back 1.2 metres from the onset of zebra markings.



Figure 15: Signage and pavement markings: (a) Zona de Seguridad (Safety Zone) sign; (b) Post-mounted street sign; (c) Wall-mounted street sign; (d) Zebra markings in good condition; (e) Zebra markings in poor condition; (f) Stop line set back to accommodate ambulance entrance to hospital

4.4. PEDESTRIAN SIGNAL DESIGN AND TIMING

The evaluation of pedestrian signal design is presented in Table 12 and Figure 16.

Pedestrian signal timing and phase composition is subsequently discussed.

Table 12: Evaluation of Pedestrian Signal Design

Parameter	Observations	Best Practice
Pedestrian signal location	The mount height of the pedestrian signal head ranged from 2.3 metres to 3.0 metres above ground surface, with 2.6 metres as the average. The average offset between the pedestrian signal head pole and the onset of the zebra markings was 0.5 metres. The most common offset was zero metres (i.e., the pedestrian signal pole was located directly in line with the onset of zebra markings). The largest offset was 12.6 metres.	Pedestrian signals should be placed in line with the crosswalk for maximum visibility to crossing pedestrians so that the appropriate time to cross is clear. The signal head should be mounted between two metres and three metres above ground level.
Pedestrian signal visibility	The pedestrian signal head was perpendicularly directed along the crosswalk at all 19 sites that operate a pedestrian phase. The signal head on one terminal was damaged and directed slightly down, toward the pavement. The pedestrian signal head was visible for the entire crosswalk length at 18 sites. One site does not operate a pedestrian phase and the pedestrian signal displays are not visible at one site because the pole is greatly offset from the crosswalk (at 12.6 metres). This site was at a pedestrian mall with a particularly wide crosswalk. The offset was so large that the pedestrian signal head was not visible to pedestrians as they crossed the intersection and was located in the pedestrian's periphery vision. Signal visors at this location further blocked displays.	Pedestrian signals should be placed for maximum visibility to crossing pedestrians so that the appropriate time to cross is clear. The signal head should perpendicularly face crossing pedestrians.
Pedestrian signal head configuration	The pedestrian signal head was vertically positioned at all 19 sites that operate a pedestrian phase, and the DON'T WALK display was always mounted above the WALK display. Signal visors were present on all pedestrian signal heads. All pedestrian signal heads were yellow and none had retroreflective backboards.	In Costa Rica, pedestrian signal lenses should be vertically arranged with the DON'T WALK indication above the WALK indication. Signal visors help to reduce glare and are beneficial in inclement weather.
Pedestrian signal display	All pedestrian signal lenses were circular. Of the 38 pedestrian signal heads, 36 had 30 cm diameter lenses. Two displays had 22 cm diameter lenses. The WALK interval represented by a green pedestrian that flashed during the Flashing WALK interval or by a dynamic green pedestrian that walked during the WALK interval and ran during the Flashing WALK interval. The DON'T WALK interval was represented by a red pedestrian or red ball. Both LED and incandescent displays were used. LED displays were always in better condition than incandescent displays. Display condition varied: • Good condition (i.e., new lenses with LED displays that have clear images, not burnt out, and unobstructed view of display) was recorded for 12 lenses. • Poor condition (i.e., old incandescent lenses that may be partially blocked by visors, slightly burnt out, dirty or foggy in appearance) was recorded for 64 lenses.	Pedestrian signal displays should be clear and visible. LED lenses with 30 cm diameters provide the greatest visibility. Uniform symbols should be used to display each pedestrian interval. In Costa Rica, circular or square lenses can be used with the following displays: WALK interval: green pedestrian or PASE (PASS) in green text Flashing WALK: flashing green pedestrian or flashing PASE in green text DON'T WALK: red pedestrian or ALTO (STOP) in red text. A red ball is reserved for vehicular signal displays.

Table 12 continued...

Parameter	Observations	Best Practice
Presence of conflicting phases	Conflicting phases between pedestrians and motor vehicles were not present. However, right-turns on <i>red</i> and left-turns on <i>red</i> at certain one-way street intersections are allowed at most sites.	Prohibiting turns on <i>red</i> should be considered at locations with high volumes of pedestrians and turning vehicles to eliminate possible conflicts and collisions.
Method of actuation	The pedestrian signal operated on fixed-time without actuation at 18 sites (one site does not operate a pedestrian phase). One site was actuated using pedestrian pushbuttons. On the north terminal, the pushbutton was mounted parallel to the crosswalk, on the east side of the pole, mounted at 1.55 metres in height from the ground surface. On the south terminal, the pushbutton was mounted perpendicular to the crosswalk, on the north side of the pole, also at 1.55 metres in height from ground surface.	Pushbuttons should be mounted parallel with the crosswalk to help indicate crossing direction for pedestrians with vision impairments. Pushbutton mount height should be between 1.1 metres and 1.25 metres above ground surface so that they are accessible for pedestrians with mobility impairments.

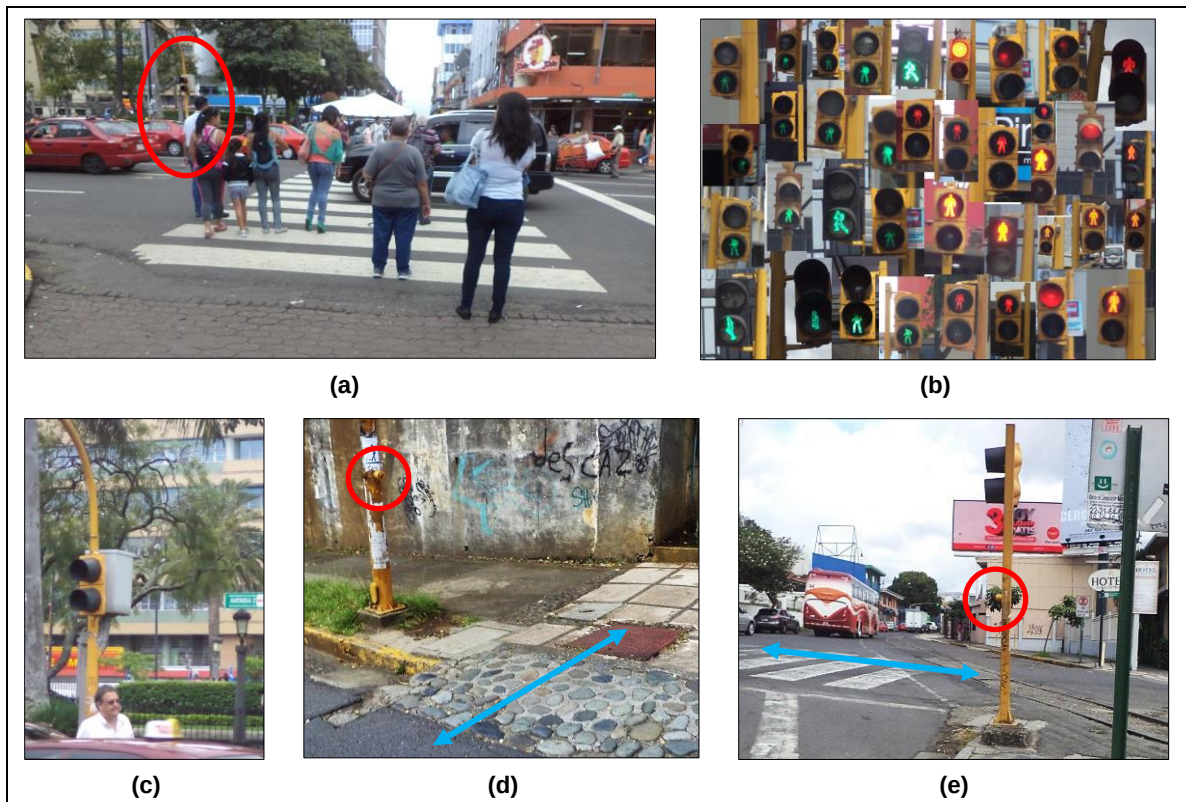


Figure 16: Pedestrian signal design: (a) Pole offset large distance from crosswalk and not visible to crossing pedestrians; (b) Compilation of pedestrian signal head displays on the study corridor; (c) Visors further obstruct view of pedestrian signal head that is offset a large distance from crosswalk; (d) Pushbutton parallel to crosswalk; and (e) Pushbutton perpendicular to crosswalk.

4.4.1. Pedestrian Signal Timing and Phase Composition

The discussion on pedestrian signal timing and phase composition focuses on the portion of the cycle that is allotted to crossing pedestrians while conflicting traffic is held on *red*. The minor street phase and pedestrian phase operate concurrently. Motor vehicle traffic on the major street (i.e., the study corridor) is held on *red* while the minor street and pedestrian phases are active. The evaluation of signal timing and phase composition looked for potential pedestrian expectancy violations and centered on four questions:

1. What is the duration of the pedestrian phase and how is it split between the WALK, Flashing WALK, and DON'T WALK intervals?
2. What is the duration of the pedestrian clearance interval and how is it split between the Flashing WALK and DON'T WALK intervals?
3. During what interval of the minor street phase do the pedestrian clearance interval and the DON'T WALK interval begin? The minor street phase has four intervals: *green*, *flashing green*, *amber*, and *red*.
4. Are pedestrians given sufficient time during the pedestrian clearance interval to reach the far terminal before conflicting traffic is released?

Pedestrians rely on the information provided by the signal to determine when it is safe to cross. Pedestrian expectancy is less likely to be violated, and pedestrians are more likely to understand and respond appropriately to the given directions when consistent signal timing practices are used. The study corridor is a relatively uniform road segment with respect to cross-section, signal spacing, pedestrian activity, motor vehicle activity, and surrounding land use. For this reason, pedestrians likely expect equivalent signal operations at each site on the study corridor.

Figure 17 illustrates the pedestrian phase splits at all 19 sites on the study corridor that operate a pedestrian phase. The minor street intervals that are active at the time the Flashing WALK and DON'T WALK intervals begin are also illustrated.

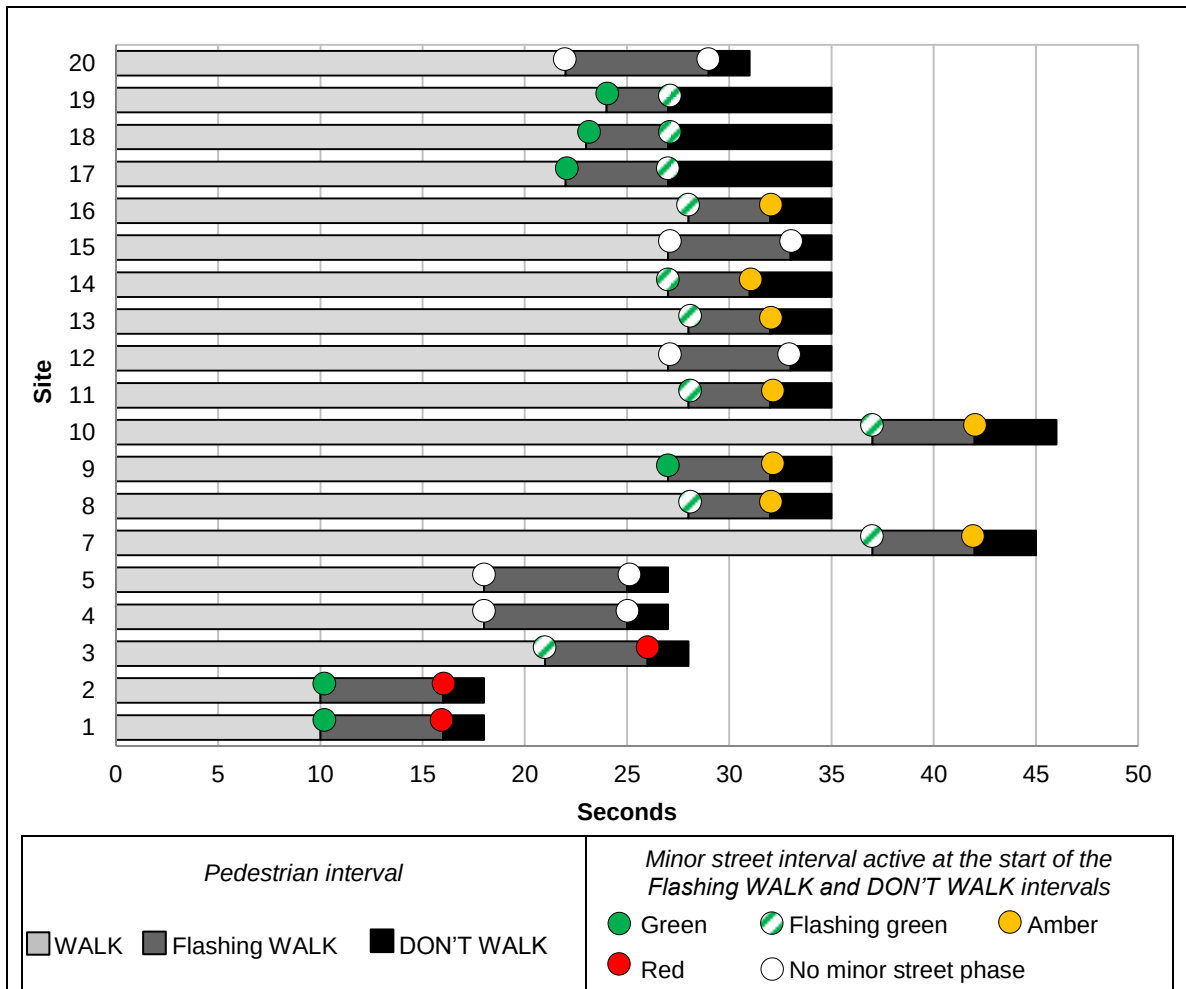


Figure 17: Pedestrian phase splits and the minor street vehicular intervals that are active at the start of the Flashing WALK and DON'T WALK intervals

The following can be observed in Figure 17:

- The duration of the pedestrian phase ranged from 18 seconds to 46 seconds. The pedestrian phase is shorter at Site 1 and Site 2 to accommodate a protected turn that happens in advance of the pedestrian phase.

- The WALK interval is allotted the largest proportion of the pedestrian phase and the WALK interval duration is always greater than the minimum required by the MUTCDCA (SIECA, 2000, p. 430).
- The duration of the pedestrian clearance interval and the times allotted to the Flashing WALK and DON'T WALK intervals are inconsistent. For example, at Site 11 the Flashing WALK duration is greater than the DON'T WALK duration, while at Site 17 the Flashing WALK duration is less than the DON'T WALK duration. This type of inconsistency can violate pedestrian expectancy regarding how much time remains to safely clear the intersection.
- The Flashing WALK and DON'T WALK intervals begin during different minor street intervals. DON'T WALK interval durations are longer when they begin earlier in the minor street phase. On average, the DON'T WALK interval begins during the minor street *amber* interval, lasts for four seconds, and terminates at the end of the intersection *all-red* when conflicting traffic is released.

A crossing pedestrian will gauge whether they have sufficient time to reach the far terminal or if they should return to the original terminal based on where they are in the intersection and based on the pedestrian interval that is currently displayed. Inconsistent pedestrian clearance intervals hinder a pedestrian's ability to gauge how much time remains to clear the intersection, and whether they should finish crossing or return to the original terminal. These inconsistencies can have safety implications for pedestrians that expected to have more time to cross than what was actually provided and were left within the intersection when conflicting traffic was released.

Pedestrian clearance interval timing at Site 11 and Site 17, as illustrated in Figure 17, can be compared to illustrate a pedestrian expectancy violation and potential safety implication:

- Site 17: A crossing pedestrian that is already within the intersection when the DON'T WALK interval begins has up to eight seconds to clear the intersection before conflicting traffic is released. Depending on where the pedestrian is within the intersection, eight seconds could be sufficient for them to reach the far terminal. This pedestrian may innately expect the DON'T WALK interval to be eight seconds at other sites, which influences their crossing behaviour.
- Site 11: Based on their experience crossing at Site 17, a pedestrian that is already within the intersection when the DON'T WALK interval begins may expect to have eight seconds to clear before conflicting traffic is released, and may try to reach the far terminal in this time. However, the DON'T WALK interval is shorter at Site 11 and pedestrians are only given four seconds to clear the intersection. This expectancy violation would put the pedestrian at risk of being in a collision or conflict because they would be left within the intersection when conflicting traffic is released.

Best practice is to ensure that pedestrians can cover the full crossing distance during the pedestrian clearance interval before conflicting traffic is released, while traveling at a walking speed between 0.8 m/s and 1.0 m/s. Figure 18 illustrates the required distance to cross and the distance that a pedestrian travelling at 1.0 m/s and 1.2 m/s, which is the documented design walking speed in Costa Rica, could cover during the pedestrian clearance interval. At all sites on the study corridor, it is not possible for a pedestrian traveling at these speeds to reach the far terminal during the pedestrian clearance

interval before conflicting traffic is released. Effectively, pedestrian clearance intervals on the study corridor only serve to clear pedestrians to the far terminal if they have covered more than half of the crossing distance during the WALK interval. Pedestrians traveling at 1.2 m/s are given sufficient time to cross during the full pedestrian phase (WALK plus pedestrian clearance) at all sites.

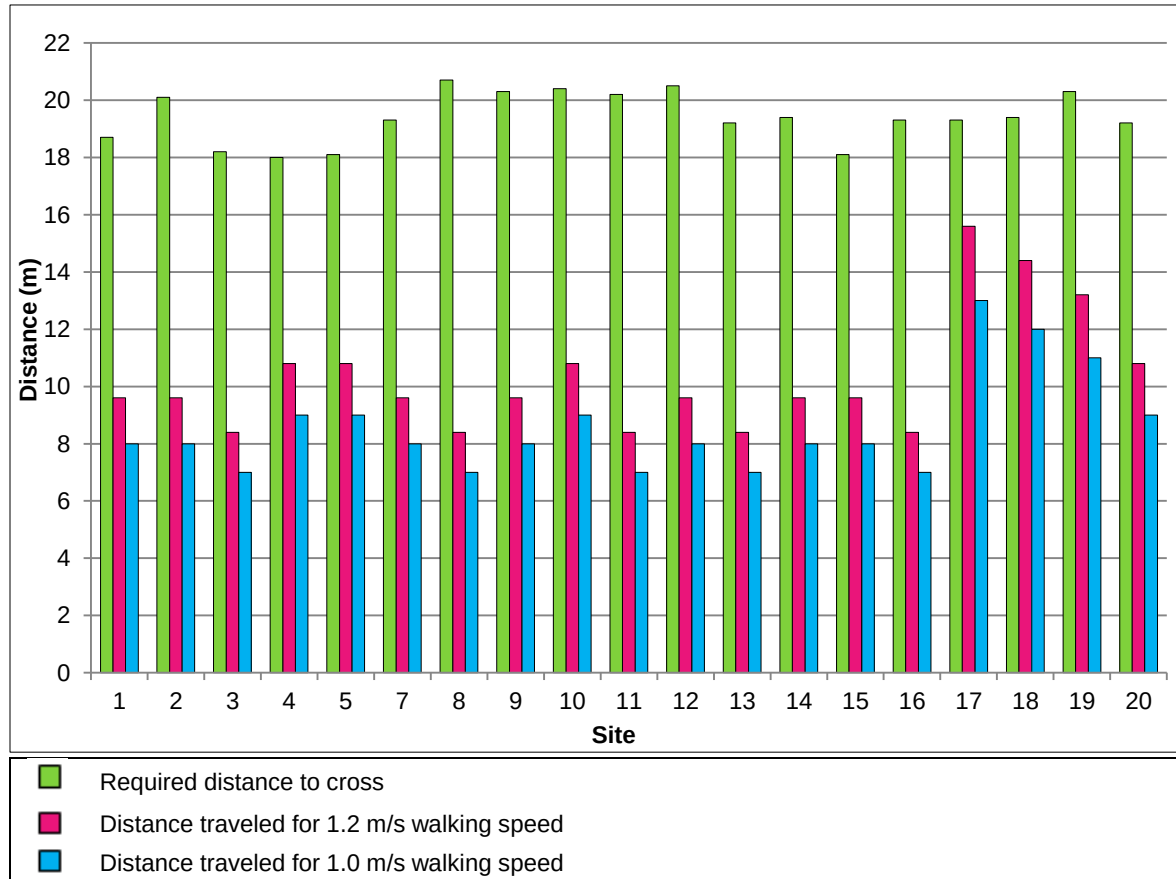


Figure 18: Crossing distance and distance traveled during the pedestrian clearance interval provided at each site on the study corridor (note that Site 6 does not operate a pedestrian phase)

Table 13 summarizes the pedestrian clearance interval duration, required distance to cross, and the walking speed required to travel the full crossing distance during the pedestrian clearance interval for each site on the study corridor that operates a pedestrian phase. Pedestrians that begin crossing at the onset of the pedestrian clearance interval would have to travel at as fast as 3.0 m/s to reach the far terminal

before conflicting traffic is released. Pedestrians unable to travel at this speed, due to a mobility impairment for example, would be left within the intersection when conflicting traffic is released.

Table 13: Required Walking Speed to Cross during Pedestrian Clearance Interval

Site	Pedestrian clearance interval [s]	Required distance to cross [m]	Walking speed required to travel crossing distance during pedestrian clearance interval [m/s]
1	8	18.7	2.3
2	8	20.1	2.5
3	7	18.2	2.6
4	9	18.0	2.0
5	9	18.1	2.0
7	8	19.3	2.4
8	7	20.7	3.0
9	8	20.3	2.5
10	9	20.4	2.3
11	7	20.2	2.9
12	8	20.5	2.6
13	7	19.2	2.7
14	8	19.4	2.4
15	8	18.1	2.3
16	7	19.3	2.8
17	13	19.3	1.5
18	12	19.4	1.6
19	11	20.3	1.8
20	9	19.2	2.1

4.5. ACCESSIBLE FEATURES

The evaluation of accessible features included curb ramps, tactile markings, and audible signals. The evaluation of curb ramps is presented in Table 14 and Figure 19.

Table 14: Evaluation of Curb Ramps

Parameter	Observations	Best Practice
Presence	Curb ramps were present on both terminals at 14 sites, on only one terminal at three sites, and on neither terminal at three sites. Handrails were present on four ramps and mounted at 90 cm in height.	Provide curb ramps on both terminals to give access to pedestrians with impairments.
Alignment	Curb ramps were aligned with each other (from terminal to terminal) at six sites, and not aligned or a ramp was present on only one terminal at 14 sites. Pedestrians with vision impairments travelling with canes for guidance were observed having difficulties crossing at sites with unaligned curb ramps.	A straight path of travel between the initial ramp, centre of the intersection, and final ramp is ideal for orienting pedestrians with vision impairments and also good for pedestrians in wheelchairs, who often require a straight path of travel to build enough momentum to pass the ramp.
Direction	Curb ramps were directed along the crosswalk at 19 terminals, toward the centre of the intersection at six terminals, and into traffic lanes on the study corridor at five terminals.	Direct ramps along the crosswalk, or to the centre of the intersection if they serve multiple crossing directions and adequate landing space is provided.
Location	Curb ramps were wholly located within the zebra markings at 23 terminals and located outside of the zebra markings at eight terminals.	When ramps are located outside of the crosswalk, pedestrians that require the ramps for travel must enter the vehicular right-of-way, which is a safety concern. Pedestrians outside of the crosswalk are less likely to be seen by drivers because they are in an unexpected location
Width	Curb ramp width ranged from 84 cm to 2.7 metres, with 1.2 metres being the most common width.	Regulations in Costa Rica specify require curb ramps to be a minimum width of 1.2 metres. Narrower ramps are not traversable for pedestrians in wheelchairs.
Longitudinal grade	Curb ramps were completely level between the sidewalk and road at five terminals, had minor grades at eight terminals, medium grades at 15 terminals, and steep grades at two terminals.	Although ideal for people with mobility impairments, level grades are difficult for people with vision impairments to detect and may be a tripping hazard for them. Best practices recommend a longitudinal grade of 7.1 ± 1.2 percent.
Gap	A gap between the bottom of the ramp and the crosswalk/roadway was present at 19 terminals. Gap width ranged from 15 cm to 72 cm, with 50 cm being the most common. Ponding can form in these gaps.	Flush transitions are ideal at the base of curb ramps. Traveling over gaps can put pedestrians with impairments off-balance and act as a tripping hazard.
Upward grade	An upward grade was present at 16 terminals. Upward grades were often caused by asphalt overlays that were not cut to a traversable grade for pedestrians with mobility impairments. Pedestrians were observed tripping over upward grades at multiple sites.	Severe or sudden grade changes should be avoided because they can be tripping hazards and can tip people in wheelchairs. Asphalt overlays should be adequately milled or cut to limit grade changes from the base of the ramp to the roadway.
Curb height	Curb height was 20 cm at locations without curb ramps. People using wheelchairs who crossed at these locations continued traveling on the minor street because they could not access the terminal without a ramp.	Pedestrians traveling on the roadway are exposed to traffic and at a greater risk of being in a collision than those travelling on the sidewalk.



Figure 19: Curb ramps: (a) Ramp with handrail located outside of zebra markings; (b) Aligned ramps and with cut asphalt overlay for accessible upward grade; (c) Ramp located outside of zebra markings and directed into traffic lanes; (d) Ramp directed to the centre of the intersection with narrow ramp width; (e) Gap between bottom of curb ramp and crosswalk/roadway with ponding; (f) Upward grade between bottom of ramp and crosswalk/roadway caused by asphalt overlay

The evaluation of tactile markings is presented in Table 15 and Figure 20.

Table 15: Evaluation of Tactile Markings

Parameter	Observations	Best Practice
Overall presence	Tactile markings were not consistently present on the study corridor and the style of application varied considerably. Tactile marking designs do not fully conform to the National Standard for Signage on Horizontal Surfaces. Tactile markings were present at eight sites. All tactile markings were yellow. Detectable warning had truncated domes, some of which were quite worn down. Directional surface tiles had textured bars running parallel with the direction of intended travel.	Tactile markings should convey a unique message in a standardized format. Uniform application is critical to best serve pedestrians with vision impairments. Tactile markings should be yellow. Truncated domes on detectable warnings should be raised and in good condition. Textured bars should run parallel with intended travel direction on directional surface tiles.
Sidewalks	Directional surfaces ran along sidewalks connecting the first six sites on the study corridor. Utility grates on sidewalks interrupted the continuity of directional surfaces. At some grates, detectable warnings indicated the hazard and change in direction, while at other locations tactile markings were not used to identify the grate. Many obstacles and hazards on sidewalks were not marked with detectable warnings.	Directional surfaces convey wayfinding information on sidewalks or along predictable paths in large spaces where physical elements commonly used for reference are absent. Directional surfaces can be used with detectable warnings to indicate changes in travel direction. A single strip of detectable warnings should be used to indicate hazards.
Terminals	There were two main types of applications: (1) <i>Terminal squared off with detectable warnings</i>: Directional surfaces run along the sidewalk until meeting a transverse strip of detectable warnings. The transverse strip intersects at a right angle with a second strip of detectable warnings running parallel with the sidewalk, effectively squaring off the terminal from the intersection. The crosswalk was located within or outside of the squared off area. The transverse strip of detectable warnings terminated at the curb ramp, before or after the curb ramp. (2) <i>Single transverse strip of detectable warnings</i>: Transverse strip of detectable warnings located in-line with the marked crosswalk. Directional surfaces were not present on sidewalks with this type of application. Obstacles at terminals were never marked with detectable warnings and often interfered with the placement of tiles, resulting in incomplete applications of tactile markings.	Tactile markings at terminals can indicate the presence of the intersection. Applications should be consistent so that user expectancy is not violated. Inconsistent application of tactile markings could confuse pedestrians with a vision impairments and impede their ability to identify hazards and appropriate crossing locations. A single strip of detectable warnings should be used to indicate hazards.
Curb ramps	Tactile markings were not present on curb ramps.	A single strip of detectable warnings should be provided at the base of curb ramps to align pedestrians with vision impairments and indicate where to wait to cross.



Figure 20: Tactile markings: (a) Directional surface on sidewalk broken by grate; (b) Directional surface on sidewalk changing direction for grate; (c) Incomplete squared off application at terminal due to grates; (d) Crosswalk located outside of squared off area at terminal, obstacles not marked; (e) Crosswalk located inside of squared off area at terminal, transverse strip of detectable warnings terminates at curb ramp, obstacles not marked; (f) Directional surface leads to curb ramp at terminal with squared off application; (g) Vendor set up over transverse strip of detectable warnings at terminal; (h) Transverse strip of detectable warnings at terminal;

The inventory results for audible signals are presented in Table 16 and Figure 21.

Table 16: Evaluation of Audible Signals

Parameter	Observations	Best Practice
Presence	Audible signals were present at 19 sites, but only on one terminal at each site. Audible signals were located on the south terminal at 16 sites and on the north terminal at three sites.	One audible signal should be provided at each terminal and installed within the crosswalk, close to the terminal.
Direction	Audible signals were directed along the crosswalk at 12 sites, down towards the terminal at four sites, and angled partially towards the crosswalk and partially toward the terminal at three sites. Some audible signals were mounted behind the signal head, which obstructed their sound and limited their capacity to carry the sound to the far terminal.	The emitted tone should be audible from both terminals but should not create too much audible disturbance to the surrounding areas. Audible signals should be unobstructed. The audible signal should be directed down to the terminal (if audible signals are provided at both terminals) or along the crosswalk (if an audible signal is only provided at one terminal).
Indication	Audible signals began emitting a tone at the onset of the WALK interval. The tone quickened in pace at the onset of the Flashing WALK interval and ended at the onset of the DON'T WALK interval.	In North America, audible signals only indicate the start of the WALK interval and terminate at the start of the Flashing DON'T WALK interval. Pedestrians in Costa Rica are likely accustomed to the system that is applied on the study corridor.

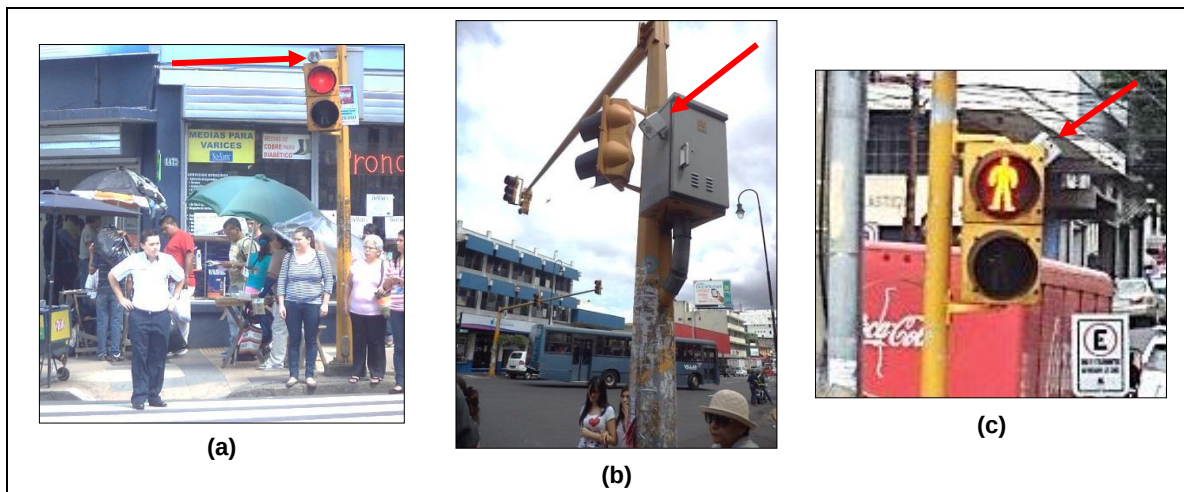


Figure 21: Audible signals: (a) Directed along crosswalk; (b) Directed down to the terminal; (c) Mounted behind and obstructed by the signal head

4.6. KEY PHYSICAL AND OPERATIONAL ISSUES FOR THE SAFE ACCOMMODATION OF PEDESTRIANS

The review of the physical and operational site conditions on the study corridor revealed the following issues of importance for the safe accommodation of pedestrians in this environment:

1. Deviation from regulations and best practices:

- Tactile markings are inconsistently applied and do not follow the National Standard for Signage on Horizontal Surfaces. Uniform application is critical to best serve pedestrians with vision impairments.
- The symbols used to indicate the WALK, Flashing WALK, and DON`T WALK intervals vary. A red ball is used to indicate the DON`T WALK interval at some sites, which is not allowed by the MUTCDCA.

2. Insufficient guidance for pedestrians with impairments:

- Pedestrian signals are not placed for maximum visibility to crossing pedestrians at some sites. Pedestrians need to see the signal to know when it is appropriate to cross.
- Pedestrian signal lenses are 30 cm at most sites, but 22 cm lenses are also present. Larger displays provide greater visibility.
- Incandescent lenses are in poor condition and may not be sufficiently visible for pedestrians with vision impairments or during periods of inclement weather. LED lenses provide greater visibility.

- Audible signals do not adequately serve both terminals at each site. Audible signals are needed to assist pedestrians with vision impairments.

3. Inaccessible infrastructure for pedestrians with impairments:

- Temporary and protruding obstacles are present on sidewalks and crossing terminals. These obstacles block pedestrian movement and can be impassible for pedestrians with impairments.
- Curb ramps are not always provided on both terminals. The majority of curb ramps are not designed according to best practices, and do not provide sufficient access for pedestrians.

4. Allowance of potentially conflicting movements:

- Turns on *red* which cross over the pedestrian crosswalk are allowed at many sites. These turning vehicles could be in conflict with crossing pedestrians.

5. Inconsistent signal timing practices and unaccommodating pedestrian clearance intervals:

- The duration and split of the pedestrian clearance interval varies. Inconsistencies can violate pedestrian expectancy regarding how much time remains to clear the intersection.
- The duration of the pedestrian clearance intervals do not allow pedestrians traveling at the design walking speed to reach the far terminal of the intersection before conflicting traffic is released. The pedestrian

clearance intervals are timed for a walking speed that is unachievable for many pedestrians with mobility impairments.

Pedestrian countdown signals are not currently used in Costa Rica, but have the potential to improve safety for pedestrians crossing at signalized intersections. Pedestrian countdown signals provide more information to pedestrians regarding the amount of time remaining to cross before conflicting traffic is released than conventional WALK/DON'T WALK signals. This information allows pedestrians arriving at the initial terminal to make a more informed decision on whether to cross or wait until the next cycle, which can result in reduced incidents of pedestrians being left within the intersection when conflicting traffic is released.

5.0. PEDESTRIAN COMPLIANCE AND CONFLICT ANALYSIS

This chapter presents an overview of: (1) the analysis approach including determination of minimum sample size for the compliance and conflict studies; (2) pedestrian compliance characteristics and analysis results; and (3) pedestrian conflict characteristics and analysis results. Conflict studies evaluated the severity and type of unsafe interactions between motor vehicles and pedestrians that crossed at sites on the study corridor. Compliance studies evaluated pedestrian compliance with the signal by examining the interval that was active at the time pedestrians crossed the study corridor.

5.1. ANALYSIS APPROACH

Pedestrian compliance and conflict data were analyzed in terms of total pedestrians on the study corridor and in terms of total pedestrians at each site. Appendix C provides safety performance profiles of each site, while this chapter focuses on the safety performance of the total study corridor and key sites which contributed high proportions of non-compliant pedestrians and high proportions of pedestrian conflicts. The analysis also examines the influence of pedestrian gender on safety performance.

The minimum sample size required for pedestrians crossing at each site was calculated based on a Normal approximation for inference about a population proportion. There were two population proportions of interest: (1) proportion of compliant pedestrians, and (2) proportion of pedestrians in a conflict. The population is considered to be total pedestrians crossing at a site on the study corridor and the sample is those pedestrians that were observed in the research. Inference about population proportions is a suitable statistical analysis method for this research because the variables of interest are categorical. Equation 1 was used to calculate minimum sample size with the following input parameters:

- The proportion of successes was initially estimated at $p^* = 0.5$ to give the largest required sample size.
- The desired confidence level C is 95 percent ($z = 1.96$ for 95 percent confidence) and the specified margin of error m is 5 percent. This research aims to conclude that it is 95 percent probable that the true proportion of compliant pedestrians and the true proportion of pedestrians in conflict fall within plus or minus 5 percent of the sample proportion.

When the sample size n satisfies Equation 1, the level C confidence for a proportion p will have a margin of error approximately equal to a specified value of m .

Equation 1: Sample size for desired margin of error

$$n = \left(\frac{z^*}{m}\right)^2 \times p^* \times (1 - p^*)$$

Where: n is the sample size (i.e., total pedestrians at each site)
 z^* is the critical value for confidence C ($z^* = 1.96$ for 95 percent confidence)
 m is the margin of error ($m = 0.05$)
 p^* is a guessed value for the proportion of successes in the future sample (i.e., proportion of compliant pedestrians or proportion of pedestrians in a conflict, $p^* = 0.5$)

This approach resulted in a minimum sample size of 400 pedestrians at each of the 20 sites. An even split between male and female pedestrians were recorded so that the influence of gender on pedestrian safety performance could be evaluated. However, at most sites, samples greater than 400 pedestrians were obtained because pedestrian

crossing volumes were so high that observers did not have the opportunity to sum total observations before achieving the minimum required sample size.

The influence of gender on pedestrian compliance and conflicts was analyzed for total pedestrians on the study corridor through significance tests for comparing two proportions. Significance tests for comparing two proportions analyze the difference between the proportion of successes in each population (i.e., the proportion of compliant male pedestrians versus the proportion of compliant female pedestrians, and the proportion of male pedestrians in conflicts versus the proportion of female pedestrians in conflicts). The z test was used to evaluate significance. The z test is based on the Normal approximation to the binomial distribution. Alpha was set at $\alpha = 0.05$ for 95 percent confidence.

Table 17 summarizes the number of total pedestrians, male pedestrians, and female pedestrians observed at each of the 20 sites, as well as the type of study conducted. At sites with high crossing activity, a complete sample could be obtained in 30 minutes or less. As much as 5 hours of data collection over three days were required to achieve a minimum sample at sites with low crossing activity. The research observed 13,716 total pedestrians (6209 males and 6723 females) split among the 20 sites on the study corridor. Pedestrian gender was not recorded at one site because volumes were too high to accurately record gender through manual collection.

Table 17: Pedestrians Observed and Studies Conducted at Each Site

Site	Total Pedestrians Observed	Total Male Pedestrians Observed	Total Female Pedestrians Observed	Compliance Study Completed for Total Pedestrians by Gender	Conflict Study Completed for Total Pedestrians by Gender
1	572	274	298	Yes	Yes
2	430	201	229	Yes	Yes
3	445	214	231	Yes	Yes
4	552	263	289	Yes	Yes
5	748	304	444	Yes	Yes
6	1513	676	837	Compliance study not completed because site does not operate a pedestrian phase. A two hour pedestrian volume count was recorded by gender.	Yes
7	563	317	246	Yes	Yes
8	1110	574	536	Yes	Yes
9	1249	556	693	Yes	Yes
10	663	310	353	Yes	Yes
11	748	403	345	Yes	Yes
12	784	N/A	N/A	Compliance study conducted for total pedestrians, but not by gender. Pedestrian volumes were too high to accurately record gender.	Conflict study conducted for total pedestrians, but not by gender. Pedestrian volumes were too high to accurately record gender
13	536	254	282	Yes	Yes
14	592	312	280	Yes	Yes
15	616	334	282	Yes	Yes
16	597	295	302	Yes	Yes
17	551	272	279	Yes	Yes
18	521	240	281	Yes	Yes
19	478	210	268	Yes	Yes
20	448	200	248	Yes	Yes
Total	13,716	6209	6723	19 compliance studies: 18 by gender and 1 for total pedestrians amounting to 12,203 total pedestrians (5259 male, 5588 female) 1, 2-hour pedestrian volume count amounting to 1513 total pedestrians (676 male, 837 female)	20 conflict studies: 19 by gender and 1 for total pedestrians amounting to 13 716 total pedestrians (6209 male, 6723 female)

5.2. PEDESTRIAN COMPLIANCE ANALYSIS

Compliance studies examined the interval that was active at the time pedestrians crossed the study corridor. Pedestrian compliance was recorded as green-walking, amber-walking, or red-walking, as defined by 10 crossing scenarios developed in this research and presented in Section 3.3.4. This section presents the analysis results for total pedestrian compliance on the study corridor and discusses conditions at sites that contributed the greatest proportion of non-compliant pedestrians on the study corridor. Appendix C contains compliance characteristics for each site.

5.2.1. Total Pedestrian Compliance

Pedestrian compliance studies were conducted at 19 of the 20 study sites for a total of 12,203 pedestrians. A pedestrian compliance study was not conducted at Site 6 because the signal does not operate a pedestrian phase. Compliant pedestrians are those that green-walked and non-compliant pedestrians are those that amber-walked or red-walked. Table 18 and Figure 22 illustrate the pedestrian compliance results for total pedestrians on the study corridor.

Table 18: Total Pedestrian Compliance on the Study Corridor

Compliance	Pedestrians	Proportion of Total Pedestrians
Compliant	10,700	88%
<i>Green-walk</i>	<i>10,700</i>	<i>88%</i>
Non-Compliant	1503	12%
<i>Amber-walk</i>	<i>260</i>	<i>2%</i>
<i>Red-walk</i>	<i>1243</i>	<i>10%</i>
Total	12,203	100%

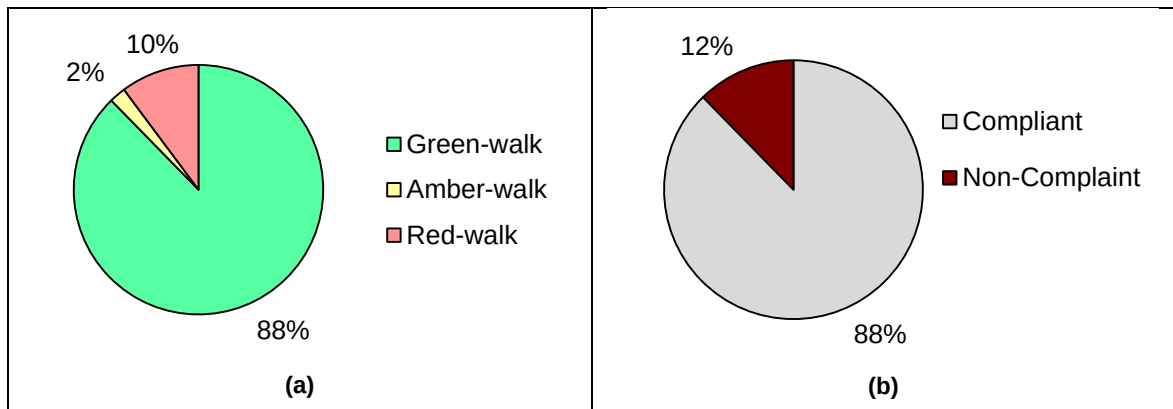


Figure 22: Total pedestrian compliance on the study corridor (n = 12,203): (a) Compliance by classification; (b) Overall compliance

The majority of pedestrians complied with the signals on the study corridor: 88 percent of pedestrians green-walked. A greater proportion of non-compliant pedestrians red-walked than amber-walked: 10 percent of total pedestrians red-walked and two percent amber-walked. Figure 23 illustrates the proportion of non-compliant pedestrians that each site contributed to total non-compliance on the study corridor. For example, non-compliant pedestrians at Site 1 accounted for 22 percent of total non-compliant pedestrians on the study corridor. Non-compliant pedestrians at Sites 1, 8, 12, 18, and 20 accounted for over half of total non-compliance on the study corridor: 54 percent of non-compliant pedestrians on the study corridor crossed at these five sites.

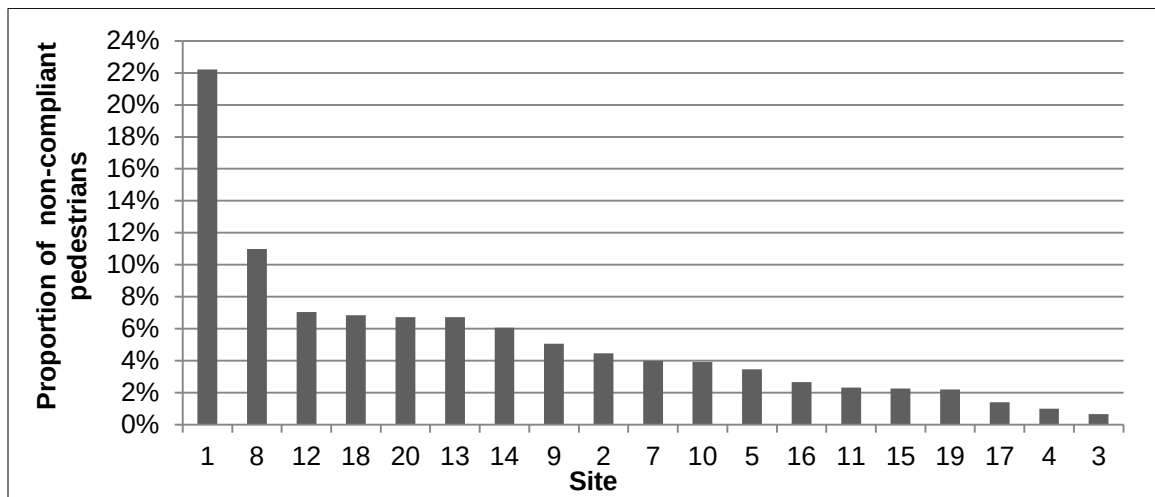


Figure 23: Contribution of non-compliant pedestrians from each site to total non-compliance on the study corridor (n = 1503)

Physical and operational factors contributing to non-compliance included poor visibility of the pedestrian signal, insufficient guidance on the need to use the pushbutton to actuate the signal, audible signals that did not serve both terminals, and signal phase sequences that were not characteristic of the majority of sites on the study corridor. Some sites with poor compliance, such as Site 13 and Site 18, did not present unique physical and operational conditions that could explain the poor compliance observed at these sites. Conditions at Site 13 and Site 18 were consistent with sites on the study corridor that had good compliance. Non-engineering related factors that were not of focus in this research, such as specific behavioural traits of pedestrians, could be explored to try to explain poor compliance at Site 13 and Site 18.

5.2.2. Pedestrian Compliance by Gender

Pedestrian gender was recorded in 18 of the 19 pedestrian compliance studies, for a total of 10,847 pedestrians (5259 males and 5588 females). It was not possible to record pedestrian compliance by gender at Site 12 because pedestrian volumes were too high for observers to manually record this attribute. Table 19 and Figure 24 illustrate pedestrian compliance results by gender at the 18 sites.

Table 19: Pedestrian Compliance by Gender on the Study Corridor

Compliance	Males	Proportion of Total Male Pedestrians	Females	Proportion of Total Females Pedestrians
Compliant	4608	88%	5176	93%
<i>Green-walk</i>	4608	87.6%	5176	92.6%
Non-Compliant	651	12%	412	7%
<i>Amber-walk</i>	134	2.5%	107	1.9%
<i>Red-walk</i>	517	9.8%	305	5.5%
Total	5259	100%	5588	100%

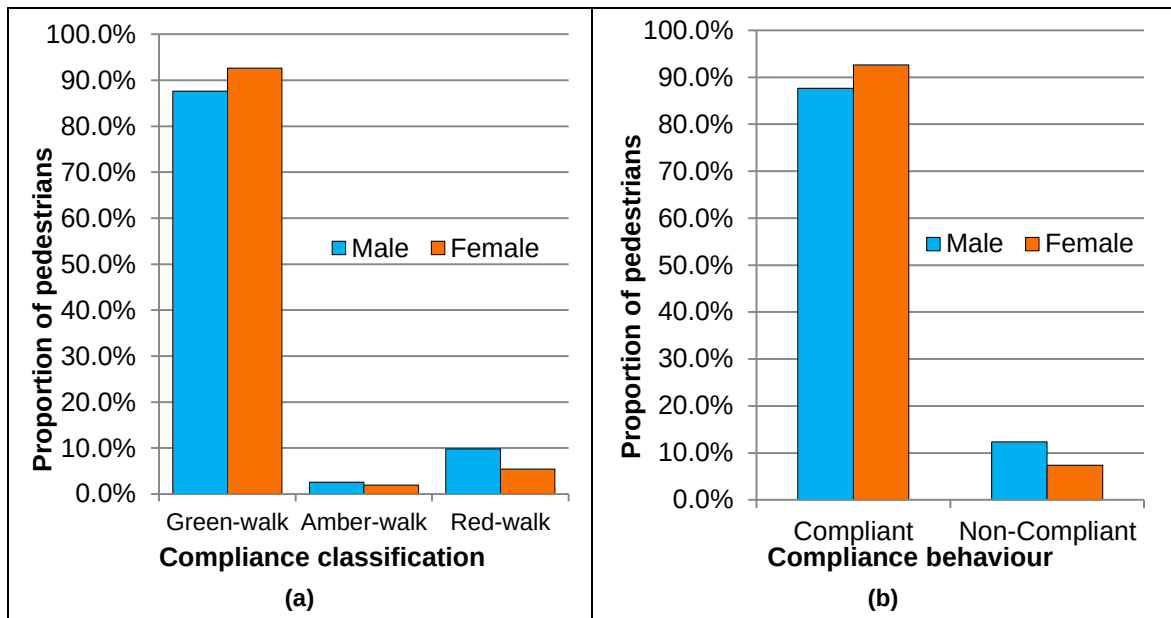


Figure 24: Pedestrian compliance by gender on the study corridor (n = 10,847): (a) Compliance by classification; (b) Overall compliance behaviour

The proportion of total compliant male pedestrians (88 percent) was lower than the proportion of total compliant female pedestrians (93 percent). For male pedestrians, 12 percent did not comply with the signal: 2.5 percent of male pedestrians amber-walked and 9.8 percent red-walked. For female pedestrians, 7 percent did not comply with the signal: 1.9 percent of female pedestrians amber-walked and 5.5 percent red-walked.

Table 20 summarizes the z test results for the difference in the proportion of male and female compliant pedestrians on the study corridor. With 95 percent confidence, pedestrian compliance differs by gender on the study corridor: female pedestrians are more compliant than male pedestrians.

Table 20: Z test for the Difference in Proportions of Total Male and Female Compliant Pedestrians on the Study Corridor

Null hypothesis: The proportion of compliant female pedestrians equals the proportion of compliant male pedestrians.	
$\hat{p}_1 = \hat{p}_2$	
Alternate hypothesis: The proportion of compliant male pedestrians does not equal the proportion of compliant female pedestrians.	
$\hat{p}_1 \neq \hat{p}_2$	
Parameter	Value
Pooled estimate $\hat{p}$	0.902
Pooled standard error SE_{D_p}	0.006
Z statistic	8.764
2P(Z>=8.764)	1.9E-18, < $\alpha=0.05$
Conclusion	Reject the null hypothesis and conclude with 95 percent confidence that the proportion of compliant male pedestrians differs from the proportion of compliant female pedestrians. Female pedestrians are more compliant than male pedestrians on the study corridor.

5.2.3. Pedestrian Compliance Discussion

The majority of pedestrians complied with the signals on the study corridor: 88 percent of pedestrians green-walked. Pedestrian compliance studies conducted on a similar urban corridor in Brisbane, Australia, reported 13 percent non-compliance, which is consistent with the findings from this research (King, Soole, & Ghafourian, 2009). However, comparing pedestrian compliance results between different locations may not be a useful practice, because road user behaviour changes depending on the local demographics and surrounding environment. Female pedestrians are more compliant than male pedestrians on the study corridor, which is consistent with findings in previous research (Tom & Granie, 2011; Garder, 1989; Wang, Wang, & Tremont, 2013; Tiwari, S., Saraswat, & Gaurav, 2007; Vujanic, Pesic, Antic, & Smailovic, 2014; Rosenbloom, 2009).

Factors contributing to non-compliance included pedestrian arrival time, pedestrians choosing to amber-walk or red-walk, poor visibility of the pedestrian signal, insufficient

guidance on the need to use the pushbutton to actuate the signal, audible signals that do not serve both terminals, and signal phase sequences that were not characteristic of the majority of sites on the study corridor.

The point in the pedestrian phase that a pedestrian arrives at the intersection could influence their compliance with the signal. If the majority of crossing pedestrians arrive during the WALK interval, it is likely that the majority of pedestrians will green-walk, and therefore compliance will be high. It is unlikely that a pedestrian who arrives at the intersection during the WALK interval will amber-walk or red-walk. Pedestrian arrival time was not collected in this research because it was an additional attribute that would overload the observers who manually collected all of the data.

As discussed in Section 4.4, the pedestrian signal head was not clearly visible to crossing pedestrians at some locations. When buses blocked the pedestrian signal and obstructed the audible indication at Site 7, pedestrians did not comply because they could not see or hear the indication to know when it was appropriate to cross. Bus stops were present at other sites and buses often blocked the pedestrian signal head and obstructed the audible indication. Signals at Site 1 were not sufficiently visible to pedestrians. The signal at Site 1 was damaged and directed slightly down toward the pavement, had incandescent displays, and smaller 22 cm lenses.

The pedestrian signals at Site 12 were offset a considerable distance from the crosswalk and their displays were not clearly visible from the terminal. The signal displays vary in size, condition, and display type on the study corridor. Uniform and consistent use of signal displays improves message clarity and helps ensure road users understand and comply with the given direction.

Site 20 is the only site which operates a pushbutton to actuate the signal. Some pedestrians crossing at Site 20 did not use the pushbutton to actuate the signal, appeared to become impatient waiting for the WALK interval, and proceeded to red-walk. At other sites, pedestrians were observed scanning the pole with their hands, as if they were searching for a pushbutton to actuate the phase. This reflects a lack of understanding for how the signal is operated.

Audible signals were only provided on one terminal at each site. At some sites, the audible signal was mounted slightly behind the pedestrian signal head, which obstructed the tone and carrying capacity of the signal. Audible signals indicate the start of the WALK interval which assists pedestrians with vision impairments and captures the attention of waiting pedestrians to notify them that it is time to cross. Poor compliance could be partially attributed to inadequate performance of the audible signals.

Compliance at Site 1 was considerably lower than compliance for the total study corridor: 88 percent of crossing pedestrians complied with the signals on the study corridor, while less than half of pedestrians (42 percent) complied at Site 1. The major contributing factor to poor compliance at Site 1 is related to the sequence of the signal phases. Figure 25 illustrates the signal sequence and display for the minor street (southbound) and pedestrian movements during the time the major street (east/westbound) interval is *red*. The minor street and pedestrian phases are concurrent. Note that a *flashing green* interval is first displayed during the vehicular clearance interval in Costa Rica.

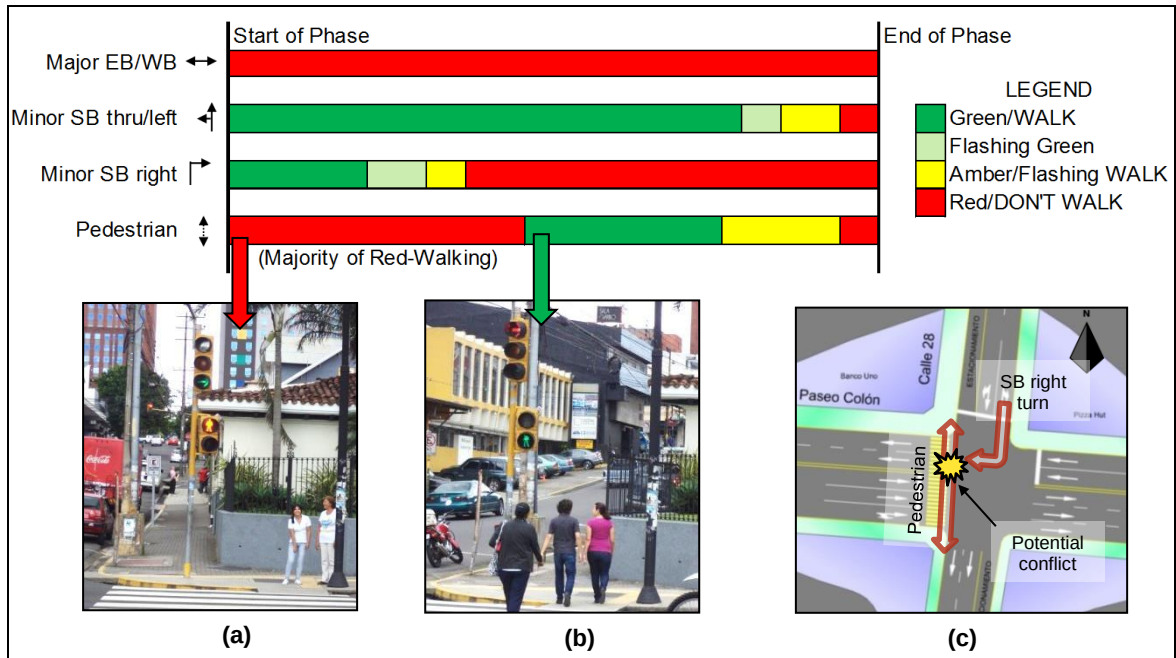


Figure 25: Site 1 signal sequence and displays at south terminal: (a) Green arrow for southbound right-turn with DON'T WALK display; (b) Red arrow for southbound right-turn with WALK display; (c) Potential conflict avoided by protected right-turn phase

A protected southbound right-turn movement operates at the start of the minor street *green*, in advance of the WALK interval. The majority of red-walking occurs at this time. To avoid conflict, the pedestrian interval is held on DON'T WALK while the protected southbound right-turn has the right-of-way. Many pedestrians expect to cross simultaneously with southbound thru traffic at the start of their *green*. Pedestrians often fail to recognize that they do not receive the WALK indication until after the southbound right-turn phase has terminated.

5.3. PEDESTRIAN CONFLICT ANALYSIS

Conflict studies evaluated the severity and type of unsafe interactions between motor vehicles and pedestrians that crossed at sites on the study corridor. This research adopted the U.S. FHWA traffic conflict definition, which states:

A traffic conflict is an event involving two or more road users, in which the action of one user causes the other user to make an evasive manoeuvre to avoid a collision (Parker & Zegeer, 1989).

This research categorized conflicts as severe or minor and defined nine different conflict types which are described in Section 3.3.3. This section presents the analysis results for total pedestrian conflicts on the study corridor, conflict severity and type, and the relationship between conflict severity and the pedestrian interval displayed at the time of conflict. Physical and operational site conditions contributing to conflict occurrence are discussed.

5.3.1. Total Pedestrian Conflicts

Pedestrian conflict studies were conducted at all 20 sites on the study corridor for a total of 13,716 pedestrians. Table 21 illustrates pedestrian conflicts results for total pedestrians on the study corridor.

Table 21: Total Pedestrian Conflicts on the Study Corridor

Conflict Occurrence	Pedestrians	Proportion of Total Pedestrians
Conflict	1293	9%
No conflict	12,423	91%
Total	13,716	100%

A total of 1293 pedestrian conflicts were observed on the study corridor, which amounts to nine percent of total pedestrians. Figure 26 illustrates the proportion of pedestrian conflicts that each site contributed to total conflicts on the study corridor. For example, total pedestrian conflicts at Site 5 accounted for 17 percent of total pedestrian conflicts on the study corridor. Pedestrian conflicts at Sites 5, 17, 7, 20, and 1 accounted for over half of all pedestrian conflicts on the study corridor: 50.8 percent of all pedestrian conflicts on the study corridor occurred at these five sites.

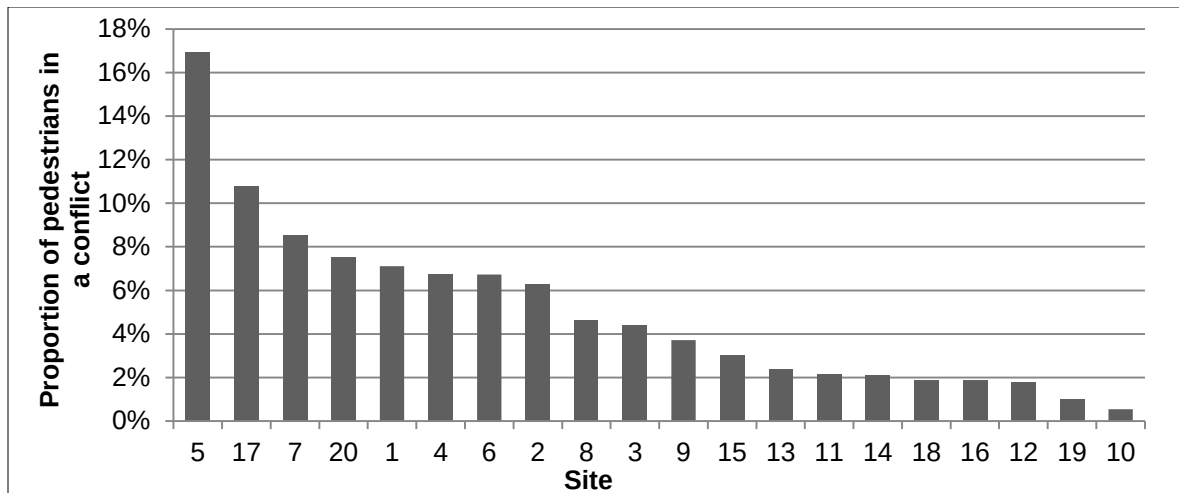


Figure 26: Contribution of pedestrian conflicts from each site to total pedestrian conflicts on the study corridor (n = 1293)

Physical and operational factors contributing to pedestrian conflicts included the active pedestrian signal interval, vehicles turning on *red*, short pedestrian clearance intervals, vehicles blocking the crosswalk, and vendors and obstructions at the crosswalk terminal which forced pedestrians to queue on the street. Contributing factors are further discussed in Sections 5.3.4 and 5.3.5.

5.3.3.1. Conflicts by Gender

The influence of pedestrian gender on conflict occurrence was analyzed for 19 of the 20 sites where conflict studies were conducted. Gender data was not available for Site 12. The analysis of pedestrian gender and conflict occurrence included a total of 12,932 pedestrians (6209 males and 6723 females).

Table 22 and Figure 27 illustrate conflict results on the study corridor by pedestrian gender. A greater proportion of male pedestrians were involved in conflicts than female pedestrians: 11 percent of total male pedestrians and nine percent of total female pedestrians were involved in a conflict.

Table 22: Pedestrian Compliance by Gender on the Study Corridor

Conflict Occurrence	Males	Proportion of Total Males	Females	Proportion of Total Females
Conflict	693	11%	577	9%
No Conflict	5516	89%	6146	91%
Total	6209	100%	6723	100%

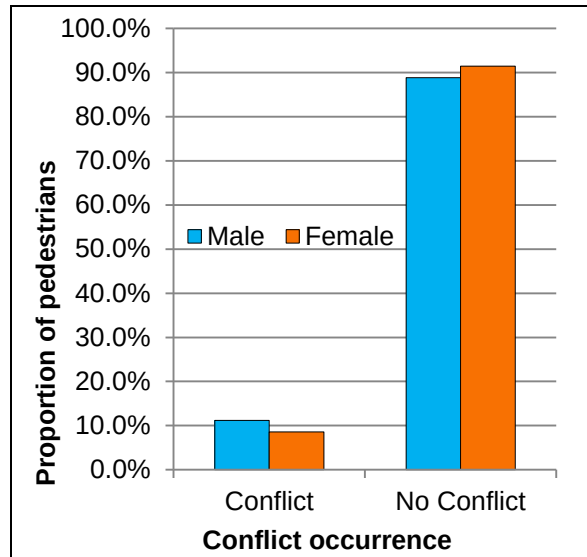


Figure 27: Total pedestrian conflict occurrence by gender on the study corridor (n = 12,932)

Table 23 summarizes the z test results for the difference in the proportion of male and female pedestrians involved in a conflict on the study corridor. With 95 percent confidence, pedestrian conflict occurrence differs by gender: male pedestrians are involved in more conflicts than female pedestrians when crossing the study corridor at a signalized intersection.

Table 23: Z Test for Significance of Pedestrian Gender and Conflict Occurrence

Null hypothesis: The proportion of total male pedestrians involved in a conflict equals the proportion of total female pedestrians involved in a conflict.	
$\hat{p}_1 = \hat{p}_2$	
Alternate hypothesis: The proportion of total male pedestrians involved in a conflict does not equal the proportion of total female pedestrians involved in a conflict.	
$\hat{p}_1 \neq \hat{p}_2$	
Parameter	Value
Pooled estimate $\hat{p}$	0.098
Pooled standard error SE_{Dp}	0.005
Z statistic	4.923
$2P(Z \geq 4.923)$	9E-07, <0.05
Conclusion	Reject the null hypothesis and conclude with 95 percent confidence that the proportion of male pedestrians involved in a conflict differs from the proportion of female pedestrians involved in a conflict. Male pedestrians are involved in more conflicts than female pedestrians on the study corridor.

5.3.2. Conflict Severity

Conflict severity was analyzed as minor or severe, as described in Section 3.3.3. Table 24 illustrates the pedestrian conflict severity results for total pedestrians on the study corridor.

Table 24: Total Pedestrian Conflicts on the Study Corridor

Conflict Occurrence	Pedestrians	Proportion of Total Pedestrians
Minor conflicts	1149	8% (89% of total conflicts)
Severe conflicts	144	1% (11% of total conflicts)
No conflict	12,423	91%
Total	13,716	100%

Of the 1293 total conflicts on the study corridor, 89 percent were minor and nine percent were severe. Approximately eight out of every 100 pedestrians that crossed a study site were involved in a minor conflict, and approximately one out of every 100 pedestrians was involved in a severe conflict.

Site 6 presented a high proportion of severe conflicts: 34 percent of a total of 87 pedestrian conflicts observed at Site 6 were severe. Site 6 does not operate a pedestrian phase or provide a marked crosswalk (Figure 28). However, pedestrian crossing activity is high and comparable with crossing activity at other sites on the study corridor. The most common type of severe conflict was type SC, where a pedestrian drastically increases their traveling speed by sprinting, running, or jumping forward to avoid an oncoming motorist.



Figure 28: Pedestrians crossing at Site 6: (a) Pedestrians waiting for suitable gap to cross; (b) High pedestrian crossing volume

Without a pedestrian phase to control crossing times, pedestrians were observed crossing whenever a suitable gap permitted. Conflicts occurred when pedestrians crossed through gaps in motor vehicle traffic that were too small for them to safely reach the far terminal. Without a pedestrian phase, pedestrians are not able to estimate how much time is left in the concurrent minor street signal phase to cross, and begin crossing when they do not have enough time to clear the intersection before conflict traffic is released. Additionally, since this is the only signal on the study corridor with an unmarked crosswalk, drivers may not expect to see pedestrians crossing at this location.

5.3.2.1. Conflict Severity by Gender

Table 25 and Figure 29 present conflict severity results in terms of total male and total female pedestrians. The proportion of total male pedestrians involved in a severe conflict equals the proportion of total female pedestrians involved in a severe conflict: one percent of total male and total female pedestrians were involved in a severe conflict.

Table 25: Pedestrian Conflict Severity by Gender on the Study Corridor for Total Pedestrians

Conflict Severity	Males	Proportion of Total Male Pedestrians	Females	Proportion of Total Female Pedestrians
Minor	618	10%	513	8%
Severe	75	1%	64	1%
No conflict	5516	89%	6146	91%
Total	6209	100%	6723	100%

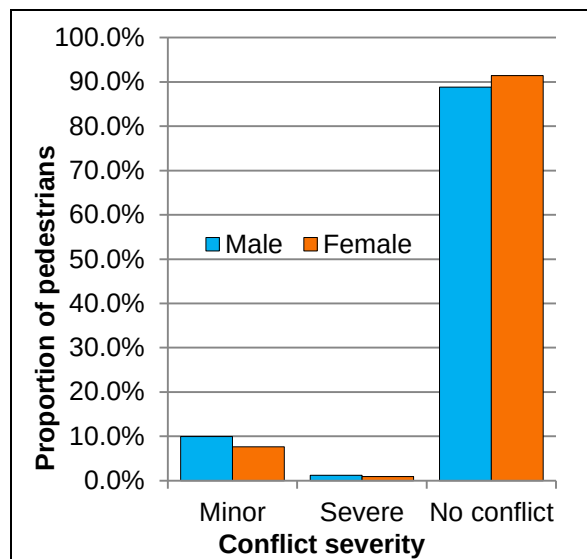


Figure 29: Total pedestrian conflict severity by gender on the study corridor for total pedestrians (n = 12,932)

Table 26 summarizes the z test results for the significance of pedestrian gender and severe conflict occurrence. The z test results confirm that the same proportions of male and female pedestrians are involved in a severe conflict when crossing the study corridor at a signalized intersection.

Table 26: Z Test for Significance of Pedestrian Gender and Conflict Severity

Null hypothesis: The proportion of male pedestrians involved in a severe conflict equals the proportion of female pedestrians involved in a severe conflict.	
$\hat{p}_1 = \hat{p}_2$	
Alternate hypothesis: The proportion of male pedestrians involved in a severe conflict does not equal the proportion of females involved a severe conflict.	
$\hat{p}_1 \neq \hat{p}_2$	
Parameter	Value
Pooled estimate $\hat{p}$	0.011
Pooled standard error SE_{Dp}	0.002
Z statistic	1.410
$2P(Z \geq 1.410)$	0.159 > $\alpha = 0.05$
Conclusion	Fail to reject the null hypothesis. There is insufficient evidence to conclude that there is a significant difference in the proportion of male and female pedestrians involved in a severe conflict.

5.3.3. Conflict Type

The nine conflict types defined in this research are presented in Section 3.3.3. Figure 30 illustrates the conflict type distribution for total minor and total severe conflicts on the study corridor. The most common type of minor conflict was type MB, where a pedestrian travels around a vehicle that is stopped and blocking the crosswalk: 52 percent of total minor conflicts (106 out of 1149 total minor conflicts) were type MB. The two most common types of severe conflicts were type SB, where a pedestrian abruptly stops while crossing to avoid an oncoming motorist, and type SC, where a pedestrian drastically increases their travel speed by sprinting, running, or jumping forward to avoid an oncoming motorist. Type SB and type SC accounted for 47 percent (67 out of 144 total severe conflicts) and 38 percent (55 out of 144 total severe conflicts) of total severe conflicts, respectively. Severe conflicts are closely related to the pedestrian interval displayed at the time of the conflict, which is discussed in Section 5.3.4.

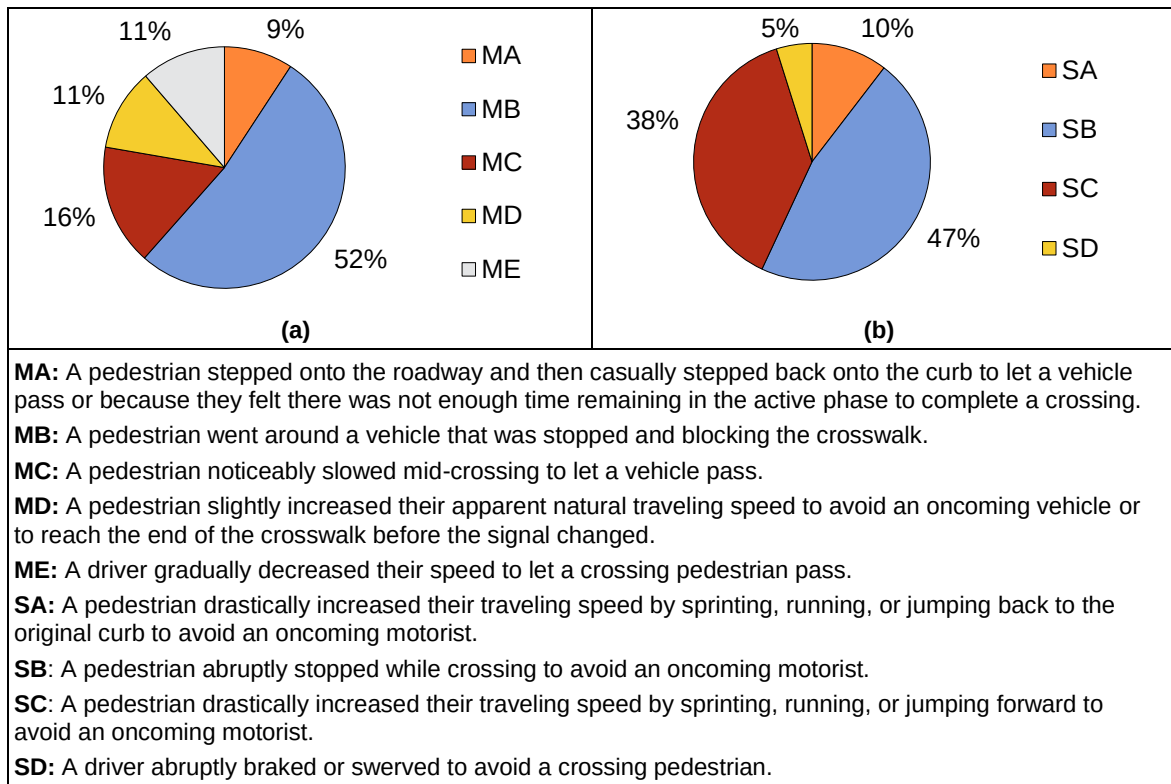


Figure 30: Conflict types for total pedestrian conflicts on the study corridor:
(a) Minor conflict types (n = 1149); (b) Severe conflict types (n = 144)

Type MB conflicts occur when crossing pedestrians have to weave around traffic that is stopped and blocking the crosswalk. There are three main reasons that vehicles blocked the crosswalk: (1) queue spill-back reached through the intersection and drivers entered the intersection when there was no room to clear; (2) drivers on the study corridor failed to stop for the *red* on or before the stop line; (3) buses or taxi stands extended into the crosswalk; and (4) vehicles turning on *red* pulled into the crosswalk while waiting to make their turn (Figure 31).



Figure 31: Conflict type MB: (a) Drivers fail to stop at stop line and enter crosswalk; (b) Buses queue in crosswalk while turning

5.3.4. Conflicts and the Pedestrian Interval

The interval displayed at the time of conflict does not necessarily reflect pedestrian compliance with the signal. For example, a compliant pedestrian can be within the intersection during all three intervals of the pedestrian phase: if they begin crossing on the WALK interval, reach the centre of the intersection on the Flashing WALK interval, and reach the far terminal on the DON'T WALK interval. Their compliance would be recorded as a green-walker, but the pedestrian interval displayed at the time of conflict could be WALK, Flashing WALK, or DON'T WALK. This analysis only considers the relationship between conflict severity and the interval displayed at the time of conflict. The analysis does not consider the relationship between conflict severity and pedestrian compliance because pedestrian volumes were too high to manually record this data link.

5.3.4.1. *Analysis of Conflicts and the Pedestrian Interval*

The relationship between conflict severity and the pedestrian interval displayed at the time of conflict was analyzed using data from the conflict studies conducted at 19 sites. Conflict data from Site 6 was not included because the signal does not operate a pedestrian phase. A total of 872 conflicts were observed and recorded by severity and by the pedestrian interval displayed at the time of conflict. Table 27, Figure 32 and

Figure 33 illustrate the conflict severity distribution by the pedestrian interval displayed at the time of conflict for total conflicts at 19 sites on the study corridor.

Table 27: Conflict Severity Distribution by Pedestrian Interval Displayed at the Time of Conflict

Pedestrian Interval Displayed at the Time of Conflict	Conflict Severity		Total
	Minor	Severe	
WALK	660	7	667
% of total minor/severe conflicts	87%	6%	-
% of total WALK conflicts	99%	1%	100%
% of total conflicts	76%	1%	78%
Flashing WALK	49	3	52
% of total minor/severe conflicts	6%	3%	-
% of total Flashing WALK conflicts	94%	6%	100%
% of total conflicts	6%	0%	6%
DON'T WALK	49	104	153
% of total minor/severe conflicts	6%	91%	-
% of total DON'T WALK conflicts	32%	68%	100%
% of total conflicts	6%	12%	18%
Total	758	114	872
% of total minor/severe conflicts	100%	100%	100%
% of total conflicts	87%	13%	100%

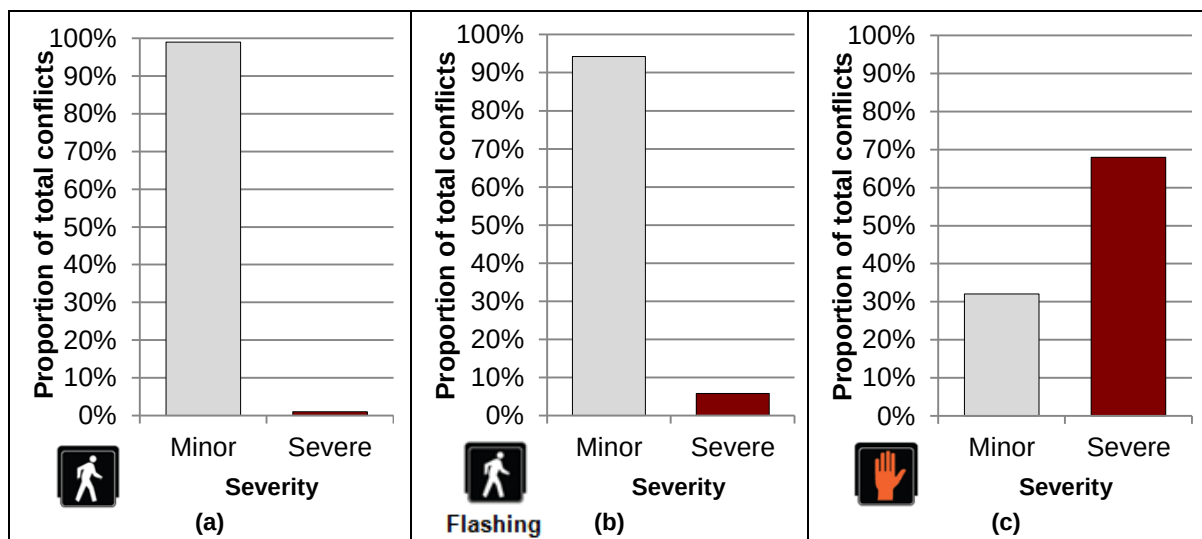


Figure 32: Conflict severity distribution by pedestrian interval displayed at the time of conflict: (a) WALK interval (n = 667); (b) Flashing WALK interval (n = 52); (c) DON'T WALK interval (n = 153)

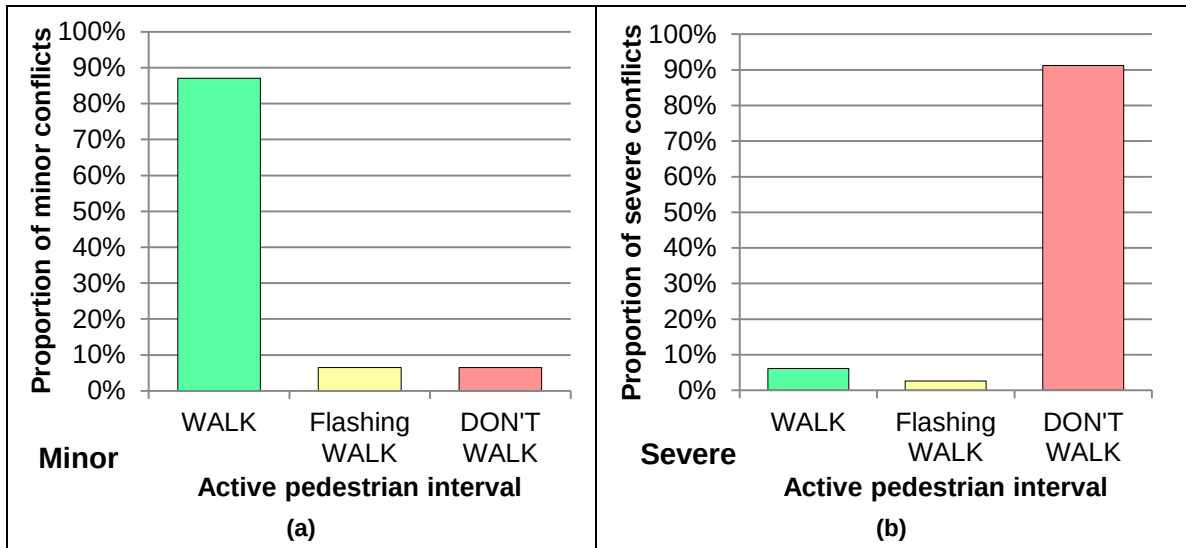


Figure 33: Pedestrian interval distribution displayed at the time of conflict by conflict severity:
(a) Minor conflicts (n = 748); (b) Severe conflicts (n = 114)

The following can be observed from Table 27, Figure 32, and Figure 33:

- The majority of conflicts occurred during the WALK interval: 667 conflicts (78 percent of total conflicts) occurred during the WALK interval, 52 conflicts (6 percent of total conflicts) occurred during the Flashing WALK interval, and 153 conflicts (18 percent of total conflicts) occurred during the DON'T WALK interval.
- The majority of conflicts during the WALK interval were minor: 660 minor conflicts (99 percent of total conflicts during the WALK interval) and seven severe conflicts (one percent of total conflicts during the WALK interval) occurred.
- The majority of conflicts during the Flashing WALK interval were minor: 49 minor conflicts (94 percent of total conflicts during the Flashing WALK interval) and three severe conflicts (six percent of total conflicts during the Flashing WALK interval) occurred.
- The majority of conflicts during the DON'T WALK interval were severe: 49 minor conflicts (32 percent of total conflicts during the DON'T WALK interval) and 104

severe conflicts (68 percent of total conflicts during the DON'T WALK interval) occurred.

A Chi-square test was conducted to analyze the relationship between conflict severity and the pedestrian interval displayed at the time of conflict. Chi-square tests analyze inference in two-way tables of categorical variables. The desired level of confidence was 95 percent ($\alpha = 0.05$). The Chi-square test concluded with 95 percent confidence that a relationship exists between conflict severity and the pedestrian interval displayed at the time of conflict. By examining this relationship in Figure 32 and Figure 33, it is apparent that severe conflicts are more likely to occur during the DON'T WALK interval than minor conflicts, and minor conflicts are more likely to occur during the WALK interval than severe conflicts.

5.3.4.2. *Discussion of Conflicts and the Pedestrian Interval*

The majority of conflicts occurred while the WALK interval was displayed (78 percent of total conflicts). Theoretically, minimal conflicts should occur during the WALK interval because the signal allocates the right-of-way to pedestrians while motor vehicle traffic is held on *red*. The high proportion of conflicts during the WALK interval can be attributed to the following factors:

Turning vehicles

Vehicular traffic on the study corridor, perpendicular to the crosswalk, is held on *red* during the WALK interval. However, these vehicles are permitted to turn right-on-red or left-on-red – at certain one-way street intersections – at many intersections on the study corridor. Pedestrians could be in conflict with turning vehicles from the study corridor during the WALK interval. Vehicular traffic on minor streets, parallel with the crosswalk, is given the *green* during the WALK interval. The location of the crosswalk at the majority

of intersections removes the possibility for turning traffic on the minor street to conflict with crossing pedestrians. For example, Figure 34 illustrates the minor street, study corridor, and pedestrian traffic movements at Site 10.



Figure 34: Conflict opportunity between turning vehicles and crossing pedestrians during the WALK interval at Site 10

Source: adapted from Google Earth

The crosswalk is on the west approach of the intersection. Traffic from the minor street is one-way, southbound, and is permitted to turn right in the eastbound direction onto the study corridor. There is no opportunity for conflicts between turning vehicles from the minor street and pedestrians on the crosswalk because westbound turns are not permitted, as the study corridor runs one-way, eastbound. During the WALK interval,

right-turning traffic from the study corridor to the minor street is permitted on *red*. These vehicles could be in conflict with crossing pedestrians.

Conflict type

Figure 35 illustrates the conflict type distribution for minor conflicts during the WALK interval and severe conflicts during the DON'T WALK interval.

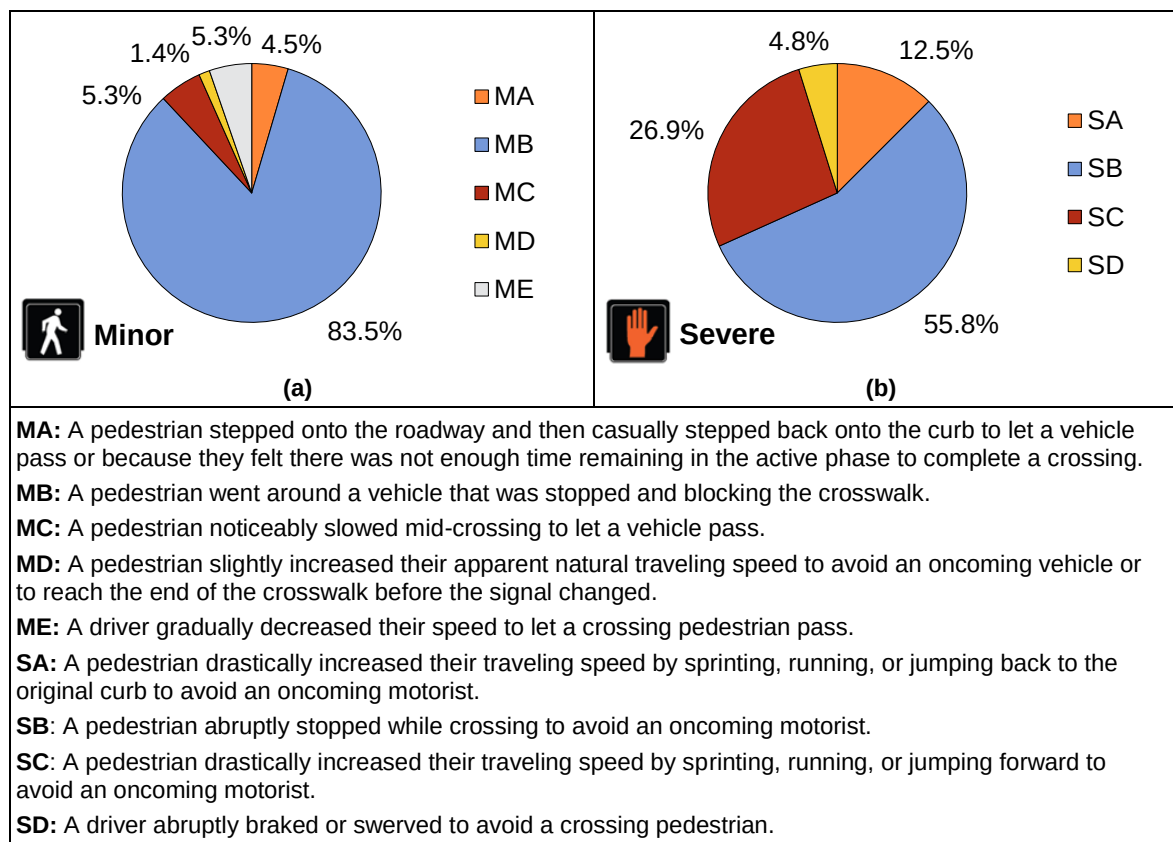


Figure 35: Conflict types during pedestrian intervals: (a) Minor conflict types during the WALK interval (n = 660); (b) Severe conflict types during the DON'T WALK interval (n = 104)

The majority of minor conflicts that occurred during the WALK interval were type MB. Conflict type MB is for when a pedestrian has to weave around a vehicle or multiple vehicles that are stopped and blocking the crosswalk. Vehicles queuing on the study corridor in response to *red*, waiting for the *green* indication, often did so while blocking the crosswalk. These vehicles would have passed the stop-line and waited within the

zebra markings. Conflict type MB occurred as pedestrians crossing during the WALK interval encountered these vehicles within the crosswalk and had to weave in and around them to complete their crossing. The majority of total MB conflicts occurred during the WALK interval: 93 percent of MB conflicts occurred during the WALK interval.

The majority of severe conflicts that occurred during the DON'T WALK interval were type SB, which is for a pedestrian that abruptly stops while crossing to avoid an oncoming motorist. Type SC conflicts contributed the second largest proportion of severe conflicts during the DON'T WALK interval. A type SC conflict is for a pedestrian that drastically increases their traveling speed by sprinting, running, or jumping forward to avoid an oncoming motorist. Both type SB and SC conflicts are for pedestrians reacting to the actions of oncoming motorists. Oncoming motorists are expected during the DON'T WALK interval because they have the right-of-way at this time. It is reasonable to accept that severe conflicts are more likely during the DON'T WALK interval because pedestrian exposure to traffic is greater: pedestrians are exposed to a greater volume of thru traffic on the study corridor during the DON'T WALK interval compared to the lower volume of turning traffic that they are exposed to during the WALK interval.

5.3.5. Pedestrian Conflict Discussion

Key findings from the pedestrian conflict analysis are:

- The majority of pedestrians that crossed at a study site were not involved in a conflict: approximately nine out of every 100 pedestrians were in a conflict.
- The majority of total conflicts on the study corridor were minor: 89 percent of total conflicts were minor and nine percent were severe.
- Male pedestrians are involved in more conflicts than female pedestrians when crossing at a signalized intersection on the study corridor.

- Equivalent proportions of total male and total female pedestrians are involved in severe conflicts: approximately one out of every 100 total male and total female pedestrians is involved in a severe conflict.
- The most common type of conflict was type MB, where a pedestrian travels around a vehicle that is stopped and blocking the crosswalk.
- Severe conflicts are more likely to occur during the DON'T WALK interval than minor conflicts. Minor conflicts are more likely to occur during the WALK interval than severe conflicts.

Factors contributing to conflict occurrence include the absence of a pedestrian phase and marked crosswalk, vehicles turning on *red*, short pedestrian clearance intervals, vendors obstructing crossing terminals, activity in the outer lanes causing drivers to block the crosswalk and crosswalk terminals, and non-compliant pedestrians who cross into free-flowing traffic when gaps are insufficient.

Turns on *red* are allowed at most intersections on the study corridor. Conflicts were observed between vehicles turning on *red* and pedestrians crossing the study corridor. Pedestrian crossing volume was high at all sites on the study corridor and there rarely were sufficient gaps in pedestrian flows to permit a vehicle to turn on *red* without resulting in a conflict.

Short pedestrian clearance intervals at all sites on the study corridor often left pedestrians within the intersection when conflicting traffic was released. Many of the severe conflicts that occurred during the DON'T WALK interval happened because pedestrians did not have sufficient time to complete their crossing. Figure 36 illustrates a pedestrian with a mobility impairment traveling with an assistive device who was unable to complete her crossing during the pedestrian clearance interval, before conflicting

traffic was released. This pedestrian, and the pedestrian she was traveling with, were both in a conflict.



Figure 36: Pedestrian unable to complete crossing during pedestrian clearance interval

Pedestrian volumes were high, and at some terminals there was insufficient queuing space for them to wait on the terminal to cross. While waiting for the WALK interval, pedestrians often stood on the street in the outer traffic lanes as they waited to cross (Figure 37). Parked vehicles were often present in the outer lanes and blocked the view of pedestrians who were waiting on the street to cross. Turning vehicles that weave around parked cars may not expect to see pedestrians queuing on the street. Conflicts were observed between pedestrians queuing on the street and vehicles traveling in the outer lanes. Obstructions at the terminals, like vendors, take up space that should be used for pedestrians to safely wait to cross.



Figure 37: Pedestrians waiting on street to cross in near conflict with turning vehicle

Conflicts also occur when non-compliant pedestrians cross the road through insufficient gaps in free-flowing traffic. Measures to improve pedestrian compliance could help reduce conflicts associated with this type of non-compliant pedestrian.

Site 5 contributed the largest proportion of total conflicts on the study corridor: 17 percent of total conflicts on the study corridor occurred at Site 5. A total of 748 pedestrians were observed at Site 5 and 219 (29 percent) of these pedestrians were in a conflict. The majority of conflicts at Site 5 were minor: 99 percent of conflicts at Site 5 were minor. Figure 38 illustrates the conflict type distribution for minor and severe conflicts at Site 5. The most common type of minor conflict was type MB, where a pedestrian travels around a vehicle that is stopped and blocking the crosswalk: 81 percent of total minor conflicts at Site 5 were type MB.

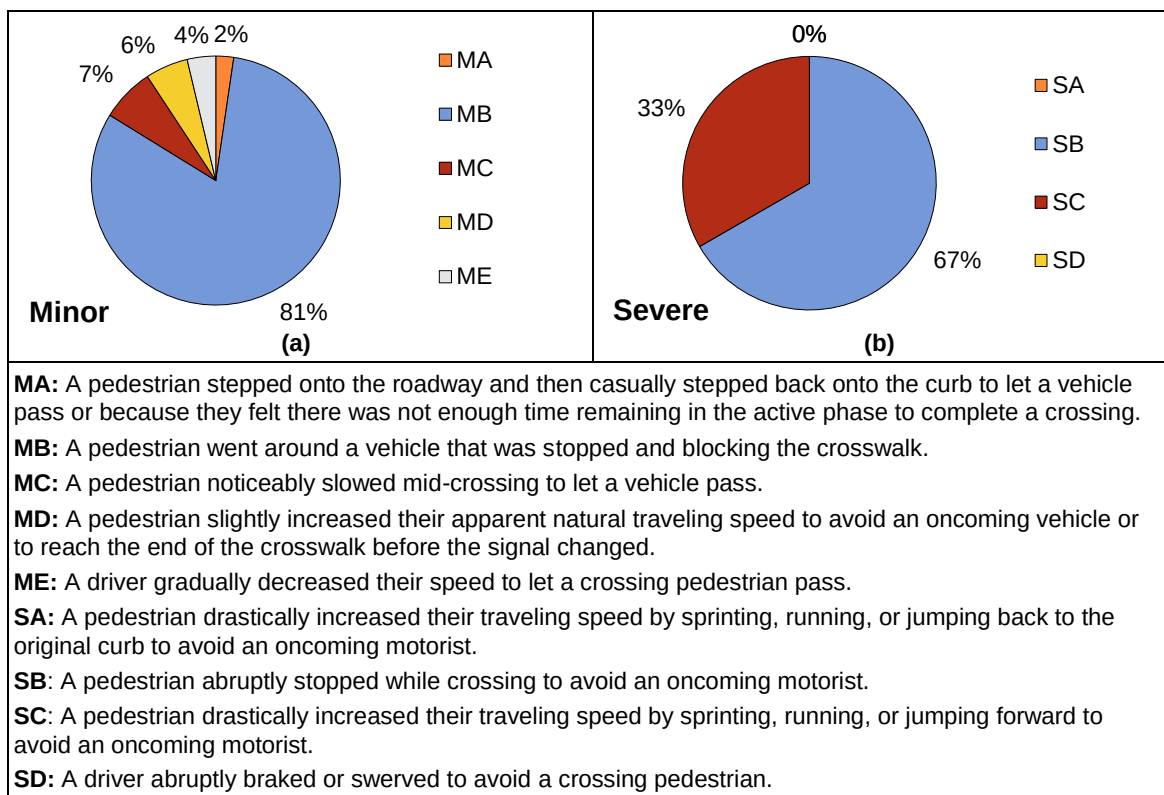


Figure 38: Conflict type distribution for Site 5: (a) Minor conflict types (n = 216); (b) Severe conflict types (n = 3)

Site 5 is located in front of the main entrance to a hospital on the study corridor. The hospital does not have a designated passenger loading zone on the study corridor, so drivers frequently stop in front of the south terminal at Site 5 to pick up and drop off passengers. The only curb ramp provided from the road to the hospital entrance is the crosswalk curb ramp. Many people traveling to and from the hospital have mobility impairments and need to use the ramp for access. Drivers specifically position their vehicles in front of the crosswalk terminal so that their passengers can use the curb ramp (Figure 39a). The south terminal was often blocked by these vehicles as well as a queue of taxis waiting to receive fares (Figure 39b).



Figure 39: Vehicles blocking south terminal at Site 5: (a) Taxi; (b) Vehicle unloading passenger at curb ramp

5.4. COMPLIANCE AND CONFLICT IMPLICATIONS FOR THE SAFE ACCOMMODATION OF PEDESTRIANS AT SIGNALIZED INTERSECTIONS

The analysis of pedestrian compliance and conflicts on the study corridor emphasized the safety implications of some of the key physical and operational site condition issues raised in Chapter 4. Overall, total pedestrian compliance was high at signalized intersections on the study corridor. However, a number of contributing factors and safety implications related to non-compliance were identified:

- 1. Insufficient signal visibility:** Visibility of the pedestrian signal was restricted by large offsets of the signal from the crosswalk, damaged signals that did not face pedestrians, and obstructions to the signal from queuing buses and other vehicles within the crosswalk. Pedestrians need to see the signal to know when it is appropriate to cross.
- 2. Inadequate performance of audible signals:** Audible signals that are incorrectly mounted or obstructed by poles and queuing vehicles do not adequately emit their tone to pedestrians queuing at both terminals. Hearing the audible indication at the start of the WALK interval helps capture the attention of queuing pedestrians to inform them of the appropriate time to cross, and assists pedestrians with vision impairments.
- 3. Insufficient guidance on signal actuation:** Signage is not provided at Site 20 on the need to operate the pushbutton to actuate the pedestrian phase. This is the only site that operates a pushbutton for signal actuation. Pedestrians may not expect to have to use a pushbutton to actuate the signal and may red-walk after becoming impatient while waiting for the WALK interval.
- 4. Motor vehicle priority in signal phase composition:** The leading interval for turning vehicles at Site 1 creates additional delay for queuing pedestrians. Pedestrian compliance was considerably lower at Site 1 compared with average compliance on the study corridor. Pedestrians red-walk because they expect to cross concurrently with adjacent traffic and do not anticipate that they must wait to cross during the leading motor vehicle right turn phase before receive the WALK.

The majority of pedestrians were not in a conflict when crossing at a signalized intersection on the study corridor, and the majority of conflicts that did occur were minor in severity. A number of contributing factors and safety implications related to pedestrian conflicts were identified:

1. **Absence of a pedestrian phase and marked crosswalk:** Site 6 is the only signalized intersection on the study corridor that does not operate a pedestrian phase or marked crosswalk. A greater proportion of severe conflicts were observed at Site 6 compared with the study corridor average.
2. **Presence of motor vehicles in the crosswalk:** Parked vehicles, taxi stands, buses, and other motor vehicle traffic often queues within the crosswalk and blocks access for pedestrians to curb ramps at the terminal. Conflicts occur when pedestrians weave around traffic that is stopped and blocking the crosswalk.
3. **Allowance of potentially conflicting movements:** Turns on *red* which cross over the pedestrian crosswalk are allowed at many sites. Conflicts were observed between crossing pedestrians and vehicles turning on *red*.
4. **Non-compliant pedestrians:** Non-compliant pedestrians were involved in conflicts when they crossed during insufficient gaps in free-flowing traffic.
5. **Unaccommodating pedestrian clearance intervals:** Short pedestrian clearance intervals do not allow pedestrians to reach the far terminal before conflicting traffic is released. Conflicts were observed between motor vehicles and pedestrians that were unable to clear the intersection before conflicting traffic was released. The majority conflicts that occurred during the DON'T WALK interval were severe.

- 6. Obstructions at the crossing terminals:** Vendors that set up on the terminal take space away from pedestrians that are waiting for the WALK indication to cross. Pedestrians often stand on the street, exposed to traffic, when vendors are set up on the terminal. Conflicts were observed between motor vehicles and pedestrians queuing on the street.

6.0. CONCLUSIONS AND RECOMMENDATIONS

This chapter summarizes key findings of the research and recommends revisions to the documented practices in Costa Rica and well as engineering treatments to improve pedestrian accommodation and safety at signalized intersections. Opportunities for future research are discussed.

6.1. CONCLUSIONS

The main conclusions of this research are:

- Pedestrian accommodation is considered in the documented practices for designing and operating signalized intersections in Costa Rica; however, content is excluded or differs from North American best practices in several areas and could be revised to better address the needs of pedestrians who cross at these sites. When guidelines are insufficient or lack relevant content, pedestrian facilities are correspondingly designed to a lower standard and pedestrian accommodation suffers.
- The existing physical and operational site conditions on the study corridor do not adequately meet the needs of pedestrians and pose accessibility and safety concerns for these vulnerable road users.
- Most pedestrians are compliant with signals on the study corridor and female pedestrians are more likely to comply than male pedestrians; average compliance was 88 percent for total pedestrians, 93 percent for total female pedestrians, and 88 percent for total male pedestrians. Large proportions of non-compliant pedestrians crossed at specific sites on the study corridor, where unique operational conditions contributed to non-compliance. Pedestrian

compliance studies conducted on a similar urban corridor in Brisbane, Australia, reported 13 percent non-compliance, which is consistent with the findings from this research (King, Soole, & Ghafourian, 2009). However, comparing pedestrian compliance results between different locations may not be a useful practice, because road user behaviour changes depending on the local demographics and surrounding environment. Previous research on pedestrian compliance and crossing behaviour also found female pedestrians to be more compliant than male pedestrians (Tom & Granie, 2011; Garder, 1989; Wang, Wang, & Tremont, 2013; Tiwari, S., Saraswat, & Gaurav, 2007; Vujanic, Pesic, Antic, & Smailovic, 2014; Rosenbloom, 2009)

- Most pedestrians are not in a conflict when crossing at a signalized intersection on the study corridor and male pedestrians are more likely to be in a conflict than female pedestrians; nine percent of total pedestrians and total female pedestrians were in a conflict, while 11 percent of total male pedestrians were in a conflict. Pedestrian conflict studies conducted at signalized intersections in Bulgaria also found male pedestrians to be in more conflicts than female pedestrians (Vujanic, Pesic, Antic, & Smailovic, 2014).
- Most conflicts are minor in severity; 89 percent of total conflicts were minor and nine percent were severe. Severe conflicts are more likely to occur during the DON'T WALK interval, while minor conflicts are more likely to occur during the WALK interval. Previous research found pedestrian conflicts to be more likely to occur during the DON'T WALK interval (Vujanic, Pesic, Antic, & Smailovic, 2014). Equivalent proportions of total male and total female pedestrians are involved in severe conflicts; one percent of total male and total female pedestrians were involved in a severe conflict. Severe conflicts during the DON'T WALK interval

often occur because pedestrians are not given sufficient time to clear the intersection. The fact that equal proportions of male and female pedestrians are involved in severe conflicts suggests that, even though males walk faster than females (Arango Diaz, 2008), both are equally impacted by the short pedestrian clearance intervals.

Several physical and operational conditions restricted pedestrian accessibility and contributed to pedestrian non-compliance and pedestrian conflicts. These conditions are discussed in Table 28 as key issues for the safe accommodation of pedestrians at signalized intersections.

Table 28: Key Issues for the Safe Accommodation of Pedestrians at Signalized Intersections

Key issue	Overview	Impact on pedestrian accommodation and safety
Documented practices in Costa Rica deviate or exclude content from North American best practices regarding the accommodation of pedestrians at signalized intersections.	Guidelines and standards in Costa Rica lack sufficient and relevant content regarding the operational design of pedestrian signals and the geometric design of pedestrian infrastructure at signalized intersections.	Pedestrian facilities at signalized intersections are not designed or operated according to best practices because the practices are not sufficiently documented or standardized to follow.
Site conditions deviate from standards and guidelines in Costa Rica and from best practices.	Following guidelines and standards helps ensure facilities are designed and operated consistently, which is a guiding principle for the provision of pedestrian crossing control.	Inconsistent designs can violate driver and pedestrian expectancy. Less accommodating pedestrian facilities are installed and operated when guidelines and standards are not followed.
Insufficient guidance for pedestrians, particularly pedestrians with impairments, regarding signal operation.	Signal visibility is poor for crossing pedestrians. Lenses are in poor condition with limited conspicuity. Audible signals do not adequately serve both terminals and guidance on the need to use the pushbutton for signal actuation is not provided.	Pedestrians should understand how the signal is actuated and should be able to see the signal to know when it is appropriate to cross. Audible signals assist pedestrians with vision impairments. Insufficient guidance regarding signal operation contributes to non-compliant pedestrian behaviour.

Table 28 continued...

Key issue	Overview	Impact on pedestrian accommodation and safety
Inaccessible infrastructure for pedestrians with impairments.	Facilities should follow universal design standards and be accessible for all users, including those with impairments. Accessibility is limited at signalized intersections by obstacles within the pedestrian zone and by substandard or nonexistent curb ramps.	Obstacles within the pedestrian zone are hazards for pedestrians with vision impairments and may effectively block the travel way for people using wheelchairs. Conflicts occur when pedestrians are forced to queue on the street because vendors and other obstacles take up space at the terminal. Pedestrians with mobility impairments may not be able to cross without accessible curb ramps and could be left within the intersection.
Motor vehicle activity in outer lanes.	Motor vehicle activity in the outer lanes adjacent to crosswalks, including taxi stands, buses, parking, loading, pick up and drop off obstructs sightlines and blocks curb ramps at terminals.	Conflicts occur when pedestrians have to weave around vehicles that are blocking the curb ramp and crosswalk. Pedestrians with mobility impairments may not be able to cross when curb ramps are blocked by motor vehicles.
Allowance of potentially conflicting movements.	Turns on <i>red</i> which cross over the pedestrian crosswalk are allowed at many sites.	Conflicts occur between motor vehicles turning on <i>red</i> and pedestrians who are in the crosswalk. Turning traffic is a principal threat for pedestrians (Garder, 1989) and prohibiting right turns on red eliminates this conflict potential (Steinman & Hines, 2003).
Inconsistent signal timing practices and unaccommodating pedestrian clearance intervals.	The duration and split of the pedestrian clearance interval varies among sites. Pedestrian clearance intervals are timed for a walking speed that is unachievable for many pedestrians with mobility impairments.	Inconsistencies can violate pedestrian expectancy regarding how much time remains to clear the intersection. The duration of the pedestrian clearance interval does not allow pedestrians to clear the intersection before conflicting traffic is released, and many pedestrians are left within the intersection when the DON'T WALK interval is displayed. Most conflicts that occur at this time are severe. Short pedestrian clearance intervals most greatly effects pedestrians with mobility impairments and older pedestrians, who travel at slower speeds. Older pedestrians are most prone to fatal injuries when involved in a pedestrian collision (Mohamed, Saunier, Miranda-Moreno, & Ukkusuri, 2012).
Absence of a pedestrian phase and marked crosswalk.	Site 6 has comparable volumes of crossing pedestrians, however it is the only site on the study corridor that does not operate a pedestrian phase or have a marked crosswalk.	Pedestrians have difficulty estimating how much time remains to cross without a pedestrian signal. Drivers may be less likely to expect pedestrians to cross at this site, since it is the only unmarked. Crossing. Conflict severity is higher at Site 6. Pedestrian crossings with no signal may increase the likelihood of fatal pedestrian collisions (Mohamed, Saunier, Miranda-Moreno, & Ukkusuri, 2012)

6.2. RECOMMENDATIONS FOR THE SAFE ACCOMMODATION OF PEDESTRIANS AT SIGNALIZED INTERSECTIONS

Revisions to documented practices and engineering measures are recommended to improve the safety and accommodation of pedestrians at signalized intersections.

6.2.1. Documented Practices

Table 29 summarizes recommended revisions to documented practices in Costa Rica for the operational and geometric design of pedestrian crossing facilities at signalized intersections. These recommendations are the result of the comparison between documented practices in Costa Rica and North American best practices presented in Chapter 2 and Appendix A.

Table 29: Recommended Revisions to Documented Practices in Costa Rica for Safe Pedestrian Accommodation at Signalized Intersections

Aspect	Recommended Revisions
Signage	• Add recommendation to provide signage information in alternative formats for pedestrians with vision impairments, such as with Braille. • Develop a local standard for the application of pedestrian-related signage in San Jose to indicate allowable deviations from the MUTCDCA and assist local engineers responsible for designing signing plans.
Tactile Markings	• Provide specific guidance on the application of detectable warnings on perpendicular curb ramps. • Provide criteria to indicate when directional surfaces are required. • Recommend the application of detectable warnings on the edge of depressed corners, border of raised crosswalks and raised intersections, and the border of medians and islands. Accompany revision with an educational program for people with vision impairments. • Require a single strip of detectable warnings be placed at the base of the curb ramps regardless of sidewalk and curb ramp width. The current standard requires covering the entire curb ramp with detectable warnings which can be difficult to traverse for pedestrians with mobility impairments, such as people in wheelchairs.
Signal Installation	• When pedestrian signals are justified for one crossing direction at an intersection, add recommendation that they be installed for all crossing directions to improve uniformity.
Signal Displays	• Increase the minimum allowable pedestrian signal lens size to 30 cm diameters for circular lenses and 30 cm sides for square lenses to improve signal visibility, particularly for pedestrians with low vision.

Table 29 continued...

Aspect	Recommended Revisions
Signal Phasing	• Adjust the pedestrian clearance interval to allow crossing pedestrians to reach the far terminal, as opposed to the centre of the furthest lane, before conflicting traffic is released. • Reduce the design walking speed from 1.2 m/s to a recommended range of walking speeds between 0.8 m/s to 1.0 m/s. • Provide guidance on the application of leading pedestrian intervals that is reflective of North American best practices.
Accessible Pedestrian Signals	• Develop a guideline for the design and application of accessible pedestrian signals that is reflective of North American best practices.
Pedestrian Countdown Signals	• If there is interest to operate pedestrian countdown signals in Costa Rica, develop a guideline for their design and application that is reflective of North American best practices.
Infrastructure in the crossing zone	• Develop design specifications and allowances for curb extensions. • Develop design specifications and allowances for raised crosswalks. • Provide guidance on the relationship between the size of intersection turning radii, pedestrian crossing distance, and potential conflicts between crossing pedestrians and large turning vehicles in appropriate guidelines.
Infrastructure connecting to the crosswalk terminal	• Transfer sidewalk ownership from property owners to the municipality, so that sidewalks are consistently constructed, reconstructed, and maintained. • Increase minimum sidewalk width from 1.2 m to 1.5 m to allow two pedestrians to comfortably pass each other. • Provide guidance on when it is appropriate to design a sidewalk that is wider than the minimum width requirement.
Infrastructure connecting to the crosswalk terminal continued...	• Discuss the treatment of removable and protruding obstacles on sidewalks. • Require level landings when sidewalk grades exceed maximum allowable grades. • Specify a maximum sidewalk gradient which ideally does not exceed 5 percent. • Recommend installing rest areas outside the pedestrian zone with amenities. • Require changes in ground level that pose tripping hazards be minimized. • Require the provision of good lighting on sidewalks.
Infrastructure at the crosswalk terminal	• Require curb ramps on all crosswalk terminals that meet the following requirements: ○ Minimum 1.2 m by 1.2 m landing space ○ Placed wholly within the crosswalk ○ Aligned on a straight path of travel with the crosswalk and receiving terminal ○ Perpendicular to the curb ○ Distinguishable from the surrounding surface ○ Defined edges to contrast with the sidewalk ○ Allowable longitudinal grade of 7.1 ± 1.2 percent ○ Maximum 2 percent cross-slope ○ Avoid grade changes in excess of 11 percent over a 61 cm interval ○ Avoid designs that require pedestrians to manoeuvre on the curb ramp ○ Flush transition to the street and gutter ○ Adequate drainage • Develop design specifications and allowances for depressed corners.

6.2.2. Engineering Measures

Recommended engineering measures are presented in Table 30 and relate to the physical infrastructure and operational conditions at sites on the study corridor. The recommendations are the result of the site condition evaluation conducted in Chapter 4 and Appendix B, and of the safety performance analysis conducted in Chapter 5 and Appendix C. The site applicability of each recommendation is presented in brackets. Many of the recommended engineering measures can serve as a best practice template and be applied to other signalized intersections in Costa Rica.

Table 30: Recommended Engineering Treatments for Safe Accommodation of Pedestrians at Signalized Intersections

Aspect	Recommended Engineering Treatment (site applicability of treatment shown in brackets)
Signage	• Provide street recognition signs at each terminal in an accessible format for pedestrians. Providing information in alternative forms of communication, such as Braille or intersection maps, assists pedestrians with vision impairment. (All) • Install sign R-11-13 from the MUTCDCA which indicates that pedestrians must push the button to cross at both terminals. (20)
Pavement markings	• Regularly maintain pavement marking condition to ensure good day and night visibility. (All) • Paint zebra and stop line markings to extend full length of the crosswalk. (19) • Paint new zebra markings. (6)
Tactile markings	• Consistently apply tactile markings according to the National Standard for Signage on Horizontal Surfaces. (All) • Replace tactile markings that do not conform to the National Standard and that give inconsistent messages to pedestrians with vision impairments regarding the location of hazards, intersections, and curb ramps. (2-6, 17, 18)
Signal phasing	• Prohibit turns on <i>red</i> which cross over the pedestrian crosswalk while the pedestrian phase is active. Enforcement will likely be required to ensure drivers comply with new turn restrictions. (All sites where turning on red movement currently allowed) • Time the duration of the pedestrian clearance interval to allow pedestrians traveling at 1.0 m/s to reach the far terminal before conflicting traffic is released. (All) • Reduce design walking speed to 0.8 m/s at sites adjacent to the hospital. (3-6) • Consider adding vehicle detection to the southbound right-turn lane to actuate the protected phase, or altering the sequence so that the pedestrian WALK interval occurs in advance of the southbound protected right-turn phase. Conducted a traffic impact study to evaluate these options. (1) • Install and operate a new pedestrian phase. (6)

Table 30 continued...

Aspect	Recommended Engineering Treatment (site applicability of treatment shown in brackets)
Signal display and visibility	- Relocate pedestrian signals that are greatly offset from the crosswalk and where their indications are not perpendicularly facing crossing pedestrians. (1, 12) - Replace 22 cm signal lenses with 30 cm lenses for greater visibility. (1, 2) - Use consistent symbols contained in the MUTCDCA to indicate the WALK, Flashing WALK, and DON'T WALK intervals. (1, 5, 15) - Replace incandescent displays in poor condition with LED displays for improved clarity. (All)
Accessible Pedestrian Signals	- Provide one audible signal on each terminal that is unobstructed and directed along the crosswalk. (All) - Remount existing pushbuttons between 1.1 metres and 1.25 metres high, parallel with the crosswalk direction. (20)
Pedestrian Countdown Signals (PCS)	Install PCSs at select sites on a trial basis to evaluate their safety impact. Operate PCSs according to best practices, with appropriate adjustments made to reflect Costa Rica conditions (e.g., symbol displayed for each pedestrian interval should be consistent with the MUTCDCA). Larger scale PCS implementation can occur if economically feasible and if trial installations demonstrate safety benefits. Potential sites to consider for initial installation are: 1 – poorest compliance; 12 – highest pedestrian volume and poor compliance; 4 & 5 – hospital region, high volumes of pedestrians with impairments.
Sidewalks	- Remove and relocate temporary and protruding obstacles from the pedestrian zone. (All) - Surround permanent and unmovable obstacles with detectable warnings to assist with detection for pedestrians with vision impairments. (All)
Terminals	- Do not allow vendors to block or obstruct the crossing terminal. (All) - Remove and relocate temporary and protruding obstacles from the terminal. (All) - Surround permanent and unmovable obstacles with detectable warnings to assist detection for pedestrians with vision impairments. (All) - Designate pick up and drop off hospital loading zone that is offset from the crosswalk and that can be used by taxis and personal vehicles. Provide curb ramps in loading zone for sidewalk access. A potential loading zone location is illustrated in Figure 40. (5) - Improve the interface between the pavement and railroad track at the south terminal so that a smooth and level surface is provided with limited gaps. (20)
Curb ramps	Provide curb ramps on both terminals at all sites which are designed according to best practices. (All)
Crossing zone	- Do not allow parking, taxi stands, or loading within the crossing zone. (1-2, 4-20) - Provide signage or increased enforcement to prohibit drivers from queuing within the intersection and blocking the crosswalk. Signage can indicate to drivers to stop at the stop line and to not enter a blocked intersection. (4,5) - Reroute buses to the terminal entrance on a route that is separate from the study corridor crosswalk so that they do not enter and block the crosswalk or obstruct views of the pedestrian signals. (7)

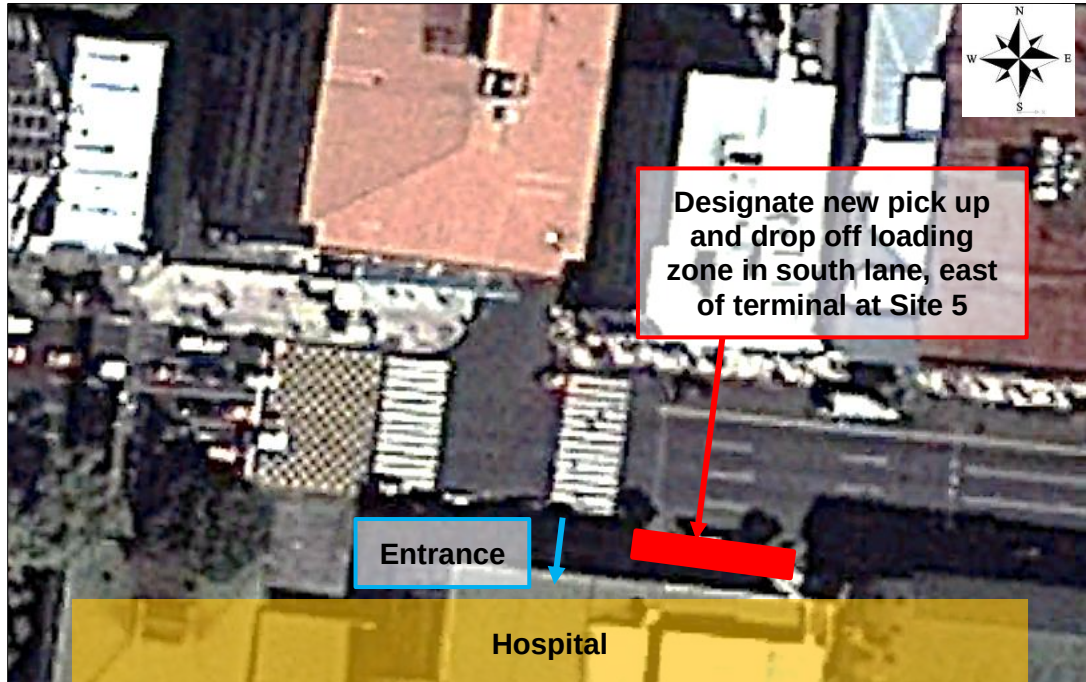


Figure 40: Potential location for new hospital passenger loading zone, east of south terminal at Site 5

6.3. RECOMMENDATIONS FOR FUTURE RESEARCH

This research identifies the need for future work to:

- The operational impacts associated with increasing the duration of the pedestrian clearance interval and reducing the design walking speed to 1.0 m/s at sites on the study corridor. Motor vehicle level of service could change when signal phases and interval durations are revised to include a more accommodating pedestrian clearance interval.
- The influence of pedestrian countdown signals on pedestrian compliance. Currently, PCSs have not been installed at any signals in Costa Rica. This research offers a pedestrian compliance study methodology, including 10 defined compliance scenarios for red-walking, amber-walking, and green-walking, which could be adopted in pedestrian compliance studies at new PCS sites in Costa

Rica. This research also provides comprehensive pedestrian compliance analysis results for 19 sites that operate traditional WALK/DON'T WALK signals, which could be compared with results from PCS compliance studies to determine their influence – both generally and within a specific Costa Rica context.

- The influence of operating a Flashing WALK interval versus a Flashing DON'T WALK interval on pedestrian compliance. A unique difference between North America and Costa Rica is the intermittent display shown between the WALK and DON'T WALK intervals: one may offer higher compliance over the other.
- Non-engineering factors that contribute to pedestrian non-compliance. Some sites on the study corridor with poor pedestrian compliance did not present unique physical and operational conditions that could explain poor compliance observed at these sites. Non-engineering related factors that were not of focus in this research, such as specific behavioural traits of pedestrians, could be explored to try to explain poor compliance at these sites.
- The influence of gender on pedestrian behaviour at crosswalks, such as looking behaviour, waiting behaviour, and knowledge of the rules of the road. This research found that pedestrian safety performance differs by gender, but additional knowledge is needed to explain these differences and to validate the need for gender-specific approaches to road safety treatments.
- Examine pedestrian accommodation and safety performance on other corridors in Costa Rica. It is likely that the key issues and recommendations identified in this research would be applicable to other corridors, and would have a wider impact on pedestrian safety and accommodation in Costa Rica if applied to the broader transportation network.

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APPENDIX A – SUMMARY OF PEDESTRIAN ACCOMODATION PRACTICES AT SIGNALIZED INTERSECTIONS

This appendix is related to Chapter 2 and summarizes the results of the literature review on practices regarding pedestrian accommodation at signalized intersections. The appendix summarizes best practices from North America and documented practices from Costa Rica for the operational design of pedestrian signals and the geometric design of pedestrian infrastructure at signalized intersections.

A - SUMMARY OF PEDESTRIAN ACCOMMODATION PRACTICES FOR SIGNALIZED INTERSECTIONS

Appendix A summarizes the results of the literature review on practices regarding pedestrian accommodation at signalized intersections. The appendix summarizes best practices from North America and documented practices from Costa Rica for: (1) the operational design of pedestrian signals, including signage, pavement markings, tactile markings, signal installation justification, pedestrian signal phasing and displays, accessible pedestrian signals, and pedestrian countdown signals; and (2) the geometric design of pedestrian infrastructure at signalized intersections, including the design of facilities connecting to the crosswalk terminal, at the terminal, and within the crossing zone over the roadway.

A.1. NORTH AMERICAN BEST PRACTICES

This section summarizes best practices from North America for pedestrian accommodation at signalized intersections. The key documents consulted to form this section were:

- Transportation Association of Canada's (TAC) Manual of Uniform Traffic Control Devices for Canada (MUTCDC) (1998) and the U.S. Federal Highway Administration's (FHWA) Manual of Uniform Traffic Control Devices (MUTCD) (2009).
- Canadian Capacity Guide for Signalized Intersections (2007).
- TAC's Pedestrian Crossing Control Guide (2012) and the Pedestrian Crossing Control Guide Technical Knowledge Base (2012).

- U.S. FHWA's Designing Sidewalks and Trails for Access: Part II of II: Best Practices Design Guide (2001).

A.1.1. Operational Design

Operational design of pedestrian crosswalks at signalized intersections includes signage, pavement markings, tactile markings, signal justification, signal phasing, signal displays, accessible pedestrian signals, and pedestrian countdown signals. Although the symbol used on traffic control devices may differ from country to country, there are some best practice concepts that are transferable. Best practice for effective traffic control devices is that they meet five basic requirements:

- “Fulfill a need
- Command attention
- Convey a clear and simple meaning
- Provide adequate time for a proper response
- Command respect of road users” (National Committee on Uniform Traffic Control, 1998)

Traffic control devices operate as complimentary elements and not in isolation. It is critical that traffic control devices provide information to road users in a consistent and uniform format. Jurisdictions should strive to standardize the application of all traffic control devices.

A.1.1.1. *Signage for Pedestrians*

Signs should fulfill the five basic requirements for effective traffic control devices. They should be consistently located and applied following a locally adopted standard. When installed, pedestrian crossing signs should face approaching pedestrians. Sign design

should be standardized and uniform in shape, colour, legend, symbols, dimensions, and finishing. The information provided on signs should also be provided in alternative formats for pedestrians with impairments, such as through Braille for pedestrians with vision impairments. Signs can inform pedestrians about a variety of elements regarding crossing at signalized intersections, including:

- Crossing only at crosswalks is allowed
- Crossing only on the *green* or WALK indication is allowed
- Push the pushbutton to cross or to receive the WALK indication
- Explanations of the pedestrian interval displays (i.e., descriptions of the WALK, Flashing DON'T WALK, and DON'T WALK displays) (FHWA, 2009, p. 93).

A.1.1.2. *Pavement Markings*

Pavement markings should fulfill the five basic requirements for effective traffic control devices. They should be consistently located and applied following a locally adopted standard. Pavement markings should be retroreflective so that they are visible at night, unless they are installed in areas with adequate illumination. White pavement markings are used to indicate crosswalks with crosswalk lines or zebra markings (also referred to as continental markings) (Figure A41). The application of crosswalk lines and zebra markings should be justified by an appropriate engineering study.

Crosswalk lines are solid, white transverse lines used to delineate the edges of a crosswalk by extending entirely across the pavement. Crosswalk lines are appropriate to use at crosswalks where: (1) there is a potential conflict between pedestrians and vehicles; (2) there are substantial pedestrian movements; or (3) where pedestrians may not naturally recognize the proper place to cross. Crosswalk line width should be between 10 cm and 20 cm (National Committee on Uniform Traffic Control, 1998, p.

A6.3). Crosswalk lines should be located so that curb ramps are contained within the bounds of the lines (FHWA, 2009, p. 385).

Zebra pavement markings are the most visible to drivers and also improve crosswalk detection for pedestrians with vision impairments (McMillen, et al., 2001, pp. 8-11). Zebra markings are not contained in the MUTCDC but are present in the MUTCD. Zebra markings are appropriate to use at crosswalks where: (1) there is high pedestrian activity and no other form of traffic control; (2) improved visibility is desired due to various physical site characteristics; (3) the placement of a crosswalk seems unexpected. Crosswalk lines are not required when zebra markings are used to mark a crosswalk. Zebra marking stripe width should be between 30 cm (12 in) and 61 cm (24 in). Stripes should be separated by 30 cm (12 in) to 1.5 metre (60 in) gaps. Gaps should not exceed 2.5 times the line width (FHWA, 2009, p. 385).

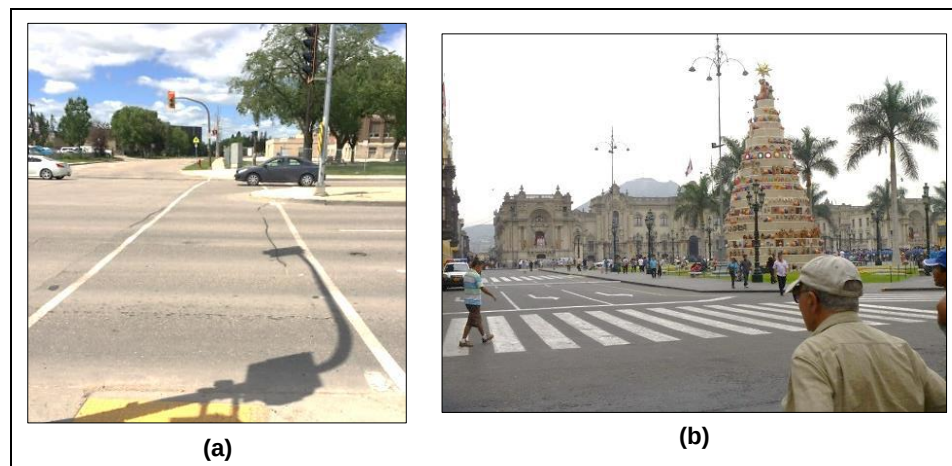


Figure A41: Crosswalk pavement markings: (a) Crosswalk lines; (b) Zebra markings

A.1.1.3. Tactile Markings

Tactile markings can be provided as detectable warnings (Figure A42a) or as directional surfaces (Figure A42b). Tactile markings should be identifiable by their texture and

contrasting colour to the surrounding surface. Tactile markings are most effective when they convey a unique message in a standardized format.

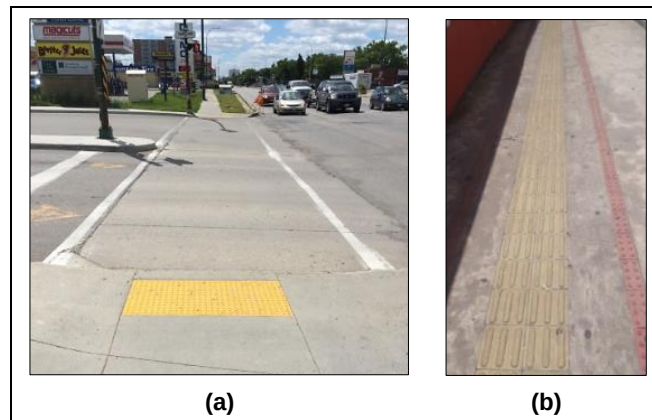


Figure A42: Tactile markings: (a) Detectable warnings with truncated domes at curb ramp, (b) Directional surface with raised bars on sidewalk

Detectable warnings are provided as truncated domes that are laid out in a grid that allows the passage of wheelchair wheels while still being detectable for pedestrians with vision impairments. The main purpose of detectable warnings is to notify pedestrians with vision impairments of hazards in their path of travel. McMillen et al. (2001) recommend the installation of a 61 cm (24 in) strip of detectable warnings with truncated domes at the following locations at crosswalks:

- Edge of depressed corners
- Border of raised crosswalks, raised intersections, medians and islands
- Base of curb ramps

Detectable warnings on curb ramps help pedestrians with vision impairments locate and align themselves with the crosswalk, and also indicate a clear space to stop and wait to cross for children and pedestrians with cognitive impairments. Detectable warnings should only be installed on the lower 61 cm (24 in) of the curb ramp so as not to impede

people in wheelchairs, who may have difficulty traversing curb ramps that are fully covered in detectable warnings (McMillen, et al., 2001, pp. 6-9).

Directional surfaces are used to convey wayfinding information and are distinctly different from detectable warnings. The main purpose of directional surfaces is to orient pedestrians with vision impairments along their desired travel path. Directional surfaces have been applied on sidewalks and along crosswalks to orient pedestrians; however, this type of tactile marking is not widely used in the U.S. and more research is required to determine appropriate standards for their use in North America (McMillen, et al., 2001, pp. 6-11).

A.1.1.4. *Signal Installation Justification*

Comprehensive studies, warrants, and engineering judgement should be used to determine the need for traffic signals and pedestrian signal heads.

The MUTCD defines engineering judgement as:

The evaluation of available pertinent information, and the application of appropriate principles, provisions, and practices contained in [the MUTCD] and other sources, for the purpose of deciding upon the applicability, design, operation, or installation of a traffic control device. Engineering judgement shall be exercised by an engineer, or by an individual working under the supervision of an engineer, through the application of procedures and criteria established by the engineer (FHWA, 2009, p. 14).

The MUTCD and MUTCDC specify that a comprehensive engineering study which evaluates traffic conditions, pedestrian characteristics, physical characteristics, safety, and operations is required to determine if a traffic signal is justified at a particular location. The study should evaluate existing operations and safety at the site, and opportunities for improvement. Warrants help standardize the installation of traffic

signals, which helps to ensure they are applied in a consistent manner and meet control objectives. However, satisfying one or more of the warrant criteria does not in itself require the installation of a traffic signal. The decision to install a signal must also consider the results of the comprehensive engineering study. The MUTCD specifies that one or more of the following nine warrant criteria should be met to justify the installation of a traffic signal in the United States:

1. 8-hour vehicular volume
2. 4-hour vehicular volume
3. Peak hour
4. Pedestrian volume
5. School crossing
6. Coordinated signal system
7. Collision experience
8. Roadway network
9. Intersection near a grade crossing (FHWA, 2009, p. 436)

Meeting the pedestrian volume warrant in the MUTCD supports the installation of a signal for locations where the traffic volume on the major street is so high that pedestrians experience excessive delays when crossing the street. The pedestrian volume warrant considers the pedestrian-vehicle volume cross product. The cross product must be above the threshold specified in the MUTCD to meet the warrant criteria.

The MUTCDC uses a different type of warranting system than the MUTCD. The warrant system in Canada is based on priority points that are earned for collisions, crossing gaps, signal progression, delay, vehicular stops, intersecting volumes, and pedestrian

volumes (National Committee on Uniform Traffic Control, 1998, p. B2.2). The priority ranking system quantifies the net effect of installing a traffic signal by collectively considering the above factors.

In Canada, pedestrian signals should be considered at crosswalks that span more than two lanes of traffic. Typically, pedestrians require more clearance time to cross this size of facility than what would be provided by the vehicular clearance interval. When pedestrian signals are required for one or more crossing directions at an intersection, it is advisable to place pedestrian signals on all crossing directions for uniformity (National Committee on Uniform Traffic Control, 1998, p. B1.5.4).

The MUTCD requires that the needs of vehicular traffic and pedestrians are considered in the design and operation of traffic signals. Pedestrian signal heads that are conveniently directed and visible to pedestrians should be provided at traffic signals when engineering judgement indicates the need to control pedestrian movements (FHWA, 2009, p. 450). In the United States, pedestrian signal heads must be used when:

- A traffic signal is justified by a comprehensive engineering study and under the pedestrian volume warrant or school crossing warrant.
- An exclusive pedestrian phase is provided for pedestrian movements in one or more directions while all conflicting traffic is held.
- It is at an established school crossing at any signalized location.
- Engineering judgement dictates that a complex phase arrangement would confuse pedestrians on when to cross or cause conflicts if only vehicular indications were provided (FHWA, 2009, p. 495).

In the United States, pedestrian signal heads are recommended, but not mandatory, when:

- Pedestrians require assistance determining when to begin crossing.
- Engineering judgement justifies their use to minimize pedestrian-vehicle conflicts.
- Pedestrians are permitted to cross a portion of a street during a particular interval but are not permitted to cross the remainder of the street during the same interval (e.g., pedestrians are permitted to cross from the near terminal to a median during a particular interval, but are not permitted to cross from the median to the far terminal during the same interval).
- Vehicular signals are not visible to pedestrians or when the vehicular signals that are visible to pedestrians do not adequately describe when pedestrians are allowed to cross (FHWA, 2009, p. 495).

A.1.1.5. Pedestrian Signal Intervals and Phasing

Three intervals comprise the pedestrian phase in North America:

- **WALK:** Pedestrians may enter the crosswalk or road and proceed in the direction of the signal.
- **Flashing DON'T WALK:** Pedestrians are not allowed to enter the crosswalk or road in the direction of the signal. Pedestrians who have already begun crossing during the WALK interval are allowed to finish crossing and continue to have the right-of-way over other traffic in the intersection.
- **DON'T WALK:** Pedestrians are not allowed to enter the crosswalk or road in the direction of the signal.

The intent of the WALK interval is to allow pedestrians to start crossing. The length of the WALK interval does not need to be long enough to allow a pedestrian to fully complete their crossing when it is active. During the WALK interval, directions of vehicular traffic that are perpendicular to the crosswalk should be held on *red*. The minimum WALK interval in the United States is seven seconds, except at crosswalks where pedestrian volumes and characteristics allow for a shorter interval, in which case a minimum of four seconds can be used (FHWA, 2009, p. 498). In Canada, the minimum WALK interval is 10 seconds, with seven seconds allowed in some cases (Teply, Allingham, Richardson, & Stephenson, 2007, pp. 3-68). Longer WALK intervals may be desirable in areas with high pedestrian volumes, such as in central business districts. The WALK interval should allow pedestrians to perceive and react to the signal change and cover a sufficient distance of the crossing before the pedestrian clearance interval begins.

Pedestrian Clearance Interval

The pedestrian clearance interval is comprised of the Flashing DON'T WALK interval plus a portion of the DON'T WALK interval that immediately follows, prior to the release of any conflicting traffic. The intent of the pedestrian clearance interval is to allow pedestrians who started crossing during the WALK interval to complete their crossing. The minimum pedestrian clearance interval should be the time it would take for a pedestrian travelling at the design walking speed to leave the initial terminal and reach the far terminal or median refuge, if provided, before conflicting traffic receives *green*. Figure A43 illustrates the different sequencing options for the pedestrian phases and concurrent vehicular phases.

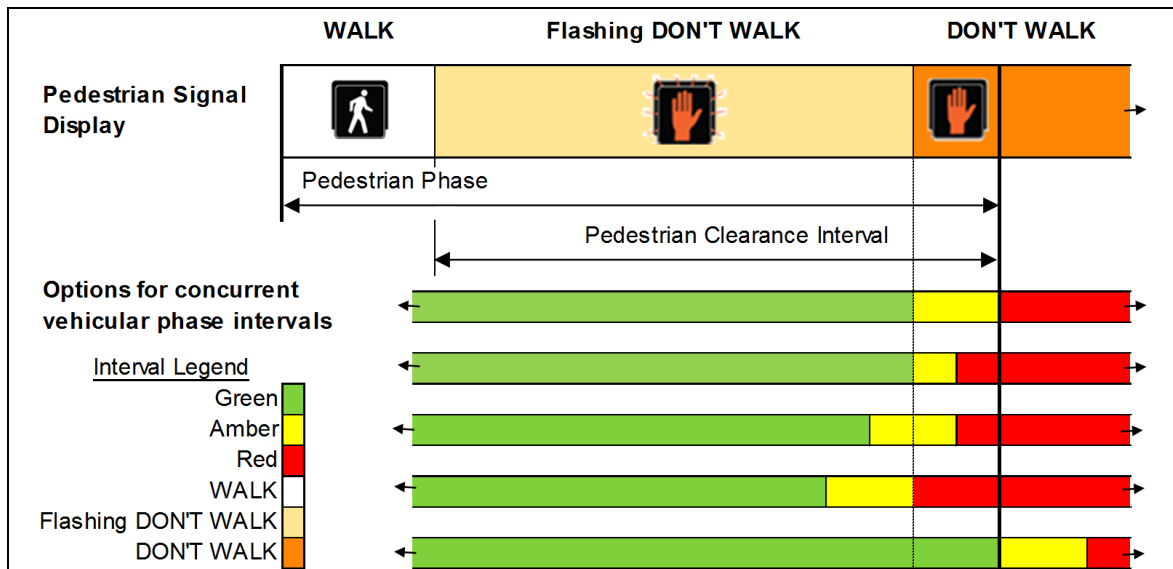


Figure A43: Sequencing of pedestrian clearance interval with concurrent vehicular intervals

Source: modified from (FHWA, 2009)

The pedestrian clearance interval should begin during *green* for parallel and concurrent vehicular phases. The Flashing DON'T WALK interval can extend into the vehicular *amber* or terminate during the vehicular *green*. The DON'T WALK portion of the pedestrian clearance interval should terminate before the onset of *green* for conflicting vehicles. The DON'T WALK interval can begin during the vehicular *green*, *amber*, or *all-red*.

Leading Pedestrian Interval

A leading pedestrian interval provides an advanced WALK while *red* is still displayed to all vehicular traffic. The purpose of a leading pedestrian interval is to provide pedestrians the opportunity to establish themselves in the intersection before concurrent vehicular phases receive *green* and begin turning across the pedestrian crosswalk. If provided, the length of the leading pedestrian interval should allow pedestrians to cross one lane of traffic or travel far enough into the intersection that they would be in front of the receiving lanes of turning traffic, before that traffic is given *green*. A minimum duration of 3

seconds is recommended for leading pedestrian intervals in the United States (FHWA, 2009, p. 499). McMillen et al. (2001) recommend providing pedestrian lead time as a best practice, to allow pedestrians to assert themselves in the crosswalk before drivers begin turning across their path.

Prohibiting turns across the crosswalk on *red* should be considered during the leading pedestrian interval. Leading pedestrian intervals can be used at intersections with high pedestrian volumes and high conflicting volumes of turning traffic. Accessible pedestrian signals are recommended with the provision of a leading pedestrian interval to assist pedestrians with vision impairments. Pedestrians with vision impairments would not anticipate the presence of a leading pedestrian interval and would wait to cross with parallel vehicular traffic, when drivers do not expect them to begin crossing. Best practices for accessible pedestrian signals are discussed in Section A.1.1.7.

Walking Speed

Pedestrian walking speed is used in determining the length of the pedestrian clearance interval. It is an important design parameter because walking speed impacts the length of time that a pedestrian will be within the crosswalk and potentially exposed to traffic. Conventional design walking speed is 1.2 m/s, however, jurisdictions are revising this standard in recognition that a considerable portion of the population travels at a slower walking speed and is not sufficiently accommodated at signalized intersections when this design value is used to time the pedestrian clearance interval:

In general, older pedestrians (65 years old and older) walk slower than younger pedestrians, women walk slower than men, people with mobility impairments walk slower than people without impairments, children walk slower than adults, and most people walk slower under normal circumstances than when they are crossing a signalized intersection (Montufar et al., 2012a, pp. S1-3).

In the United States, the design walking speed is 1.1 m/s (3.5 ft/s). A design walking speed of 1.2 m/s (4 ft/s) can be used in certain circumstances (FHWA, 2009, p. 497). Canada recently adopted a recommended range of design walking speeds of 0.8 m/s to 1.0 m/s (TAC Annual Technical Meeting, 2013).

A.1.1.6. *Pedestrian Signal Displays*

Pedestrian signal heads are exclusively intended to direct crossing pedestrians. Pedestrian signals should fulfill the five basic requirements for effective traffic control devices. The symbols displayed on pedestrian signals vary internationally. The important practice is that the displays are consistently applied following a locally adopted standard.

In Canada and the United States the *walking pedestrian*, *flashing hand*, and *steady hand* symbols are used to display the WALK, Flashing DON'T WALK, and DON'T WALK intervals, respectively. The *walking pedestrian* symbol is a solid or outlined white, walking pedestrian displayed on a black background (Figure A44a). The *hand* symbol can be a solid or outlined orange hand, displayed on a black background (Figure A44b). A *flashing walking pedestrian* has no meaning and is not permitted (FHWA, 2009, p. 495). Pedestrian signal lenses should be square, and approximately 30 cm per side. In Canada, the symbol on the pedestrian signal should be approximately 25 cm in height (National Committee on Uniform Traffic Control, 1998, p. B3.4).



Figure A44: Typical pedestrian signal displays in Canada: (a) *walking pedestrian* display for WALK interval; (b) *hand* display for DON'T WALK interval (flashes during Flashing DON'T WALK interval)

In Canada and the United States, the pedestrian signal head is mounted on the far-sided terminal, facing oncoming pedestrians. The pedestrian signal head should be mounted lower than vehicular signal heads, but not less than 2.5 metres above the street level (National Committee on Uniform Traffic Control, 1998). In the United States, the pedestrian signal head should be mounted between 2.1 metres (7 feet) and 3 metres (10 feet) above street level (FHWA, 2009). The *hand* and *walking pedestrian* displays can be arranged vertically or horizontally. When mounted vertically, the *hand* display should be above the *walking pedestrian* display. When mounted horizontally, the *hand* display should be left of the *walking pedestrian* display. The displays can also be shown overlaid upon each other, with a light source that can separately display each symbol.

A.1.1.7. Accessible Pedestrian Signals

Accessible pedestrian signals (APS) provide redundant information to pedestrians in different forms of communication (i.e., audible tones, speech messages, and/or vibrating surfaces) which coincide with the visual pedestrian signal display. Montufar et al.

(2012b) conducted a review of best practices for the provision of pedestrian crossing control. Some of their findings on accessible pedestrian signals include:

The main functions of APS are to provide information on the:

- Existence and location of the pushbutton
- Beginning of the WALK interval
- Direction of the crosswalk and location of the destination curb ramp
- Intersection street names in Braille, raised print, or through speech messages
- Intersection signalization with speech message
- Intersection geometry through tactile maps and diagrams, or through speech messages

Justification: APS may be justified after a comprehensive engineering study which considers the intersection layout and configuration, pedestrian activity, safety, and demographics, and traffic conditions.

Benefits: APS have been found to reduce crossings beginning during the DON'T WALK interval and increase the amount of crossings completed before the signal interval changes.

Audible Signals

Audible signals are a subset of APS. They provide audible indications that assist pedestrians with vision impairments in crossing the street at locations controlled by traffic signals. The MUTCDC includes a section on the design and application of audible signals (National Committee on Uniform Traffic Control, 1998, p. A6.10):

- Audible signals can be used at locations with complex phasing, where there is a high volume of pedestrians with vision impairments, or where pedestrians with

vision impairments may have navigational difficulties. If available, an official local representative of people with vision impairments should be consulted when deciding if an audible signal is appropriate to install.

- One audible signal should be installed at each terminal. The audible signal should ideally be installed within the crosswalk lines and close to the curb. Audible signals should be pedestrian-activated via pushbuttons whenever possible to minimize the effect of sounds on adjacent properties.
- Separate tones should be used for north-south crossings (cuckoo sound) and east-west crossings (peep-peep sound). Tones should indicate the start of the WALK interval and be emitted during the interval's entire duration. A tone should not be emitted during the other intervals. The MUTCD allows an alert tone to be used to indicate the beginning of the WALK interval when the regular WALK tone is not easily audible in some traffic conditions (FHWA, 2009, p. 506). An alert tone is a very brief burst of high-frequency sound that rapidly decays to the regular WALK tone.

Pedestrian Pushbutton

The following practices are recommended by McMillen et al. (2001) for installing pushbuttons for pedestrian signal actuation:

Location: The pushbutton should be located in an accessible and practical location at the crosswalk. Only one pushbutton should be installed per pole. There should be a clear, manoeuvring space around the pole so that people in wheelchairs can successfully access the pushbutton.

Mount height: The pushbutton should be mounted no higher than 1.1 metres (42 in) above the sidewalk grade so that children, people of short stature, and people in wheelchairs can reach the pushbutton (McMillen, et al., 2001, pp. 6-20). In Canada, the pushbutton is mounted at 1.25 metres above ground level (National Committee on Uniform Traffic Control, 1998).

Mount face: The pushbutton should be mounted on the side of the pole so that it is parallel with the direction of the crosswalk with which it is associated.

Operability: The pushbutton should be operable by people with limited strength and hand function. Pushbuttons activated by conductivity are not usable by pedestrians with prosthetic hands.

A.1.1.8. Pedestrian Countdown Signals

Pedestrian countdown signals provide information to pedestrians on the amount of time (in seconds) remaining to safely complete their crossing (Montufar et al., 2012b). The most widely used pedestrian countdown signal configuration in North America is called the Separate Housing Configuration and is illustrated in Figure A45.

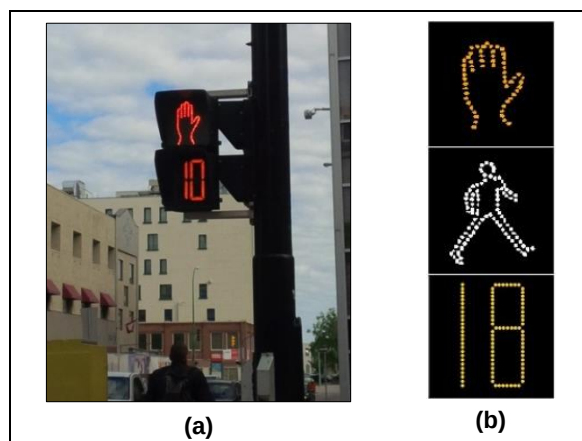


Figure A45: Pedestrian Countdown Signal: (a) Separate Housing Configuration *Photo by A. Campbell;*
(b) Separate Housing Configuration with no overlap

Source: (TOMSC, 2008)

The study conducted by Montufar et al. (2012b) included a review of best practices on the application and installation of pedestrian countdown signals. Some findings from this review include:

Justification: A variety of criteria can be considered in the application of pedestrian countdown signals:

- Location (e.g., proximity to schools, downtown, and public transit)
- Users (e.g., age, volumes, experience, and ethnic diversity)
- Operations (e.g., collision history, turning movements, traffic volume, pedestrian volume, and crossing distance)

Benefits:

- Pedestrian countdown signals do not appear to increase collisions or conflicts and may reduce pedestrian-vehicle conflicts. Collision Modification Factors for when pedestrian countdown signals replace conventional WALK/DON'T WALK signals indicate a reduction in collisions with the installation of pedestrian countdown signals.
- A greater proportion of pedestrians, including the older adults, understand the meaning of pedestrian countdown signals compared to conventional WALK/DON'T WALK signals.
- The influence of pedestrian countdown signals on pedestrian signal compliance is inconsistent. One study found pedestrian countdown signals have an undesirable effect on pedestrian compliance with the WALK indication (Huang & Zegeer, 2001), while another study found statistically significant decreases in the

proportion of non-compliant pedestrians with the installation of pedestrian countdown signals (Kennedy & Sexton, 2009).

Application: Best practices recommend that the countdown is displayed during the pedestrian clearance interval in conjunction with the Flashing DON'T WALK display. The countdown should not be displayed during the WALK interval. The countdown should display the number of seconds remaining to the end of the pedestrian clearance interval, at which point it will reach zero and remain in dark mode until the beginning of the next countdown. Information panels can be provided adjacent to pedestrian pushbuttons to explain to pedestrians how to interpret the countdown signal. Engineers should be mindful that pedestrian countdown signals may raise concerns about equity issues because they do not assist pedestrians with vision impairments.

A.1.2. Geometric Design

The geometric design of pedestrian crossing facilities at signalized intersections includes pedestrian infrastructure connecting to the crosswalk terminal, at the crosswalk terminal, and on the crossing zone over the roadway. These three crosswalk regions are illustrated in Figure A46.

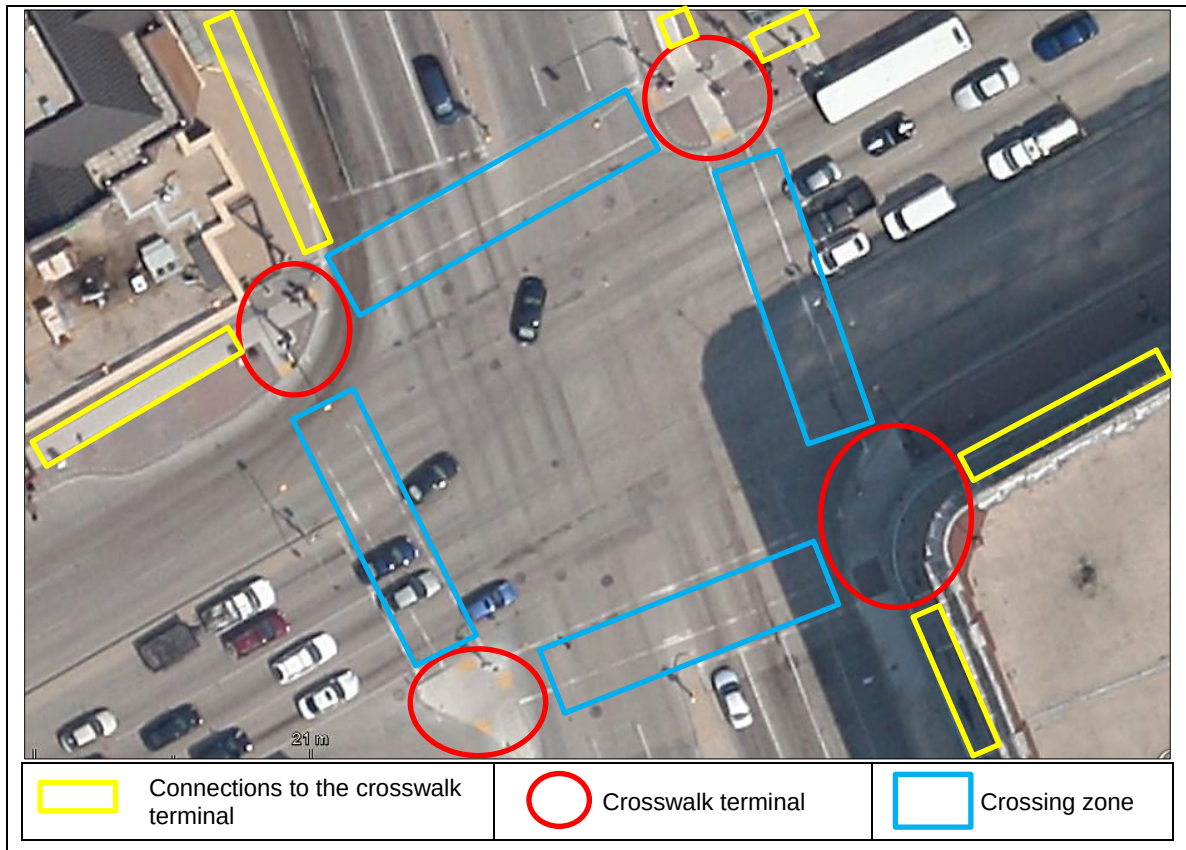


Figure A46: Crosswalk regions
Source: modified from Google Earth

The universal design philosophy is the current best practice approach to accommodating pedestrians on the road network. Universal design aims to create environments that are accessible and usable for all users to the widest extent possible. Best practices recognize that it is the physical and social environment which disables or handicaps a person, and not the person's individual impairment. The impact of a person's impairment can be minimized by designing accessible facilities. Universal design is an improvement on the older, conventional approach to designing for pedestrians, which was based on a "standard pedestrian" represented by the functions and structure of a fit and able-bodied young adult male. The standard pedestrian design approach led to the implementation of pedestrian facilities that were inaccessible for many users, particularly those with vision, hearing, cognitive, and/or mobility impairments.

A.1.2.1. *Connecting to the Crosswalk Terminal*

Providing good sidewalk infrastructure is important so that pedestrians can access the crosswalk terminal and cross the street. McMillen et al (2001) outline some best practices for promoting access on sidewalks:

Clearly defined pedestrian, furniture and frontage zones: Designating space for furniture (e.g., poles, fire hydrants, benches, bus shelters, etc.) and frontage (e.g., signboards, building entrances, etc.) ensures the pedestrian zone will be free of these obstacles.

Wide pathways: The pedestrian zone should be at least 1.5 metres (60 in) wide to allow two pedestrians to pass each other. The width of the pedestrian zone is determined by the anticipated volume of pedestrians. Narrow pathways constrain pedestrian capacity, may force pedestrians to walk in single file or uncomfortably close to buildings and traffic, and may be impassible for people traveling in wheelchairs or with other mobility assistive devices. The pedestrian zone should be increased at terminals to accommodate curb ramps.

Minimal obstacles: Obstacles located within the pedestrian zone may be impassable for pedestrians in wheelchairs or those using other mobility assistive devices and may be undetectable for pedestrians with vision impairments. Removable and protruding obstacles should be removed and relocated from the pedestrian zone. Obstacles should be flush and continuously meet the ground surface so that they can be detectable by people with vision impairments who use canes for guidance.

Minimal protruding objects: Although an obstacle may be grounded in the furniture zone, it could still protrude into the pedestrian zone, such as the phone booth illustrated

in Figure A47. Protruding obstacles are difficult to detect for people with vision impairments.

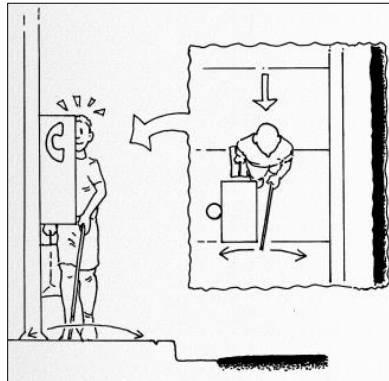


Figure A47: Protruding obstacle struck by pedestrian with vision impairment

Source: (McMillen, et al., 2001, pp. 4-10)

Moderate grades and cross slopes: Grades and cross slopes are difficult for pedestrians with mobility and/or vision impairments to traverse because they require additional physical and navigational efforts. Sidewalk grades should ideally not exceed five percent. Level landings should be installed when grades extend over long distances. Cross slopes are necessary for drainage. Cross slopes in excess of two percent compromise the balance of pedestrians with mobility impairments and are difficult for them to traverse (Figure A48).



Figure A48: Off-balance pedestrian in wheelchair on a cross slope

Source: (McMillen, et al., 2001, pp. 4-21)

Rest areas outside of the pedestrian zone: Providing opportunities for pedestrians to rest is important, particularly for pedestrians with mobility impairments who may need space to regain their composure and strength after physically exerting themselves while traveling. Rest areas can include benches, shelters, drinking fountains, and shade. Rest areas should be provided outside of the pedestrian zone so as not to impede pedestrian flow.

Minimal changes in level: Changes in the level of a sidewalk can be caused by invasive vegetation, settling, heaving, buckling of materials, and uneven transitions between streets, gutters, and curb ramps. Level changes can be tripping hazards, can entrap wheelchair wheels or other mobility assistive devices, and can be impassable for pedestrians with mobility impairments and limited strength.

Firm, stable, and slip-resistant surfaces: Sidewalks should provide a reliable and consistent travel surface for pedestrians. The surface of a sidewalk should not compress or be altered by a pedestrian walking or manoeuvring a wheelchair on it, and should be constructed out of slip-resistant materials, like asphalt or concrete, which do not allow a user's shoe, wheelchair tire, or support of an assistive device to slip when in contact with the surface.

Good lighting: Well-lit sidewalks are beneficial for pedestrians with vision impairments who have difficulty seeing in low-light conditions. Lighting also helps improve pedestrian security, deter crime, and improve pedestrian visibility for drivers at night.

A.1.2.2. *Crossing Terminal*

Pedestrian infrastructure at the crossing terminal consists of curb ramps and landing space for queuing, turning, and maneuvering. Curb ramps assist pedestrians with mobility impairments, particularly those using wheelchairs, to access the crosswalk and

sidewalk. However, they can have negative impacts for pedestrians with vision impairments who rely on the curb for orientation and navigation. Curb ramps should be designed to accommodate people with mobility and vision impairments. McMillen et al (2001) outline some best practices for designing curb ramps:

Landing space: Provide a level manoeuvring area for landing and turning at the top of the curb ramp at sidewalk grade (for perpendicular curb ramps) or at the bottom of the ramp at crosswalk grade (for parallel and diagonal ramps). Landings are critical to allow wheelchair users to manoeuvre on or off of the ramp. Pedestrians continuing along the sidewalk do not have to negotiate a change in surface grade or cross slope when a landing is provided. The minimum curb ramp clear width should be 1.2 metres (48 in) and the minimum landing space dimensions should be 1.2 by 1.2 metres (48 by 48 in). Insufficient landing space can put pedestrians in conflict with traffic (Figure A49).

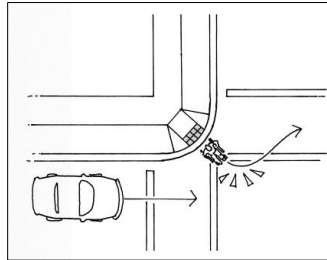


Figure A49: Diagonal curb ramp with insufficient landing space
Source: (McMillen, et al., 2001, pp. 7-9)

Placement: Place the curb ramp within the marked crosswalk area. Pedestrians outside of the marked crosswalk are less likely to be seen by drivers because they are not in an expected location.

Alignment: Align the curb ramp with the crosswalk, so there is a straight path of travel from the top of the ramp to the centre of the roadway and curb ramp at the far sided terminal. This alignment is helpful for people with vision impairments, and for people

using wheelchairs, who often require a straight path of travel to build up momentum before traversing up a curb ramp.

Perpendicular: Design ramp grades to be perpendicular to the curb. Mobility assistive devices are unstable if one side of the device is lower than the other, or if the full base of support (e.g., all four wheels on a wheelchair) is not in complete contact with the surface. This commonly occurs when the bottom of a curb ramp is not perpendicular to the curb (Figure A50).

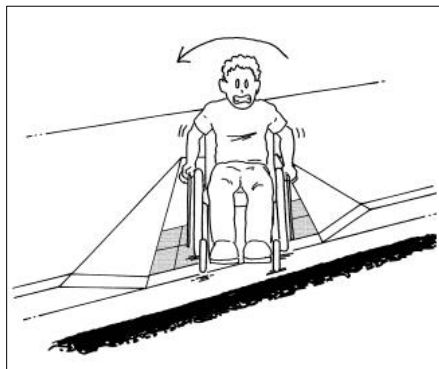


Figure A50: Person in wheelchair unstable on curb ramp that is not perpendicular to the curb

Source: (McMillen, et al., 2001, pp. 7-39)

Distinguishable: Provide a curb ramp grade that can be easily distinguished from surrounding terrain; otherwise, use detectable warnings. Gradual slopes make it difficult for people with vision impairments to detect the presence of curb ramps.

Defined edges: Provide clearly defined and easily identified edges or transitions on both sides of the ramp to contrast with the sidewalk. Clearly defined edges assist users with vision impairments to identify the presence of the ramp when it is approached from the side. Pedestrians may trip on undefined curb ramp edges that are difficult to identify (Figure A51).

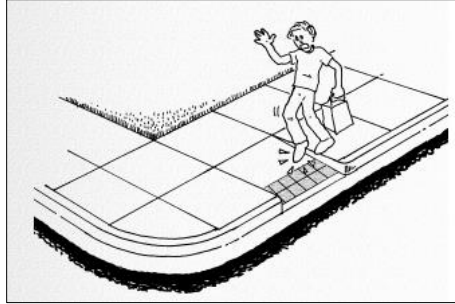


Figure A51: Tripping hazard at edge of unmarked curb located in the pedestrian travel path

Source: (McMillen, et al., 2001, pp. 7-34)

Detectable warning: Clearly identify the boundary between the bottom of the curb ramp and the street with a detectable warning, as illustrated in Figure A52. Detectable warnings help people with vision impairments identify the boundary between the sidewalk and the street. Tactile markings are further discussed in Section A.1.1.3.

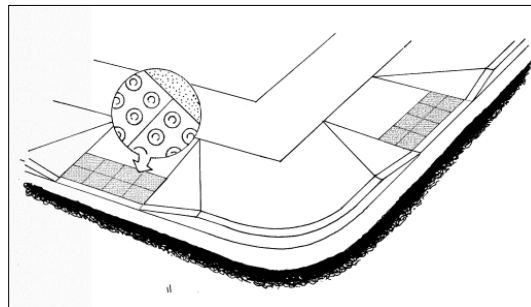


Figure A52: Detectable warning at bottom of curb ramp

Source: (McMillen, et al., 2001, pp. 7-5)

Longitudinal grade: Design the ramp with a grade of 7.1 ± 1.2 percent (do not exceed 8.33 percent or 1:12). Shallow grades are difficult for people with vision impairments to detect but steep grades are difficult for those using assistive devices for mobility.

Grade changes: Avoid changes of grade that exceed 11 percent over a 61 cm (24 in) interval. Severe or sudden grade changes may not provide sufficient clearance for a wheelchair frame, causing the user to tip forward or backward (Figure A53). Grade changes can be caused by asphalt overlays that have not been adequately milled.

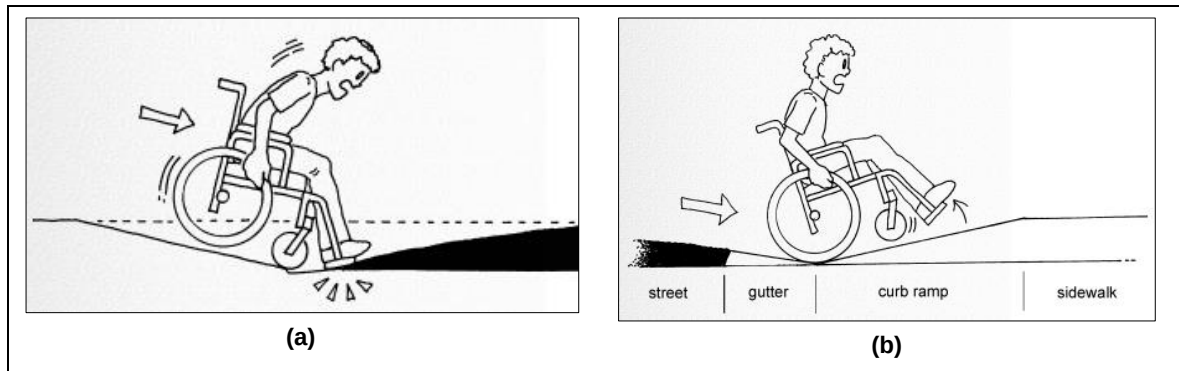


Figure A53: Grade changes between base of curb ramp and gutter/crosswalk: (a) Wheelchair tipping forward at asphalt overlay; (b) Wheelchair tipping backward at gutter;

Source: (McMillen, et al., 2001, pp. 7-30 - 7-31)

Manoeuvring on the curb ramp: Design the curb ramp so that pedestrians are not required to turn or maneuver while on the ramp surface. Maneuvering on a steep grade can be very hazardous for people with mobility impairments.

Flush transitions: Transitions from ramps to gutter and streets should be flush and free of level changes. Maneuvering over any vertical rise such as lips and defects can cause wheelchair users to propel forward when wheels hit this barrier.

Cross-slope: Design the ramp and gutter with a cross slope of two percent. Ramps should have minimal cross slope so users do not have to negotiate a steep grade and cross slope simultaneously.

Drainage: Provide adequate drainage to prevent the accumulation of water or debris on or at the bottom of the ramp. Water, ice, or debris accumulation will decrease the slip resistance of the curb ramp surface (Figure A54).

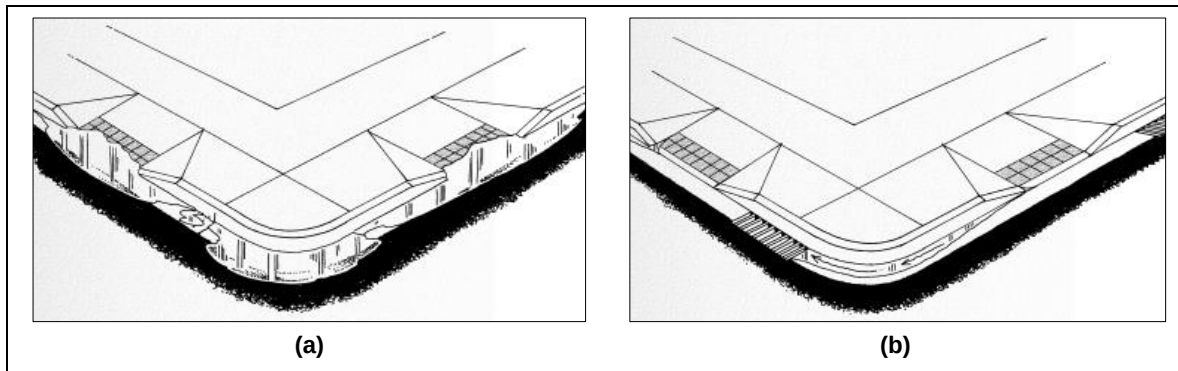


Figure A54: Drainage at base of curb ramps: (a) Pond formation is inconvenient and unsafe for pedestrians; (b) Good drainage with inlets located uphill preventing puddles

Source: (McMillen, et al., 2001, pp. 7-47)

Depressed corners eliminate the need for curb ramps by gradually lowering the intersection corner from the sidewalk grade to the street grade (Figure A55). Depressed corners are not recommended for new construction because they have several disadvantages:

- Large vehicles can encroach on the curb while making tight turns.
- It is difficult for pedestrians with vision impairments, cognitive impairments, and for guide animals to distinguish between the sidewalk and street (Figure A55a).
- Motorists may be encouraged to drive on the sidewalk if the depressed corner is sufficiently large.

To improve pedestrian accessibility and safety at existing depressed corners, measures can be taken to distinguish the separate spaces for pedestrians and vehicles, including the use of detectable warnings, distinct colours, and intermittent barriers like planting boxes and bollards (Figure A55b).

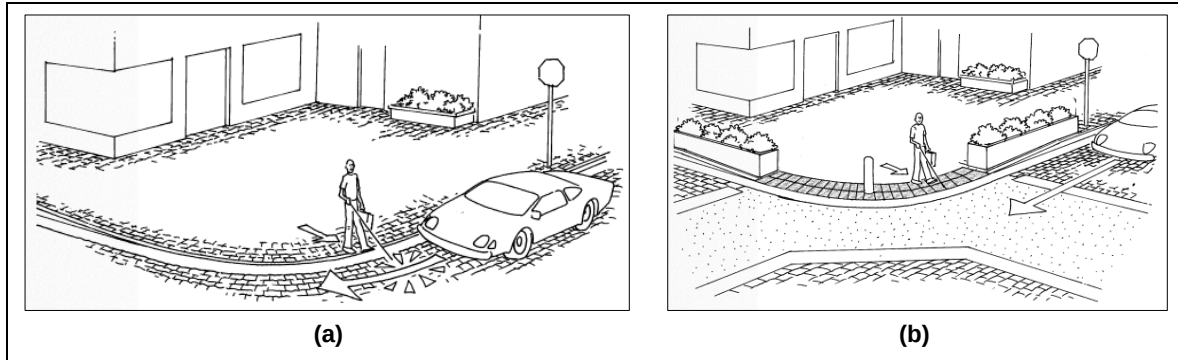


Figure A55: Depressed corners: (a) Potential conflict for pedestrian with vision impairment at depressed curb; (b) Bollard and planting boxes for improved pedestrian accessibility and safety

Source: (McMillen, et al., 2001, pp. 7-17)

A.1.2.3. Crossing Zone

McMillen et al (2001) outline some considerations for designing effective pedestrian crossings:

Crosswalks: Pedestrians should be able to travel within the marked crosswalk area for the entire length of their crossing. Curb extensions reduce crossing distances and increase pedestrian visibility (Figure A56). Raised crosswalks also improve pedestrian visibility. In Canada, the minimum crosswalk width is 2.5 metres (8.2 feet) (National Committee on Uniform Traffic Control, 1998). In the United States, the minimum crosswalk width is 1.8 metres (6 feet) (FHWA, 2009, p. 383).

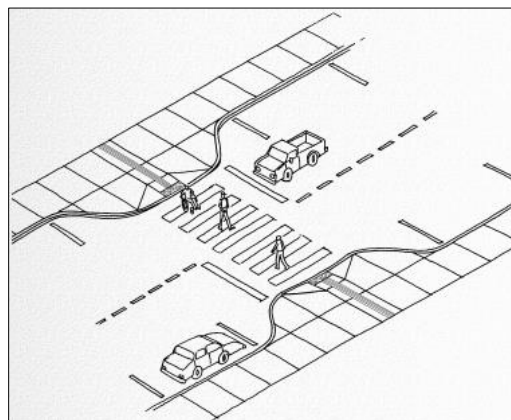


Figure A56: Curb extensions

Source: (McMillen, et al., 2001, pp. 8-6)

Median: Median islands provide refuge for slower pedestrians unable to complete their crossing before the signal phase changes. When provided, medians should be raised to separate pedestrian and vehicular traffic. Medians should be accessible via curb ramps and detectable warnings.

Sight lines: Generous and unobstructed sight lines should be provided for drivers at intersections to allow them ample opportunity to perceive and react to traffic signal indications and crossing pedestrians.

Turning radii: Intersections with smaller turning radii help slow vehicle speeds, decrease crossing distances for pedestrians, and are easier to navigate for pedestrians with vision impairments because there is greater distinction between the differing directions of traffic flow. Turning radii should not be restricted to the point that large vehicles like trucks and buses need to mount the crossing terminal to successfully effect their turn.

Intersection angle: Right-angle intersections are ideal because they are predictable, more easily detectable than skewed intersections, provide a clear and direct path of travel for pedestrians, and offer the clearest sight lines. Skewed intersections increase the crossing distance for pedestrians and require longer pedestrian clearance intervals.

A.2. DOCUMENTED PRACTICES IN COSTA RICA

This section summarizes the documented practices for pedestrian accommodation at signalized intersections in Costa Rica. The key documents consulted for this section were:

- Law 7600 for the Equal Opportunities for Persons with Disabilities (1996)
- The Urban Design Regulations for San Jose (2014)

- The Manual of Highway Geometric Design Standards for Central America (2011)
- The Manual of Uniform Traffic Control Devices for Central America (MUTCDCA) (2000)
- The National Standard in Costa Rica for Signage on Horizontal Surfaces (2008)
- Personal correspondence with transportation engineers from the Ministry of Public Works and Transportation of Costa Rica (MOPT) and from the Road Safety Unit at the National Laboratory of Materials and Structural Models at the University of Costa Rica (LanammeUCR).

A.2.1. Operational Design

The MUTCDCA specifies five basic requirements that every effective traffic control device must meet:

- Fulfill a need
- Command attention
- Convey a clear and simple meaning
- Provide adequate time for a proper response
- Command respect of road users (SIECA, 2000, p. 1.13)

A.2.1.1. *Signage for Pedestrians*

Figure A57 illustrates regulatory signs that can be used to instruct pedestrians at signals to cross only at the signal, to cross only during the green indication, and to operate the pushbutton to receive *green* or the WALK indication. They should be placed near the pedestrian signals, facing pedestrians that wish to cross the street.

 R-11-12 Cross only at the signal	 R-11-13 Press the button to cross	 R-11-14 Cross only with the green light	 R-11-15 Press the button for the green light	 R-11-16 Press the button for the walk indication
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Figure A57: Regulatory pedestrian signs for pedestrian signals

Source: (SIECA, 2000, p. 2.78)

A.2.1.2. Pavement Markings

The MUTCDCA gives specific guidance on the type and application of crosswalk pavement markings (SIECA, 2000, pp. 3.23-3.24). Marked crosswalks should be provided at intersections where:

- Pedestrian and vehicle movements could result in conflicts
- Pedestrian volume is high
- Midblock crossing locations
- In cases where pedestrians may not necessarily recognize the correct width of an unmarked crosswalk

Zebra markings are used at crosswalks with high pedestrian volumes or where it may be difficult for drivers to identify the presence of a pedestrian crossing. The width of each stripe should be between 40 cm and 60 cm (SIECA, 2000, p. 3.24). Crosswalk lines are parallel, straight-line markings that are used when the intersection geometry or the crossing distance demands exact delineation of the crosswalk. Both zebra markings and crosswalk lines should be white. Crosswalk boundaries must be consistently and accurately marked as a safeguard for pedestrians. Two continuous 20 cm wide lanes are

required to demarcate both sides of the crosswalk so as to discourage diagonal crossings. If a stop line is not provided, it is recommended to increase the width of the pedestrian crosswalk line closest to approaching vehicles to 60 cm, particularly where speeds exceed 55 km/hr. Stop lines should be between 30 cm and 45 cm in width and typically located 1.2 metres before the parallel lines of the marked crosswalk (SIECA, 2000, p. 3.23).

A.2.1.3. *Tactile Markings*

The National Standard in Costa Rica for Signage on Horizontal Surfaces specifies the primary purpose of tactile markings is to guide and orientate pedestrians, particularly those with vision impairments (INTECO, 2008). All tactile markings should be yellow and have a distinct texture from the surrounding surface that does not create glare or reflections. They should have a rugged surface with a slip-resistant finish, and should not create a tripping hazard or cause discomfort to travel on. The National Standard regulates the use of detectable warnings and directional surfaces.

Detectable warnings are installed to alert pedestrians with vision impairments of the existence of an obstacle, hazard, change in direction, or presence of an informational element. Detectable warning tiles are covered with truncated domes arranged in a grid pattern. In the roadway environment, detectable warnings can indicate:

- The start or end of directional surfaces
- Branch points in directional surfaces (Figure A58)
- The presence of ramps
- The presence of transit stops, obstacles, and informational elements
- The road boundary

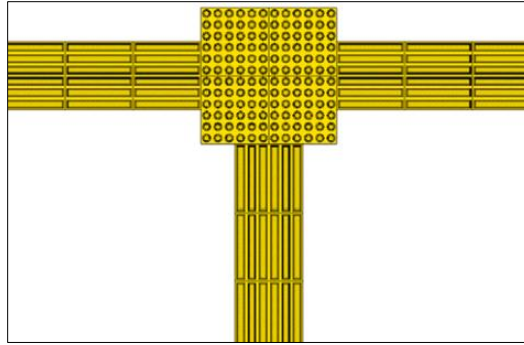


Figure A58: Detectable warnings indicating branch point in strip of directional surfaces

Source: (INTECO, 2008, p. 11)

When indicating the presence of ramps and other obstacles, a minimum one-row strip of detectable warning tiles (each tile at least 30 cm by 40 cm wide) should be placed immediately before the hazard (INTECO, 2008, p. 11). At the border of a curb ramp or pedestrian crosswalk, a strip of detectable warnings should be placed at the start of the flared approaches and at the base of the curb ramp, as illustrated in Figure A59. The size of the curb ramp dictates the amount of tile cover required: the entire curb ramp should be covered with tiles when the curb ramp and sidewalk width is 1.2 m or less (Figure A59a), whereas only a single strip of tiles is required at the base of the ramp when the curb ramp and sidewalk width is greater than 1.2 metres (Figure A59b) (INTECO, 2008, pp. 12-13).

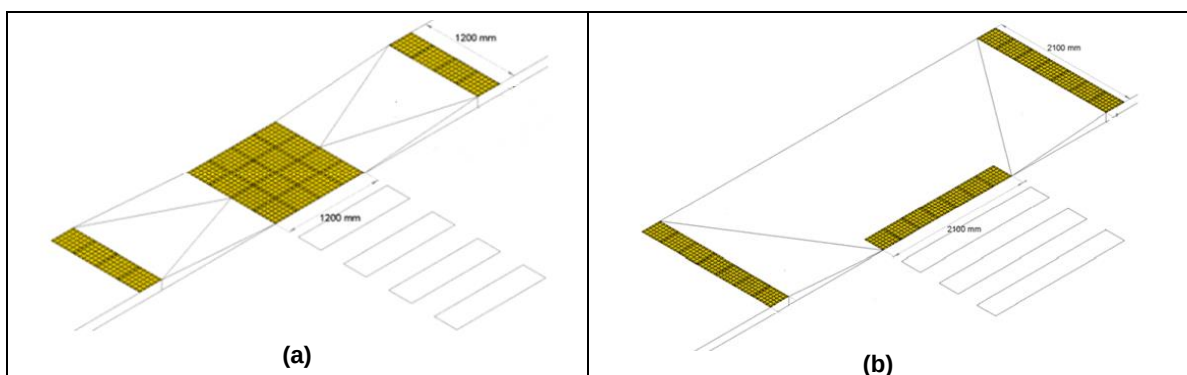


Figure A59: Detectable warnings on curb ramps: (a) Application on ramps 1.2 metres or less in width; (b) Application on ramps greater than 1.2 metres in width

Source: (INTECO, 2008, pp. 12-13)

Directional surfaces must be composed of textured bars which run parallel with the direction of intended travel. Directional tiles should be placed at least 60 cm from hazardous objects (INTECO, 2008, p. 8). It is recommended to install directional surfaces along predictable paths in large spaces where physical elements commonly used for reference are absent, such as in open parks or stations.

A.2.1.4. *Signal Installation Justification*

Comprehensive engineering studies and warrants should be used to determine the need for traffic signals and pedestrian signal heads. The MUTCDCA specifies that a comprehensive traffic engineering study should consider:

- Traffic volumes (entering volumes and classification counts during peak periods)
- Pedestrian volumes during peak periods and by pedestrian age
- 85th percentile speed of traffic
- Intersection configuration
- Locations of adjacent entrances, rail road crossings, and utilities
- Locations of signs, pavement markings, street lighting, bus stops, and bus routes
- Collision history
- Vehicle delays
- Length of gaps on the main road for cross street traffic
- Pedestrian delays (SIECA, 2000, pp. 4.15-4.16)

A traffic signal is warranted when the results of the comprehensive traffic engineering study demonstrate that a traffic signal would improve safety and operations at the site, and if one or more of the following 11 signal justification criteria specified in the MUTCDCA are met:

1. Minimum traffic volume
2. Gaps in major road for minor cross street traffic
3. Minimum pedestrian volume
4. School crosswalks
5. Progressive movement
6. Collisions
7. System conditions
8. Combination of conditions
9. 4 hour volume
10. Peak hour delay
11. Peak hour volume (SIECA, 2000, p. 4.17)

Recommended values within each of these 11 criteria are based on the 1998 MUTCD, but were adjusted to consider Central American conditions and acceptable delay and level of service. Capacities in Central America tend to be higher than capacities in North America because of differences in driver behaviour. Meeting one or more of the above signal justification criteria is not sufficient evidence to justify the installation of a signal. The results of the engineering study must also demonstrate that the installation of a signal would improve safety and operations at the site (SIECA, 2000, p. 4.16).

The third signal justification criteria, which is related to pedestrian activity, considers pedestrian volume, traffic volume, and the minimum time required for a pedestrian to cross the road (gaps). Figure A60 illustrates the minimum pedestrian volume signal justification criteria. The minimum pedestrian and traffic volumes required to justify the installation of a signal are 150 pedestrians per hour and 400 vehicles per hour, respectively. If a pedestrian signal is installed when the pedestrian and traffic volumes

do not justify it, the signal should operate on a semi-actuated basis using a pedestrian pushbutton.

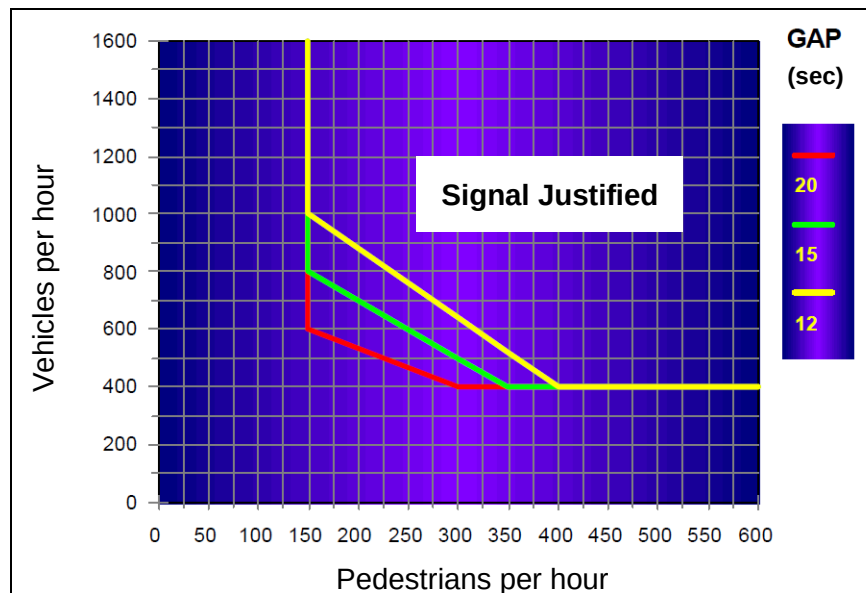


Figure A60: Minimum Pedestrian Volume Signal Justification Criteria

Source: modified from (SIECA, 2000, p. 4.19)

Pedestrian signals are devices installed for the sole purpose of directing pedestrian traffic at intersections controlled by traffic signals (SIECA, 2000, p. 4.27). They provide a crossing phase for pedestrians with separate signal displays and can be installed in areas with high pedestrian volumes or in school zones. Pedestrian signals are warranted if one or more of the following criteria are met:

- The traffic signal was installed because it satisfied the minimum pedestrian volume signal justification criteria.
- An exclusive pedestrian phase is provided for pedestrian movements in one or more directions while all conflicting traffic is held.
- The volume of crossing pedestrians requires restricted use of the right of way to minimize interference with traffic, or to help pedestrians cross safely.

- Pedestrians are permitted to cross a portion of a street during a particular interval but are not permitted to cross the remainder of the street during the same interval (e.g., pedestrians are permitted to cross from the near terminal to a median during a particular interval, but are not permitted to cross from the median to the far terminal during the same interval).
- The presence of heavy vehicles demands a semi-exclusive phase to protect crossing pedestrians.
- Large intersections are too wide or too complicated for the vehicular traffic signal displays to adequately serve pedestrians.
- The minimum green time for vehicles is less than the time required for pedestrians to cross.
- The traffic signal intervals and displays are too confusing to guide pedestrians safely across the intersection.
- Pedestrian movement is permitted on one side of the intersection while traffic is held to protect the turning movements of other vehicles on the other side of the intersection.

A.2.1.5. Pedestrian Signal Intervals and Phasing

Three intervals comprise the pedestrian phase in Costa Rica:

- **WALK:** Pedestrians may enter the crosswalk or road and proceed in the direction of the signal.
- **Flashing WALK:** Pedestrians are not allowed to enter the crosswalk or road in the direction of the signal because it will soon change to the DON'T WALK interval. Pedestrians that are mid-crossing when the Flashing WALK interval is

displayed should accelerate in pace to reach the far terminal or median refuge.

The MUTCDCA specifies that a Flashing DON'T WALK interval can be used instead of the Flashing WALK interval: both have the same meaning, but use different signal displays. A Flashing WALK interval is used in Costa Rica as opposed to a Flashing DON'T WALK interval.

- **DON'T WALK:** Pedestrians are not allowed to enter the crosswalk or road in the direction of the signal.

Under normal conditions, the minimum WALK time must be at least four to seven seconds to ensure pedestrians have the opportunity to complete crossing before the pedestrian clearance interval begins (SIECA, 2000, p. 4.30). However, it is not necessary that the WALK interval be equal or greater than the total time required to cross the full street width because many pedestrians can complete crossing during the pedestrian clearance interval. The length of the pedestrian phase governs at pre-synchronized signals when the minimum WALK and pedestrian clearance time is greater than the required vehicular *green* and vehicular clearance interval. The lengths of the vehicular intervals are adjusted to meet the length requirements of the pedestrian phase.

Pedestrian Clearance Interval

A pedestrian clearance interval must be provided at signalized intersections with pedestrian signals (SIECA, 2000, p. 7.23). The pedestrian clearance interval should consist of the Flashing WALK interval and should be sufficient in length to allow a pedestrian to leave the initial terminal and reach the centre of the furthest lane of the street before conflicting traffic receives *green*, assuming a pedestrian walking speed of 1.2 m/s (SIECA, 2000, p. 4.30). Although not documented in the MUTCDCA, in practice the pedestrian clearance interval also includes the portion of the DON'T WALK interval

which immediately precedes the *green* for conflicting traffic. This portion of the DON'T WALK interval is displayed during the intersection *all-red*.

Staged pedestrian crossing is permitted on streets with centre medians that are at least 1.2 meters wide. Staged pedestrian crossing allows pedestrians to cross from the initial terminal to the central median during the pedestrian clearance interval. Pedestrians complete crossing from the central median to the far terminal during the following pedestrian phase. An additional pedestrian detector is required on the central median if signals are pedestrian actuated.

Walking Speed

The Urban Design Regulations for San Jose were released in February 2014 to replace the former Urban Master Plan Regulations for San Jose from 1999. The former Urban Master Plan Regulations specify that at signalized intersections frequently used by people with impairments, a 1.0 m/s walking speed can be used for signal timing (Municipalidad de San Jose, 1999, p. 48). However, this stipulation was removed in the updated version of this document. Therefore, the current documented practice for pedestrian walking speed is 1.2 m/s from the MUTCDCA.

A.2.1.6. Pedestrian Signal Displays

The MUTCDCA regulates the display, mounting, and visibility of pedestrian signals in Central America.

A *green pedestrian* or *PASE* (PASS) in green text is used to indicate the WALK interval (Figure A61a). A *red pedestrian* or *ALTO* (STOP) in red text is used to indicate the DON'T WALK interval (Figure A61b). A *flashing green pedestrian* or *flashing PASE* in green text is used to indicate the Flashing WALK interval. Pedestrian signal lenses may

be circular or square. Circular lenses must be 20 or 30 cm in diameter and square lenses are typically 20 to 30 cm per side. At crosswalks that are less than 18 metres in length, the symbol should have a minimum height of 23 cm and text should have a minimum height of 10 cm (SIECA, 2000, pp. 4.28 - 4.29).



Figure A61: Typical pedestrian signal displays in Costa Rica: (a) *Standing red person* for DON'T WALK interval; (b) *Walking green person* for WALK interval (flashes during Flashing WALK interval)

The pedestrian signal head should be mounted on the far sided terminal, facing oncoming pedestrians. One pedestrian signal head should be provided for each crossing direction that operates a pedestrian phase. The signal head should be positioned to perpendicularly face crossing pedestrians. Each pedestrian signal head should contain two lenses: one to hold the WALK and Flashing WALK indication, and a second to hold the DON'T WALK indication. The lenses should be arranged vertically, with the DON'T WALK indication above the WALK indication. The pedestrian signal head should be mounted between 2 and 3 metres above street level so that the display is visible to pedestrians. There must be physical separation between pedestrian and vehicular signal heads if they are mounted on the same pole (SIECA, 2000, pp. 4.28-4.29).

Pedestrian signals should attract the attention of all those passing by and should be equally visible in both day and night. The pedestrian signal should be positioned so that

it has maximum visibility for pedestrians at the start of their crossing. Pedestrian signals should be visible from any position three metres before the crosswalk and throughout the entire length of the crosswalk (SIECA, 2000, p. 4.29). Vehicular signals should not be directly visible to pedestrians at the start of the crossing when pedestrian signal heads are mounted on the same pole.

A.2.1.7. Accessible Pedestrian Signals

Pedestrian pushbuttons are used at some signals in Costa Rica. The mount height of the pushbutton should be between 1 m and 1.2 m (SIECA, 2000, p. 4.15). In approximately 2006, the Constitutional Tribunal of Costa Rica decided that audible pedestrian signals must be operated at every signalized pedestrian crosswalk. Since this decision, audible signals have been installed at new signalized intersections that operate pedestrian phases in Costa Rica. Older, existing signalized intersections are being gradually equipped with audible signals. Different sounds are used for east-west crossings and north-south crossings. Most audible signals are actuated by a pedestrian pushbutton, except those that are fully actuated with the vehicular signal. Manuals and regulations specifically discussing the design and application of accessible pedestrian signals in Costa Rica were not identified in this research.

A.2.1.8. Pedestrian Countdown Signals

Pedestrian countdown signals are not currently used in Costa Rica and there are no documented practices for their application.

A.2.2. Geometric Design

The geometric design of pedestrian crossing facilities at signalized intersections includes pedestrian infrastructure connecting to the crosswalk terminal, at the crosswalk terminal, and on the crossing zone over the roadway.

A.2.2.1. *Connecting to the Crosswalk Terminal*

For Central America, sidewalks are recommended on roads with high vehicle and pedestrian volumes and where posted vehicle speeds exceed 60 km/hr (CEPREDENAC and SIECA, 2011). In San Jose, it is the property owner's responsibility, rather than the Municipality's, to construct, reconstruct, and maintain sidewalks in front of their properties. Property owners are responsible for ensuring that vehicles parked within the boundaries of their property do not obstruct pedestrian passage on the sidewalk (Gobierno de Costa Rica, 2014). In practice, this policy results in pedestrian facilities that are inconsistently maintained because each property owner applies a different level of in caring for sidewalks in front of their properties.

Article 10 of the Urban Design Regulations for San Jose specifies the following sidewalk requirements (Municipalidad de San Jose, 1999):

- Concrete is the only material allowed for sidewalk construction. The concrete can be precast and blasted or installed with a slip-resistant finish.
- Sidewalk cross-slope is restricted to a maximum of 3 percent and a minimum of 2 percent.
- The minimum sidewalk width for people with impairments is 1.2 metres.
- Any obstruction (e.g., benches, garbage cans, telephone booths, bus shelters, light poles, railings, safety barriers, etc.) should be installed on the same side of

the sidewalk to assist in ensuring a continuous and unobstructed width of 1.2 metres.

- Vehicular access to the property can be maintained with ramps which occupy no more than 50 cm of the sidewalk. Ramps leading from the sidewalk to the vehicle ramp should not take up more than 30 percent of the sidewalk.
- There should be a minimum space of 3 metres between the vehicular roadway and the sidewalk for street lighting, fire hydrants, phones, and other street services. An additional 60 cm metre strip of green space should be provided between the curb and sidewalk. Sidewalk width should be extended by 60 cm when the sidewalk is flush with the curb and a 60 cm green strip is not supplied.

In addition to the regulations listed above, Law 7600 for the Equal Opportunities for Persons with Disabilities specifies that stairs are not permitted on sidewalks unless accompanied by a ramp and that all ramps should have good water drainage (Centro Nacional de Recursos para la Inclusion Educativa, 1996).

A.2.2.2. Crossing Terminal

Article 10 of the Urban Design Regulations for San Jose specifies the following for ramp requirements:

- Ramps should be installed to provide access for pedestrians with impairments to public spaces, sidewalks, parks, streets, pedestrian overpasses, and plazas.
- The minimum curb ramp width is 1.2 metres.
- The maximum allowed longitudinal gradient is 10 percent.
- Curb ramps should be constructed of the same material as the sidewalk.

- Ramps should be accompanied by a hand rail mounted at 90 cm in height. It is not clear if this regulation applies to both curb ramps and larger ramps used to provide access to a pedestrian overpass or a building entrance.

A.2.2.3. Crossing Zone

The width of the crosswalk is typically governed by the width of the connecting sidewalk; however, crosswalk width should not be less than 1.8 metres (SIECA, 2000, p. 3.24). Median islands can be provided as refuge areas for pedestrians unable to complete their crossing in one signal phase. These refuge areas should not be less than 1.8 metres in width (CEPREDENAC and SIECA, 2011, p. 187). An island can be an area delineated by pavement markings or curbs, and should be easily identifiable for and visible to drivers. Clear sightlines for drivers should be provided so that they can appropriately perceive and react to traffic signals and other demands at the intersection (CEPREDENAC and SIECA, 2011, p. 208). Streets should ideally intersect at right angles: 75 degree intersection angles are generally acceptable, while the maximum allowable intersection angle is 60 degrees (CEPREDENAC and SIECA, 2011, p. 176). Intersection turning radii are determined by applicable design vehicles (CEPREDENAC and SIECA, 2011, p. 177).

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APPENDIX B – PHYSICAL AND OPERATIONAL SITE CONDITIONS

This appendix is related to Chapter 4 and contains the complete inventory of physical and operational site characteristics at all signalized intersections on the study corridor.

Table B31: Inventory of General Site Characteristics

Site	Signal type	Approach w/ xwalk	Xwalk angle	Xslope	Longitudinal grade	Surface condition ¹	North Terminal				South Terminal			
							Illumination	Outer lanes	Obstacles	Sightline obstructions	Illumination	Outer lanes	Obstacles	Sightline obstructions
1	Vehicle intersection	West	90	Level	Level	3	Yes	No activity	Tree	Tree	Yes	Buses	None	None
2	Vehicle intersection	East	70	Level	Level	2	Yes	Taxis	None	Taxis	Yes	Taxis, buses	Trees, poles, grates	Trees, poles, fence
3	Vehicle intersection	West	90	Level	Level	2	Yes	No activity	None	Trees	Yes	No activity	None	None
4	Vehicle intersection. Signal primarily serves pedestrians	West	90	Med.	Level	3	Yes	Taxis	None	Taxis, vendor structure	Yes	Taxis	Poles, vendor tables	Taxis
5	Vehicle intersection. Signal primarily serves pedestrians	East	90	Med.	Level	3	Yes	No activity	Vendor tables and umbrellas	Vendor tables and umbrellas	Yes	Taxis, loading	Vendors	Vendors
6	Vehicle intersection	No marked xwalk	90	Med.	Level	2	Yes	No activity	Vendors	Vendors, poles, vendor structure	Yes	Taxis	None	Taxis, vendors
7	Vehicle intersection	West	90	Med.	Level	2	Yes	No activity	None	Vendor structure	Yes	Taxis, buses	None	Taxis, buses
8	Vehicle intersection	West	90	Minor	Level	3	Yes	No activity	Vendor structure	Vendor structure	Yes	Buses	Vendor	None
9	Vehicle intersection	West	90	Minor	Level	2	Yes	Parking	Pole	Pole, trash can	Yes	Taxis	Vendors	Vendors, taxis, trash can
10	Vehicle intersection	West	90	Med.	Level	3	Yes	Loading	None	Vendor structure	Yes	Buses	Grates	Buses
11	Vehicle intersection	West	90	Level	Level	2	Yes	Parking	Vendors	Vendor structure, pole, building column supports	Yes	Taxis	Vendors	Vendor structure, taxis
12	Pedestrian mall	Central	90	Level	Level	3	Yes	Loading	Curbs on pedestrian mall	Phone booths	Yes	Taxis	Taxis, vendors	Taxis, vendors
13	Vehicle intersection	West	90	Med.	Level	2	Yes	Loading	Vendor, pole	Loading	Yes	Taxis	None	Poles
14	Vehicle intersection	West	90	Level	Level	3	Yes	Loading	Pole, handrail, fire hydrant	Loading, pole, fire hydrant	Yes	Taxis	Vendor structure, pole	Vendor structure
15	Pedestrian mall	Central	90	Level	Level	3	Yes	Loading, parking	Chain	Parking	Yes	Buses, taxis	None	Buses

Table B31 continued...

Site	Signal type	Approach w/ xwalk	Xwalk angle	Xslope	Longitudinal grade	Surface condition ¹	North Terminal				South Terminal			
							Illumination	Outer lanes	Obstacles	Sightline obstructions	Illumination	Outer lanes	Obstacles	Sightline obstructions
16	Vehicle intersection	West	90	Steep	Level	3	Yes	Loading	None	Trees, pole	Yes	Taxis	Poles, vendor	Vendor structure, taxis
17	Vehicle intersection	West	90	Med.	Level	3	Yes	Parking	None	Parking	Yes	Taxis	Vendor	Vendor structure, taxis
18	Vehicle intersection	West	90	Level	Level	3	Yes	Loading	None	Loading	Yes	Taxis, loading	Vendor, decorative structure	Vendor structure, taxis
19	Vehicle intersection	West	90	Level	Level	3	Yes	No activity	None	None	Yes	Buses	None	Buses
20	Pedestrian mall	Central	90	Med.	Level	2	Yes	Parking	None	None	Yes	Buses	Train tracks	Buses

Table B32: Inventory of Signs

Site	North Terminal						South Terminal					
	Xwalk warning sign				Street recognition		Xwalk warning sign				Street recognition	
	Present	Condition ²	Directed to traffic	Sightline obstructions	Present	Location	Present	Condition ²	Directed to traffic	Sightline obstructions	Present	Location
1	No	n/a	n/a	n/a	Yes	Post-mounted	No	n/a	n/a	n/a	Yes	Post-mounted
2	No	n/a	n/a	n/a	Yes	Post-mounted	No	n/a	n/a	n/a	Yes	Post-mounted
3	No	n/a	n/a	n/a	No	n/a	No	n/a	n/a	n/a	Yes	Post-mounted
4	No	n/a	n/a	n/a	Yes	Wall-mounted on corner building	No	n/a	n/a	n/a	No	n/a
5	Yes - "Zona de Seguridad"	2	Facing east	No	No	n/a	No	n/a	n/a	n/a	No	n/a
6	No	n/a	n/a	n/a	Yes	Wall-mounted on corner building	No	n/a	n/a	n/a	Yes	Wall-mounted on corner building
7	No	n/a	n/a	n/a	Yes	Post-mounted	No	n/a	n/a	n/a	Yes	Post-mounted
8	No	n/a	n/a	n/a	Yes	Wall-mounted on corner building	No	n/a	n/a	n/a	Yes	Wall-mounted on corner building
9	No	n/a	n/a	n/a	Yes	Wall-mounted on corner building	No	n/a	n/a	n/a	Yes	Wall-mounted on corner building
10	No	n/a	n/a	n/a	Yes	Post-mounted	No	n/a	n/a	n/a	Yes	Post-mounted
11	No	n/a	n/a	n/a	Yes	Wall-mounted on corner building	No	n/a	n/a	n/a	Yes	Wall-mounted on corner building
12	No	n/a	n/a	n/a	No	n/a	No	n/a	n/a	n/a	Yes	Post-mounted
13	No	n/a	n/a	n/a	Yes	Post-mounted	No	n/a	n/a	n/a	Yes	Post-mounted
14	No	n/a	n/a	n/a	Yes	Wall-mounted on corner building	No	n/a	n/a	n/a	Yes	Wall-mounted on corner building
15	No	n/a	n/a	n/a	Yes	Post-mounted	No	n/a	n/a	n/a	Yes	Wall-mounted on corner building
16	No	n/a	n/a	n/a	No	n/a	No	n/a	n/a	n/a	Yes	Post-mounted
17	No	n/a	n/a	n/a	Yes	Post-mounted	No	n/a	n/a	n/a	Yes	Post-mounted
18	No	n/a	n/a	n/a	Yes	Post-mounted	No	n/a	n/a	n/a	Yes	Post-mounted
19	No	n/a	n/a	n/a	Yes	Post-mounted	No	n/a	n/a	n/a	Yes	Post-mounted
20	No	n/a	n/a	n/a	No	n/a	No	n/a	n/a	n/a	Yes	Post-mounted

Table B33: Inventory of Pavement Markings

Site	Zebra Markings					Stop line				
	Present	Condition ³	Extend full xwalk length	Stripe width (m)	Stripe length (m)	Present	Condition ³	Extends across all relevant lanes	Width (m)	Distance to edge of xwalk (m)
1	Yes	3	Yes	0.57	3.97	Yes	2	Yes	0.40	1
2	Yes	2	Yes	0.80	4	Yes	2	Yes	0.42	1.2 – 3.3 (angled xwalk)
3	Yes	2	Yes	0.74	4	Yes	3	Yes	0.42	1.6
4	Yes	2	Yes	0.76	7	Yes	3	Yes	0.40	11.7
5	Yes	3	Yes	0.73	7	Yes	3	Yes	0.40	n/a – stop line is at Site 4 on west approach of intersection
6	No	n/a	n/a	n/a	n/a	Yes	3	Yes	0.50	n/a
7	Yes	2	Yes	0.76	3	Yes	2	Yes	0.39	2.45
8	Yes	2	Yes	0.79	4	Yes	3	Yes	0.40	2
9	Yes	2	Yes	0.78	4	Yes	3	Yes	0.42	2
10	Yes	3	Yes	0.75	4	Yes	3	Yes	0.41	2
11	Yes	3	Yes	0.61	3.97	Yes	3	Yes	0.41	1.97
12	Yes	3	Yes	0.76	5	Yes	3	Yes	0.41	2
13	Yes	3	Yes	0.44	4	Yes	3	Yes	0.42	2
14	Yes	3	Yes	0.76	4	Yes	3	Yes	0.39	2
15	Yes	3	Yes	0.75	5	Yes	3	Yes	0.45	3.75
16	Yes	3	Yes	0.77	3.9	Yes	3	Yes	0.37	2
17	Yes	2	Yes	0.76	4	Yes	2	Yes	0.40	2
18	Yes	2	Yes	0.62	4	Yes	3	Yes	0.39	3
19	Yes	2	No – not in southern-most lane	0.76	4.3	Yes	2	No – not in southern-most lane	0.40	2
20	Yes	1	Yes	0.77	6	Yes	1	Yes	0.40	11.2

Table B34: Inventory of Pedestrian Signal Head Location, Visibility and Configuration

Site	North Terminal								South Terminal							
	Pole offset ⁴ (m)	Mount height (m)	Visible for entire xwalk	Perpendicular to crosswalk	Vertically positioned	DON'T WALK above WALK	Visors present	Pushbutton present	Pole offset ⁴ (m)	Mount height (m)	Visible for entire xwalk	Perpendicular to crosswalk	Vertically positioned	DON'T WALK above WALK	Visors present	Pushbutton present
1	1.5	2.4	Yes	No	Yes	Yes	Yes	No	2.75	2.37	Yes	Yes	Yes	Yes	Yes	No
2	4	2.4	Yes	Yes	Yes	Yes	Yes	No	3.1	2.45	Yes	Yes	Yes	Yes	Yes	No
3	-4.5	2.3	Yes	Yes	Yes	Yes	Yes	No	2.13	2.6	Yes	Yes	Yes	Yes	Yes	No
4	3.45	2.55	Yes	Yes	Yes	Yes	Yes	No	3.85	2.5	Yes	Yes	Yes	Yes	Yes	No
5	3.9	2.5	Yes	Yes	Yes	Yes	Yes	No	0	2.6	Yes	Yes	Yes	Yes	Yes	No
7	-3.6	2.95	Yes	Yes	Yes	Yes	Yes	No	-0.9	2.66	Yes	Yes	Yes	Yes	Yes	No
8	-0.7	2.6	Yes	Yes	Yes	Yes	Yes	No	2.0	3.0	Yes	Yes	Yes	Yes	Yes	No
9	-1.0	2.3	Yes	Yes	Yes	Yes	Yes	No	0	2.33	Yes	Yes	Yes	Yes	Yes	No
10	0	2.65	Yes	Yes	Yes	Yes	Yes	No	0	2.84	Yes	Yes	Yes	Yes	Yes	No
11	-0.15	2.96	Yes	Yes	Yes	Yes	Yes	No	0	2.6	Yes	Yes	Yes	Yes	Yes	No
12	9.75	2.45	No	No	Yes	Yes	Yes	No	12.55	2.64	No	No	Yes	Yes	Yes	No
13	-1.9	2.9	Yes	Yes	Yes	Yes	Yes	No	3.6	2.61	Yes	Yes	Yes	Yes	Yes	No
14	-0.85	2.65	Yes	Yes	Yes	Yes	Yes	No	2.7	2.95	Yes	Yes	Yes	Yes	Yes	No
15	-8.6	2.43	Yes	Yes	Yes	Yes	Yes	No	-8.6	2.44	Yes	Yes	Yes	Yes	Yes	No
16	-0.52	2.88	Yes	Yes	Yes	Yes	Yes	No	-1.38	2.66	Yes	Yes	Yes	Yes	Yes	No
17	0	2.64	Yes	Yes	Yes	Yes	Yes	No	-3.0	2.9	Yes	Yes	Yes	Yes	Yes	No
18	2.06	2.81	Yes	Yes	Yes	Yes	Yes	No	2.5	2.9	Yes	Yes	Yes	Yes	Yes	No
19	-0.4	2.91	Yes	Yes	Yes	Yes	Yes	No	0	2.53	Yes	Yes	Yes	Yes	Yes	No
20	-2.06	2.28	Yes	Yes	Yes	Yes	Yes	Yes	-2.4	2.6	Yes	Yes	Yes	Yes	Yes	Yes
* See Figure 1 for description of																

¹ Surface condition qualitatively evaluated based on the presence of cracking, pavement deterioration, rutting, and unevenness as:

1. Poor surface condition
2. Acceptable surface condition with some damage
3. Good surface condition with negligible or no damage

² Sign condition qualitatively evaluated as:

1. Poor: Sign is severely bent and not directed towards traffic
Sign has severe graffiti that blocks the meaning of the sign
Retro-reflectivity properties are severely compromised and the sign is not likely visible during the night
2. Okay: Sign is bent but still directed towards traffic
Sign has graffiti but the meaning of the sign is still clear
Retro-reflectivity properties compromised, but the sign is still likely visible during the night
3. Good: Sign is not bent and is directed towards traffic
Sign has no graffiti
Retro-reflectivity properties of the sign are in good condition

³ Pavement marking condition qualitatively evaluated as:

1. Poor: Markings present but extremely worn and barely visible
Underlying pavement more visible than pavement markings
Pavement markings likely not visible during the night
2. Okay: Moderate wearing of pavement markings
Some underlying pavement is visible
Pavement markings likely visible during the night
3. Good: Pavement markings in perfect condition
No underlying pavement is visible
No wearing

⁴ Pole offset

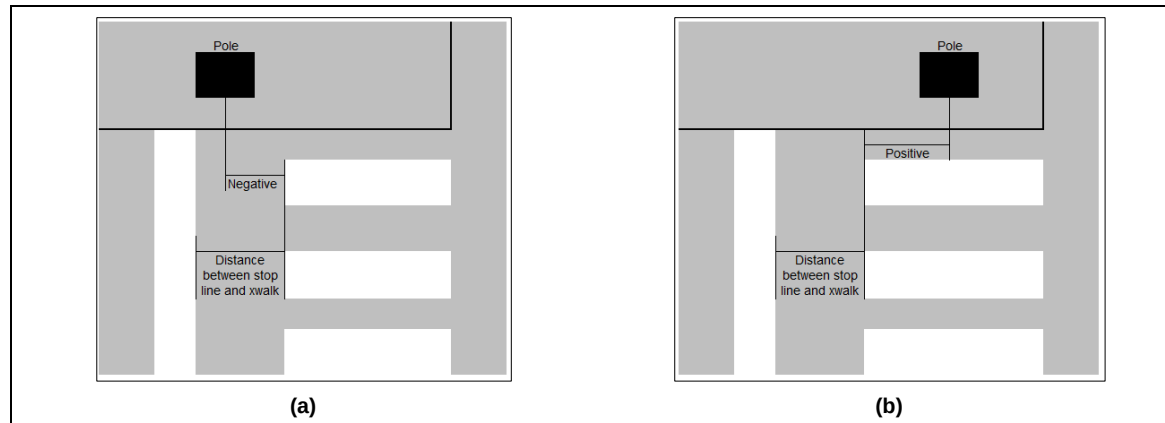


Figure 62: Pedestrian signal pole offset measurements: (a) Negative distance when located towards approach; (b) Positive distance when located towards intersection

Table B35: Inventory of Pedestrian Signal Display and Condition

Site	North Terminal							South Terminal						
	WALK	Flashing Walk	DON'T WALK	WALK condition	DON'T WALK condition	Lens shape	Lens size (cm)	WALK	Flashing Walk	DON'T WALK	WALK condition	DON'T WALK condition	Lens shape	Lens size (cm)
1	Green person, walking position	Flashing green person, walking position	Red ball	Poor	Poor	Circle	22	Green person, walking position	Flashing green person, walking position	Red person, standing position LED	Poor	Good	Circle	30
2	Dynamic green person walking LED	Dynamic green person running LED	Red person, standing position LED	Good	Good	Circle	22	Green person, walking position	Flashing green person, walking position	Red person, standing position LED	Good	Good	Circle	30
3	Dynamic green person walking LED	Dynamic green person running LED	Red person, standing position LED	Good	Good	Circle	30	Green person, walking position	Flashing green person, walking position	Red person, standing position	Poor	Poor	Circle	30
4	Green person, walking position	Flashing green person, walking position	Red person, standing position	Poor	Poor	Circle	30	Green person, walking position	Flashing green person, walking position	Red person, standing position	Poor	Poor	Circle	30
5	Green person, walking position	Flashing green person, walking position	Red ball	Poor	Poor	Circle	30	Green person, walking position	Flashing green person, walking position	Red person, standing position	Poor	Poor	Circle	30
6	Pedestrian signal not present													
7	Green person, walking position	Flashing green person, walking position	Red person, standing position	Poor	Poor	Circle	30	Green person, walking position	Flashing green person, walking position	Red person, standing position	Poor	Poor	Circle	30
8	Green person, walking position	Flashing green person, walking position	Red person, standing position	Poor	Poor	Circle	30	Green person, walking position	Flashing green person, walking position	Red person, standing position	Poor	Poor	Circle	30
9	Green person, walking position	Flashing green person, walking position	Red person, standing position	Poor	Poor	Circle	30	Green person, walking position	Flashing green person, walking position	Red person, standing position	Poor	Poor	Circle	30

1 Surface condition qualitatively evaluated based on the presence of cracking, pavement deterioration, rutting, and unevenness as:

4. Poor surface condition
5. Acceptable surface condition with some damage
6. Good surface condition with negligible or no damage

² Sign condition qualitatively evaluated as:

4. Poor: Sign is severely bent and not directed towards traffic
Sign has severe graffiti that blocks the meaning of the sign
Retro-reflectivity properties are severely compromised and the sign is not likely visible during the night
5. Okay: Sign is bent but still directed towards traffic
Sign has graffiti but the meaning of the sign is still clear
Retro-reflectivity properties compromised, but the sign is still likely visible during the night
6. Good: Sign is not bent and is directed towards traffic
Sign has no graffiti
Retro-reflectivity properties of the sign are in good condition

³ Pavement marking condition qualitatively evaluated as:

4. Poor: Markings present but extremely worn and barely visible
Underlying pavement more visible than pavement markings
Pavement markings likely not visible during the night
5. Okay: Moderate wearing of pavement markings
Some underlying pavement is visible
Pavement markings likely visible during the night
6. Good: Pavement markings in perfect condition
No underlying pavement is visible
No wearing

⁴ Pole offset

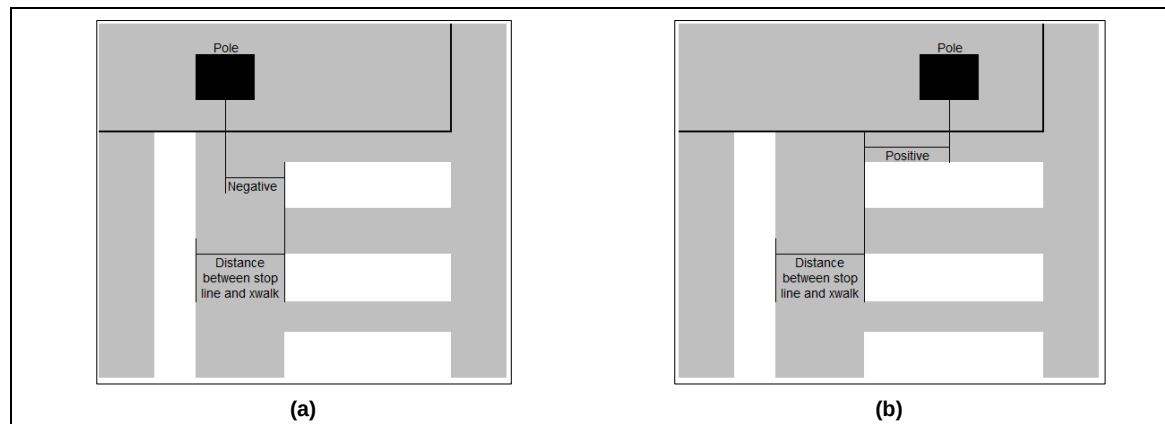


Figure 62: Pedestrian signal pole offset measurements: (a) Negative distance when located towards approach; (b) Positive distance when located towards intersection

Table B35 continued...

Site	North Terminal							South Terminal						
	WALK	Flashing Walk	DON'T WALK	WALK condition	DON'T WALK condition	Lens shape	Lens size (cm)	WALK	Flashing Walk	DON'T WALK	WALK condition	DON'T WALK condition	Lens shape	Lens size (cm)
10	Green person, walking position	Flashing green person, walking position	Red person, standing position LED	Poor	Good	Circle	30	Green person, walking position	Flashing green person, walking position	Red person, standing position	Poor	Poor	Circle	30
11	Green person, walking position	Flashing green person, walking position	Red ball LED	Poor	Good	Circle	30	Green person, walking position	Flashing green person, walking position	Red person, standing position	Poor	Poor	Circle	30
12	Green person, walking position	Flashing green person, walking position	Red person, standing position	Poor	Poor	Circle	30	Green person, walking position	Flashing green person, walking position	Red person, standing position	Poor	Poor	Circle	30
13	Green person, walking position	Flashing green person, walking position	Red person, standing position	Poor	Poor	Circle	30	Green person, walking position	Flashing green person, walking position	Red person, standing position	Poor	Poor	Circle	30
14	Green person, walking position	Flashing green person, walking position	Red person, standing position	Poor	Poor	Circle	30	Green person, walking position	Flashing green person, walking position	Red person, standing position LED	Poor	Good	Circle	30
15	Green person, walking position	Flashing green person, walking position	Red ball LED	Poor	Good	Circle	30	Green person, walking position	Flashing green person, walking position	Red ball	Poor	Poor	Circle	30
16	Green person, walking position	Flashing green person, walking position	Red person, standing position	Poor	Poor	Circle	30	Green person, walking position	Flashing green person, walking position	Red person, standing position	Poor	Poor	Circle	30

17	Green person, walking position	Flashing green person, walking position	Red person, standing position	Poor	Poor	Circle	30	Green person, walking position	Flashing green person, walking position	Red person, standing position	Poor	Poor	Circle	30
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1 Surface condition qualitatively evaluated based on the presence of cracking, pavement deterioration, rutting, and unevenness as:

7. Poor surface condition
8. Acceptable surface condition with some damage
9. Good surface condition with negligible or no damage

² Sign condition qualitatively evaluated as:

7. Poor: Sign is severely bent and not directed towards traffic
Sign has severe graffiti that blocks the meaning of the sign
Retro-reflectivity properties are severely compromised and the sign is not likely visible during the night
8. Okay: Sign is bent but still directed towards traffic
Sign has graffiti but the meaning of the sign is still clear
Retro-reflectivity properties compromised, but the sign is still likely visible during the night
9. Good: Sign is not bent and is directed towards traffic
Sign has no graffiti
Retro-reflectivity properties of the sign are in good condition

³ Pavement marking condition qualitatively evaluated as:

7. Poor: Markings present but extremely worn and barely visible
Underlying pavement more visible than pavement markings
Pavement markings likely not visible during the night
8. Okay: Moderate wearing of pavement markings
Some underlying pavement is visible
Pavement markings likely visible during the night
9. Good: Pavement markings in perfect condition

No underlying pavement is visible
No wearing

⁴ Pole offset

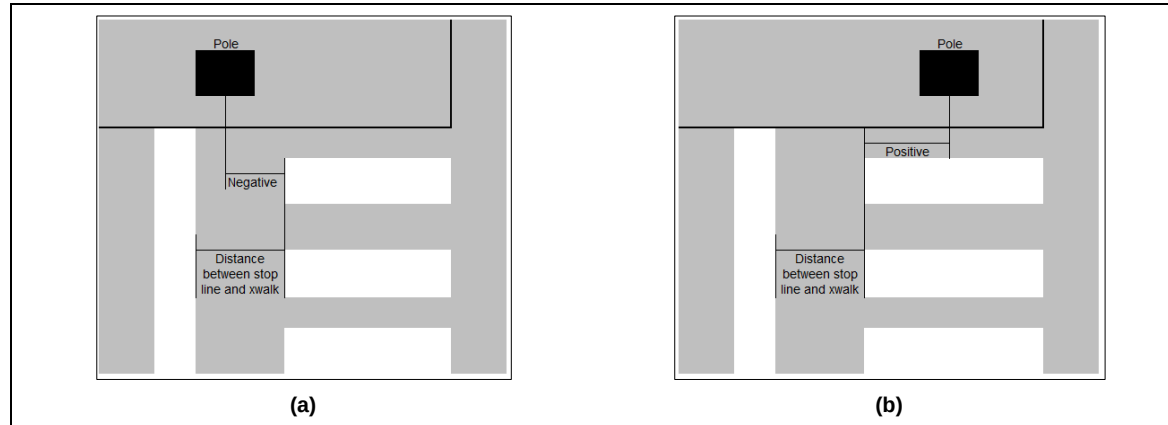


Figure 62: Pedestrian signal pole offset measurements: (a) Negative distance when located towards approach; (b) Positive distance when located towards intersection

Table B35 continued...

Site	North Terminal							South Terminal						
	WALK	Flashing Walk	DON'T WALK	WALK condition	DON'T WALK condition	Lens shape	Lens size (cm)	WALK	Flashing Walk	DON'T WALK	WALK condition	DON'T WALK condition	Lens shape	Lens size (cm)
18	Green person, walking position	Flashing green person, walking position	Red person, standing position	Poor	Poor	Circle	30	Green person, walking position	Flashing green person, walking position	Red person, standing position	Poor	Poor	Circle	30
19	Green person, walking position	Flashing green person, walking position	Red person, standing position LED	Poor	Good	Circle	30	Green person, walking position	Flashing green person, walking position	Red person, standing position	Poor	Poor	Circle	30
20	Green person, walking position	Flashing green person, walking position	Red person, standing position	Poor	Poor	Circle	30	Green person, walking position	Flashing green person, walking position	Red person, standing position	Poor	Poor	Circle	30

Table B36: Inventory of Curb Ramps

Site	North Terminal										South Terminal									
	Ramp	Direction	Aligned w/south terminal curb ramp	Within xwalk	Width (m)	Grade	Upward Grade	Gap (cm)	Curb height (cm)	Road height (cm)	Ramp	Direction	Aligned w/north terminal curb ramp	Within xwalk	Width (m)	Grade	Upward Grade	Gap (cm)	Curb height (cm)	Road height (cm)
1	Yes	Along xwalk	No	No	1.2	Min.	No	0	-	-	Yes	Along xwalk	No	Yes	1.2	Level	No	0	-	-
2	Yes	Along xwalk	n/a	Yes	1.2	Med.	Yes	0	-	-	No	n/a	n/a	n/a	n/a	n/a	n/a	0	20	-
3	Yes	Along xwalk	Yes	Yes	2.7	Med.	No	0	-	-	Yes	Along xwalk	Yes	Yes	1.17	Med.	Yes	0	-	-
4	Yes	Along xwalk	Yes	Yes	1.4	Min.	No	0	-	-	Yes	Along xwalk	Yes	Yes	1.4	Min.	No	0	-	-
5	Yes	Centre of intersection	No	Yes	1.6	Steep	Yes	0	-	-	Yes	Along xwalk	No	Yes	1.65	Min.	No	0	-	-
6	No	n/a	n/a	n/a	n/a	n/a	n/a	n/a	20	-	No	n/a	n/a	n/a	n/a	n/a	n/a	n/a	20	-
7	Yes	Centre of intersection	No	Yes	1.3	Steep	No	0	-	-	Yes	Centre of intersection	No	Yes	0.95	Min.	No	0	-	-
8	Depressed corner	Centre of intersection	No	Yes	4.1	Min.	Yes	0	-	-	Yes	Parallel ramp	No	Yes	1.25	Med.	No	0	-	-
9	No	n/a	n/a	n/a	n/a	n/a	n/a	n/a	20	-	No	n/a	n/a	n/a	n/a	n/a	n/a	n/a	20	-
10	Yes	Centre of intersection	n/a	Yes	0.84	Med.	Yes	72	0	7	No	n/a	n/a	n/a	n/a	n/a	n/a	40	18	5
11	Yes	Along xwalk	Yes	Yes	1.07	Med.	Yes	50	0	7	Yes	Along xwalk	Yes	Yes	0.94	Med.	Yes	15	0	2
12	Yes	Into traffic lanes	No	No	1.2	Med.	Yes	55	0	4	Depressed corner	Along xwalk	No	Yes		n/a	n/a	n/a	-	-
13	Yes	Into traffic lanes	No	No	2.1	Min.	Yes	50	0	9	Yes	Along xwalk	No	No	1.2	Med.	Yes	56	0	7
14	Yes	Along xwalk	No	Yes	1.22	Level	No	50	-	-	Yes	Along xwalk	No	Yes	1.5	Med.	Yes	20	0	15
15	Yes	Into traffic lanes	Yes	No	1.2	Med.	Yes	47	0	9	Yes	Into traffic lanes	Yes	No	1.13	Med.	Yes	40	0	10
16	No	n/a	n/a	n/a	n/a	n/a	n/a	50	15	13	No	n/a	n/a	n/a	n/a	n/a	n/a	50	18	0
17	Yes	Into traffic lanes	No	No	0.95	Med.	Yes	58	0	17	Yes	Along xwalk	No	No	1.17	Med.	Yes	30	-	17
18	Yes	Along xwalk	Yes	Yes	Yes	Med.	Yes	40	-	16	Yes	Along xwalk	Yes	Yes	1.3	Min.	No	50	-	-
19	Yes	Centre of intersection	n/a	Yes	1.22	Level	No	50	-	-	No	n/a	n/a	n/a	n/a	n/a	n/a	65	20	13
20	Depressed corner	Along xwalk	Yes	Yes	n/a	Level	No	0	-	-	Depressed corner	Along xwalk	Yes	Yes	n/a	Level	No	n/a	-	-

Table B37: Inventory of Audible Signals and Tactile Markings

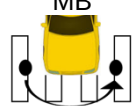
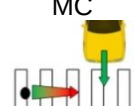
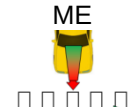
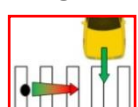
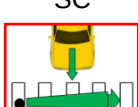
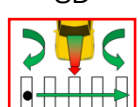
Site	North Terminal								South Terminal							
	Audible signal					Tactile Markings			Audible signal					Tactile Markings		
	Present	Direction	Start of WALK	Start of Flashing WALK	Start of DON'T WALK	Indicate presence of intersection	Directional surface from sidewalk to terminal	Fully consistent with National Standard	Present	Direction	Start of WALK	Start of Flashing WALK	Start of DON'T WALK	Detectable warnings indicate xwalk	Directional surface on sidewalk	Fully consistent with National Standard
1	No	n/a	n/a	n/a	n/a	Yes	Yes	Yes	Yes	Mounted behind signal head, directed along xwalk but also down to terminal	Begins	Quickens	Stops	Yes	Yes	Yes
2	No	n/a	n/a	n/a	n/a	Yes	Yes	Yes	Yes	Downward and along xwalk	Begins	Quickens	Stops	Yes	Yes	No
3	Yes	Downward and along xwalk	Begins	Quickens	Stops	No	Yes	No	No	n/a	n/a	n/a	n/a	Yes	Yes	No
4	No	n/a	n/a	n/a	n/a	Yes	Yes	Yes	Yes	Along xwalk	Begins	Quickens	Stops	No	Yes	No
5	Yes	Along xwalk	Begins	Quickens	Stops	Yes	No	No	No	n/a	n/a	n/a	n/a	No	Yes	No
6	Pedestrian signal not present					Yes	No	No	Pedestrian signal not present					Yes	Yes	No
7	No	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Yes	Along xwalk	Begins	Quickens	Stops	n/a	n/a	n/a
8	No	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Yes	Down to terminal	Begins	Quickens	Stops	n/a	n/a	n/a
9	No	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Yes	Along xwalk	Begins	Quickens	Stops	n/a	n/a	n/a
10	No	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Yes	Centre of intersection	Begins	Quickens	Stops	n/a	n/a	n/a
11	No	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Yes	Along xwalk	Begins	Quickens	Stops	n/a	n/a	n/a
12	No	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Yes	Along xwalk	Begins	Quickens	Stops	n/a	n/a	n/a
13	No	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Yes	Along xwalk	Begins	Quickens	Stops	n/a	n/a	n/a
14	No	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Yes	Along xwalk and towards intersection	Begins	Quickens	Stops	n/a	n/a	n/a
15	No	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Yes	Along xwalk	Begins	Quickens	Stops	n/a	n/a	n/a
16	No	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Yes	Along xwalk	Begins	Quickens	Stops	n/a	n/a	n/a
17	No	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Yes	Down to terminal	Begins	Stops	No	Yes	No	No
18	No	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Yes	Along xwalk	Begins	Stops	No	No	Yes	No

Table B37 continued...

Site	North Terminal								South Terminal							
	Audible signal					Tactile Markings			Audible signal					Tactile Markings		
	Present	Direction	Start of WALK	Start of Flashing WALK	Start of DON'T WALK	Detectable warnings indicate xwalk	Directional surface on sidewalk	Fully consistent with National Standard	Present	Direction	Start of WALK	Start of Flashing WALK	Start of DON'T WALK	Detectable warnings indicate xwalk	Directional surface on sidewalk	Fully consistent with National Standard
19	Yes	Down to terminal	Begins	Quickens	Stops	n/a	n/a	n/a	No	n/a	n/a	n/a	n/a	n/a	n/a	n/a
20	Yes	Down to terminal	Begins	Quickens	Stops	n/a	n/a	n/a	No	n/a	n/a	n/a	n/a	n/a	n/a	n/a

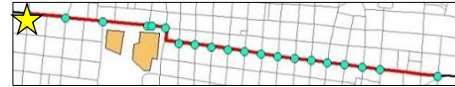
APPENDIX C – SITE SAFETY PROFILES

Appendix C is related to Chapter 5. This appendix contains the pedestrian compliance and pedestrian conflict data collection forms, and summarizes the pedestrian safety performance results for each site on the study corridor.

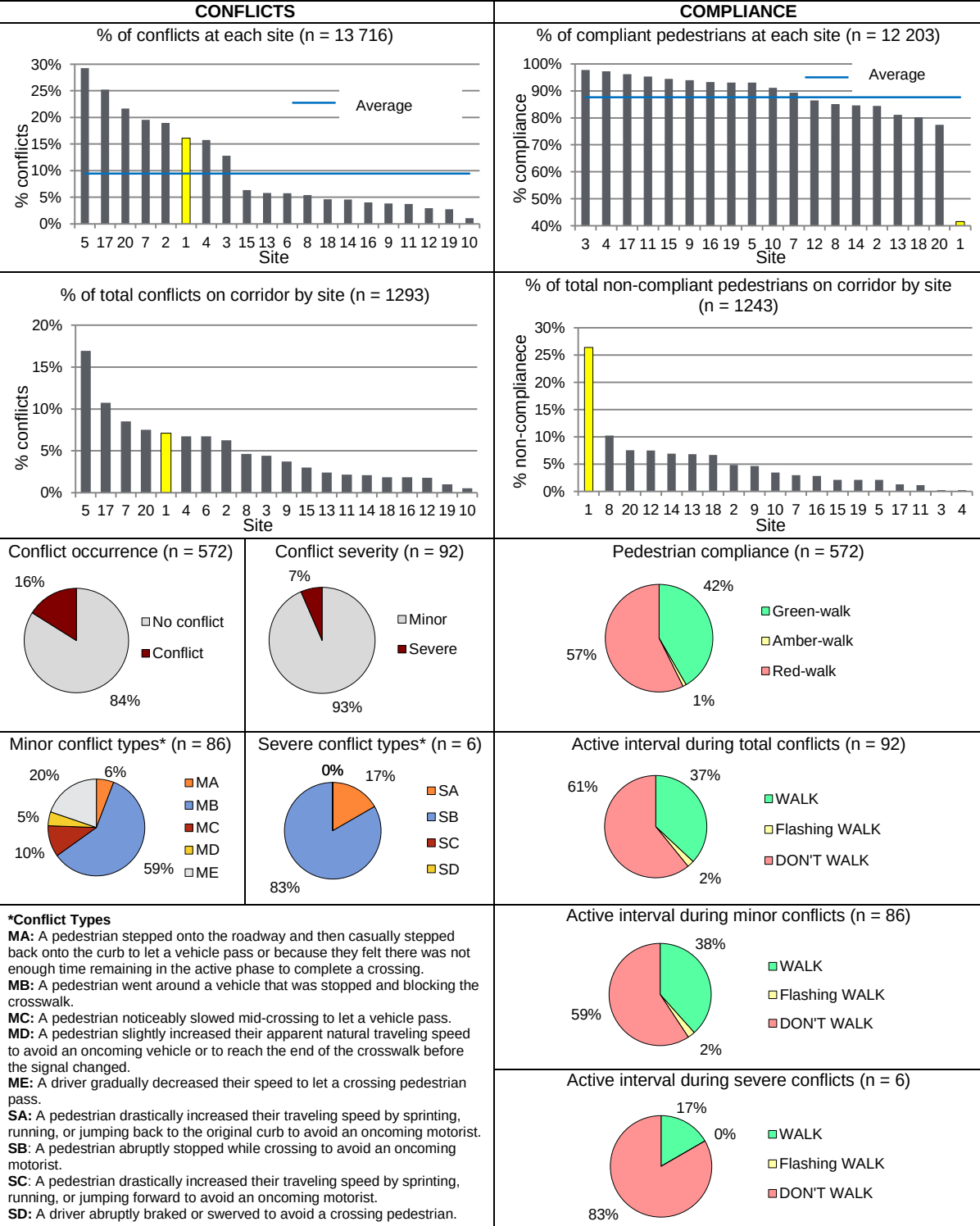
Pedestrian Conflict Data Collection Form							
Site #		Start time					
Date		End time					
Weather		Duration (hours)					
Conflict		Male			Female		
		WALK	Flashing WALK	DON'T WALK	WALK	Flashing WALK	DON'T WALK
Minor	MA 						
	MB 						
	MC 						
	MD 						
	ME 						
Severe	SA 						
	SB 						
	SC 						
	SD 						

Pedestrian Compliance Data Collection Form						
Site #		Start time				
Date		End time				
Weather		Duration (hours)				
Direction of Pedestrian travel						
Cycle	Signal Indication					
	WALK		Flashing WALK		DON'T WALK	
	Total	Female	Total	Female	Total	Female
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
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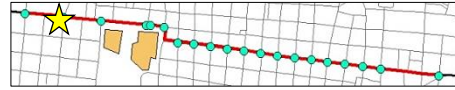
Site 1 (Paseo Colon & Calle 28)



Data collection date(s) and time(s):	T Nov 13, 9:55-11:30; W Nov 21, 9:00-11:00; TR Nov 22, 9:30-10:50
Duration of total data collection:	4.9 hr
Weather:	Cloudy 23; Sunny 28; Sunny 28
Pedestrians observed:	572

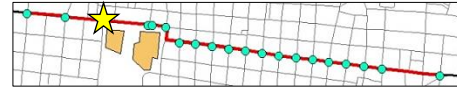


Site 2 (Paseo Colon & Calle 24)

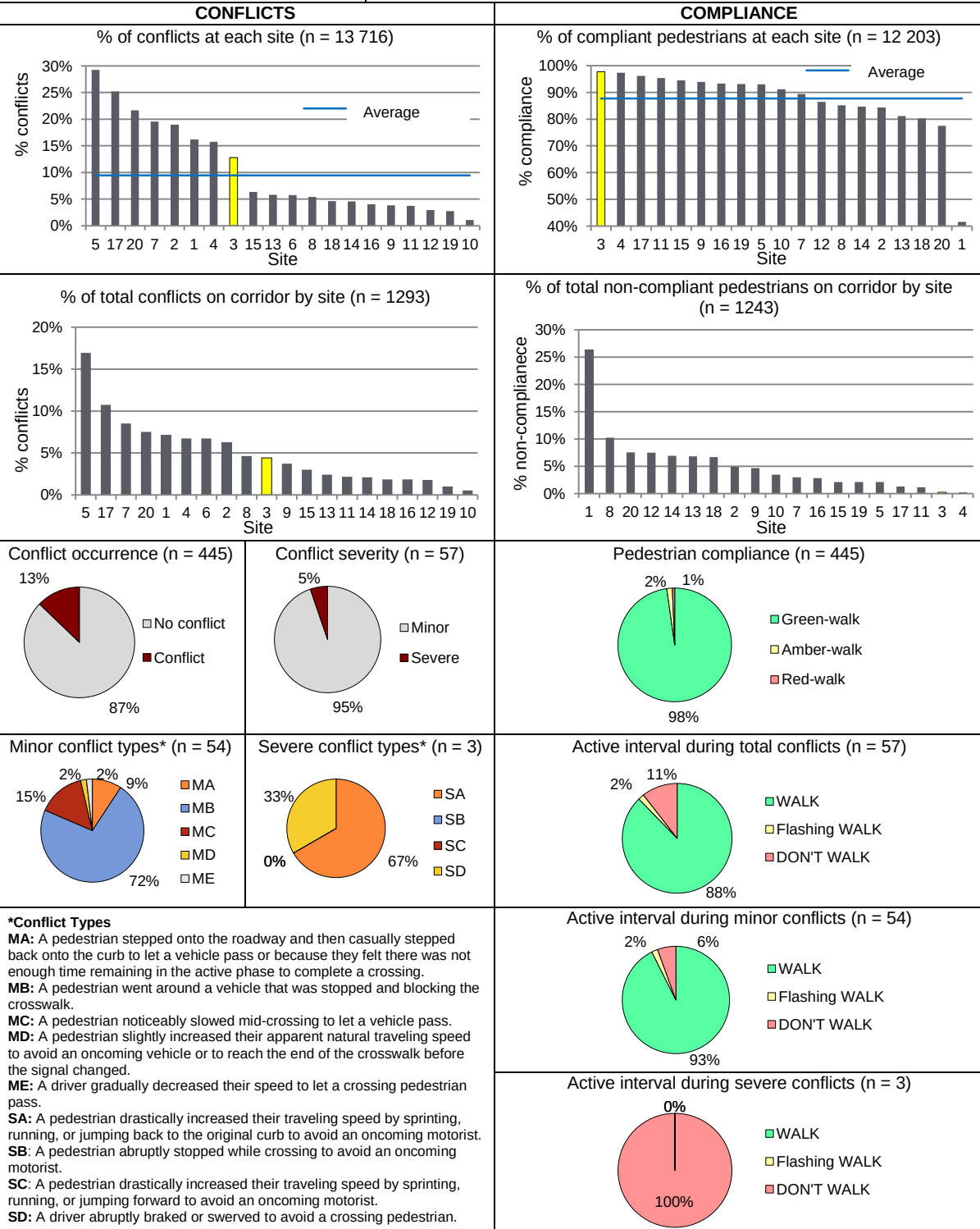


Data collection date(s) and time(s):		T Oct 29, 9:40 – 11:30; TR Nov 7, 11:00 – 11:30	
Duration of total data collection:		2.3 hr	
Weather:		Sunny 25; Sunny 28	
Pedestrians observed:		430	
CONFLICTS		COMPLIANCE	
% of conflicts at each site (n = 13 716)		% of compliant pedestrians at each site (n = 12 203)	
% of total conflicts on corridor by site (n = 1293)		% of total non-compliant pedestrians on corridor by site (n = 1243)	
Conflict occurrence (n = 430)	Conflict severity (n = 81)	Pedestrian compliance (n = 430)	
Minor conflict types* (n = 80)	Severe conflict types* (n = 1)	Active interval during total conflicts (n = 81)	
*Conflict Types MA: A pedestrian stepped onto the roadway and then casually stepped back onto the curb to let a vehicle pass or because they felt there was not enough time remaining in the active phase to complete a crossing. MB: A pedestrian went around a vehicle that was stopped and blocking the crosswalk. MC: A pedestrian noticeably slowed mid-crossing to let a vehicle pass. MD: A pedestrian slightly increased their apparent natural traveling speed to avoid an oncoming vehicle or to reach the end of the crosswalk before the signal changed. ME: A driver gradually decreased their speed to let a crossing pedestrian pass. SA: A pedestrian drastically increased their traveling speed by sprinting, running, or jumping back to the original curb to avoid an oncoming motorist. SB: A pedestrian abruptly stopped while crossing to avoid an oncoming motorist. SC: A pedestrian drastically increased their traveling speed by sprinting, running, or jumping forward to avoid an oncoming motorist. SD: A driver abruptly braked or swerved to avoid a crossing pedestrian.		Active interval during minor conflicts (n = 80)	
		Active interval during severe conflicts (n = 1)	

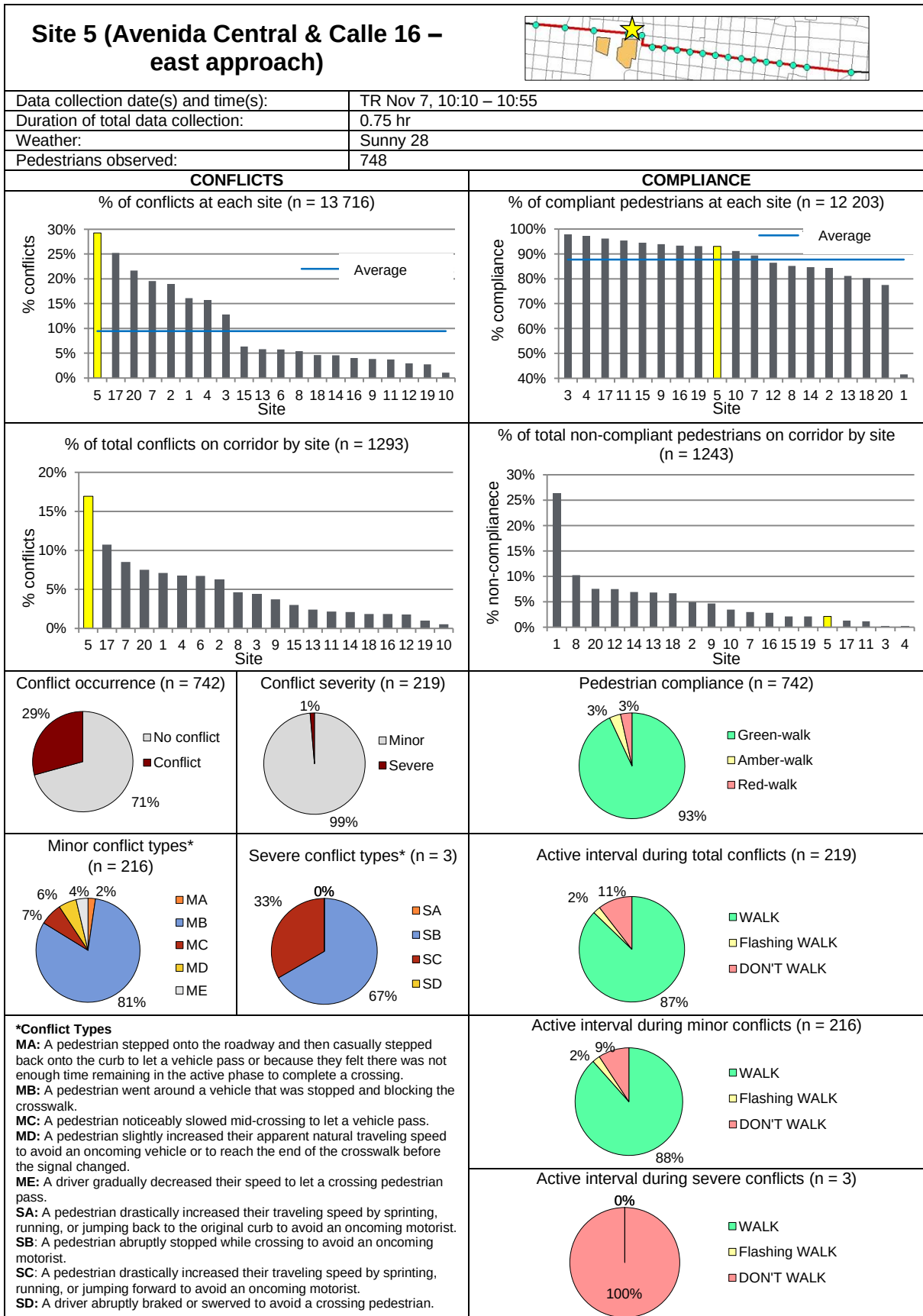
Site 3 (Avenida Central & Calle 20)



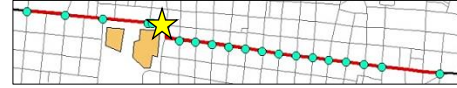
Data collection date(s) and time(s):	M Nov 25, 9:30 – 10:50
Duration of total data collection:	1.3 hr
Weather:	Sunny 23
Pedestrians observed:	445



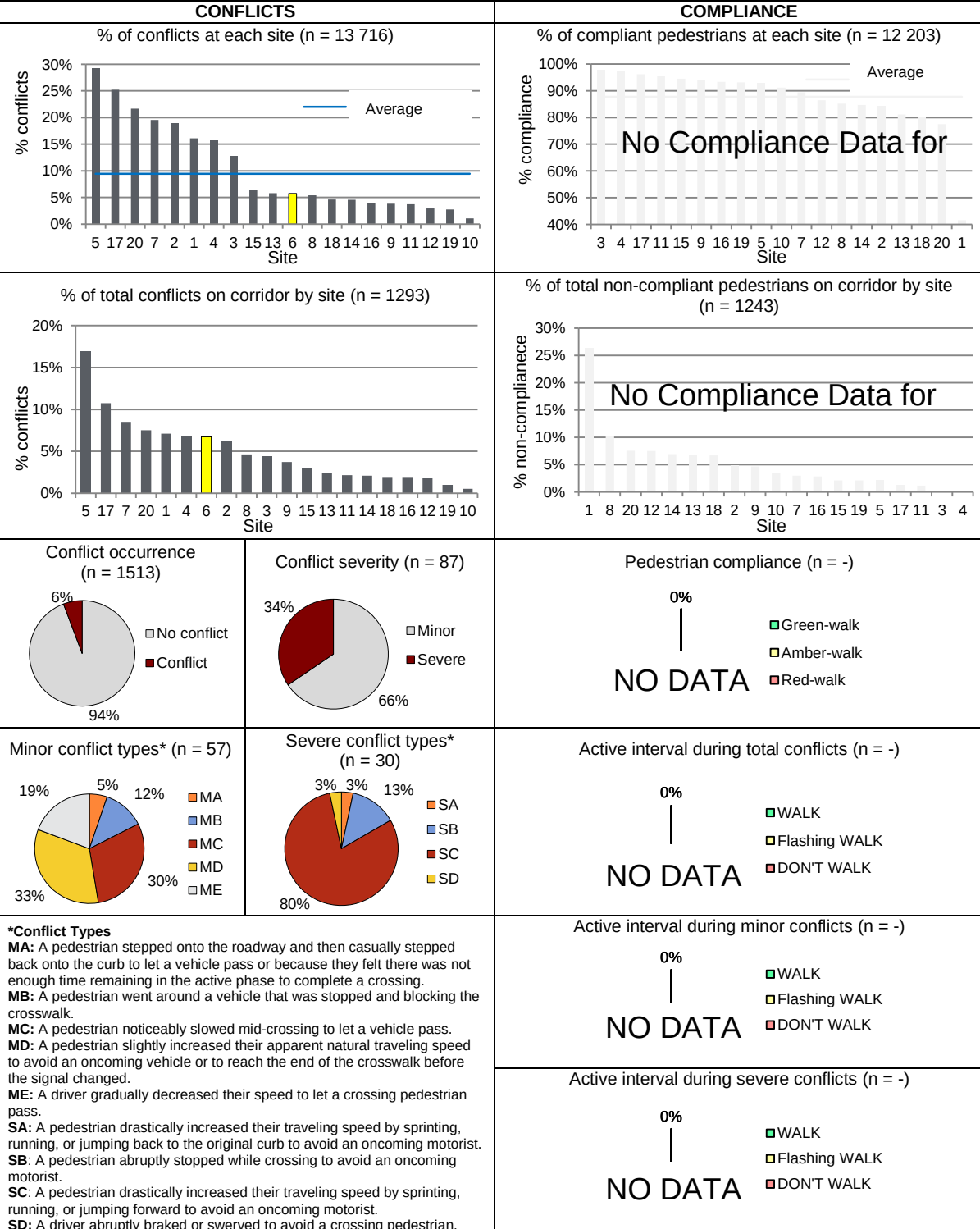




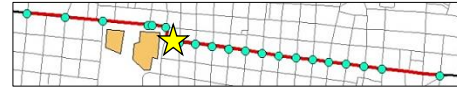
Site 6 (Avenida Central & Calle 14)



Data collection date(s) and time(s):	T Nov 26, 9:30 – 11:30
Duration of total data collection:	2 hr
Weather:	Sunny 28
Pedestrians observed:	1513

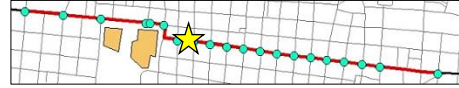


Site 7 (Avenida Segunda & Calle 12)

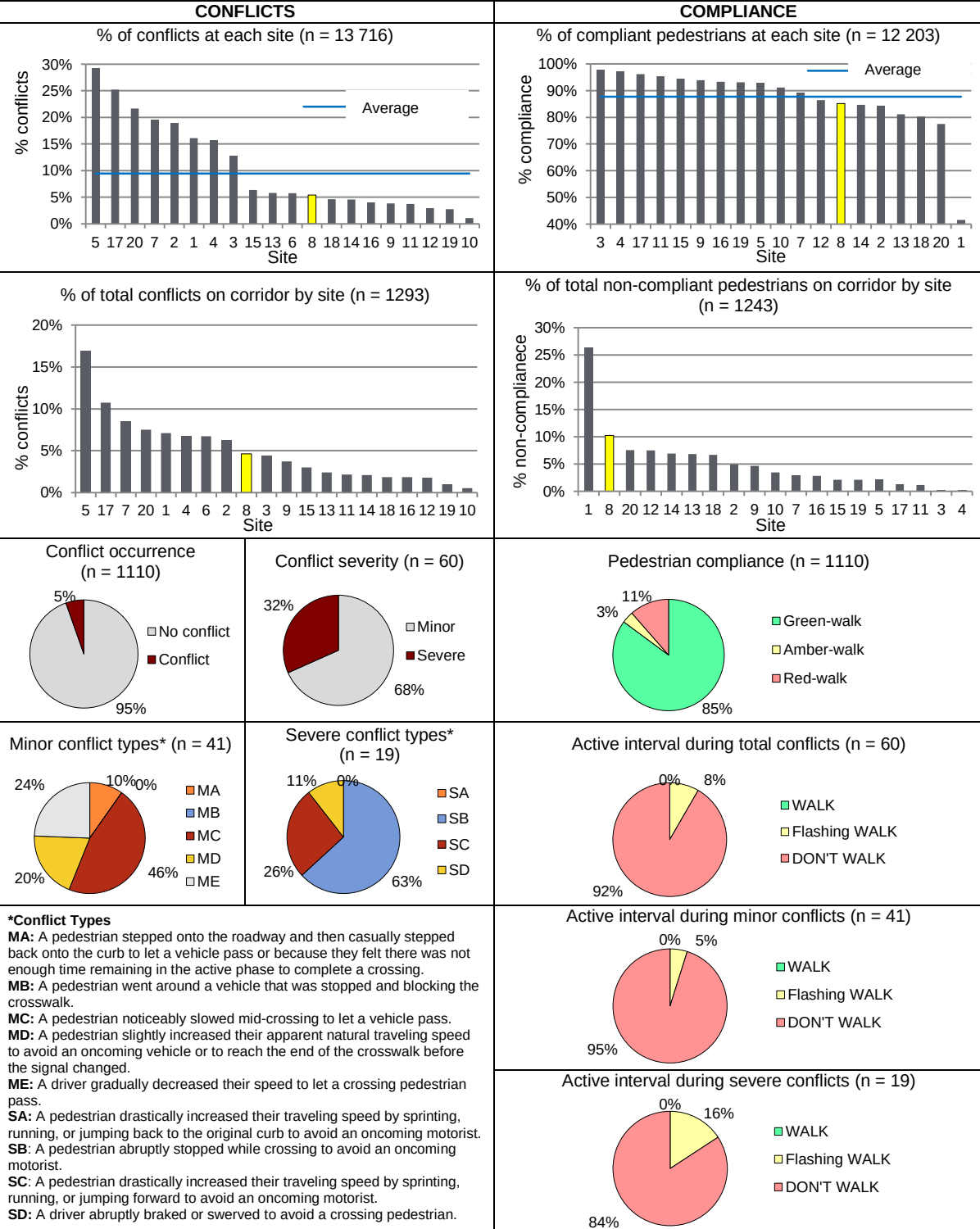


Data collection date(s) and time(s):		T Nov 5, 9:25 – 10:15																																																																																			
Duration of total data collection:		0.8 hr																																																																																			
Weather:		Sunny 30																																																																																			
Pedestrians observed:		563																																																																																			
CONFLICTS		COMPLIANCE																																																																																			
% of conflicts at each site (n = 13 716) <table><thead><tr><th>Site</th><th>% conflicts</th></tr></thead><tbody><tr><td>5</td><td>28%</td></tr><tr><td>17</td><td>25%</td></tr><tr><td>20</td><td>22%</td></tr><tr><td>7</td><td>20%</td></tr><tr><td>2</td><td>18%</td></tr><tr><td>1</td><td>16%</td></tr><tr><td>4</td><td>15%</td></tr><tr><td>3</td><td>12%</td></tr><tr><td>15</td><td>6%</td></tr><tr><td>13</td><td>5%</td></tr><tr><td>6</td><td>5%</td></tr><tr><td>8</td><td>5%</td></tr><tr><td>18</td><td>4%</td></tr><tr><td>14</td><td>4%</td></tr><tr><td>16</td><td>4%</td></tr><tr><td>9</td><td>3%</td></tr><tr><td>11</td><td>3%</td></tr><tr><td>12</td><td>2%</td></tr><tr><td>19</td><td>2%</td></tr><tr><td>10</td><td>1%</td></tr></tbody></table>		Site	% conflicts	5	28%	17	25%	20	22%	7	20%	2	18%	1	16%	4	15%	3	12%	15	6%	13	5%	6	5%	8	5%	18	4%	14	4%	16	4%	9	3%	11	3%	12	2%	19	2%	10	1%	% of compliant pedestrians at each site (n = 12 203) <table><thead><tr><th>Site</th><th>% compliance</th></tr></thead><tbody><tr><td>3</td><td>95%</td></tr><tr><td>4</td><td>95%</td></tr><tr><td>17</td><td>95%</td></tr><tr><td>11</td><td>95%</td></tr><tr><td>15</td><td>95%</td></tr><tr><td>9</td><td>95%</td></tr><tr><td>16</td><td>95%</td></tr><tr><td>19</td><td>95%</td></tr><tr><td>5</td><td>95%</td></tr><tr><td>10</td><td>95%</td></tr><tr><td>7</td><td>90%</td></tr><tr><td>12</td><td>88%</td></tr><tr><td>8</td><td>88%</td></tr><tr><td>14</td><td>88%</td></tr><tr><td>2</td><td>88%</td></tr><tr><td>13</td><td>88%</td></tr><tr><td>18</td><td>88%</td></tr><tr><td>20</td><td>88%</td></tr><tr><td>1</td><td>88%</td></tr></tbody></table>		Site	% compliance	3	95%	4	95%	17	95%	11	95%	15	95%	9	95%	16	95%	19	95%	5	95%	10	95%	7	90%	12	88%	8	88%	14	88%	2	88%	13	88%	18	88%	20	88%	1	88%
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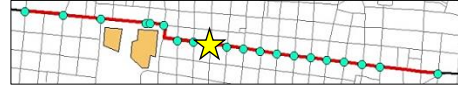
Site 8 (Avenida Segunda & Calle 10)



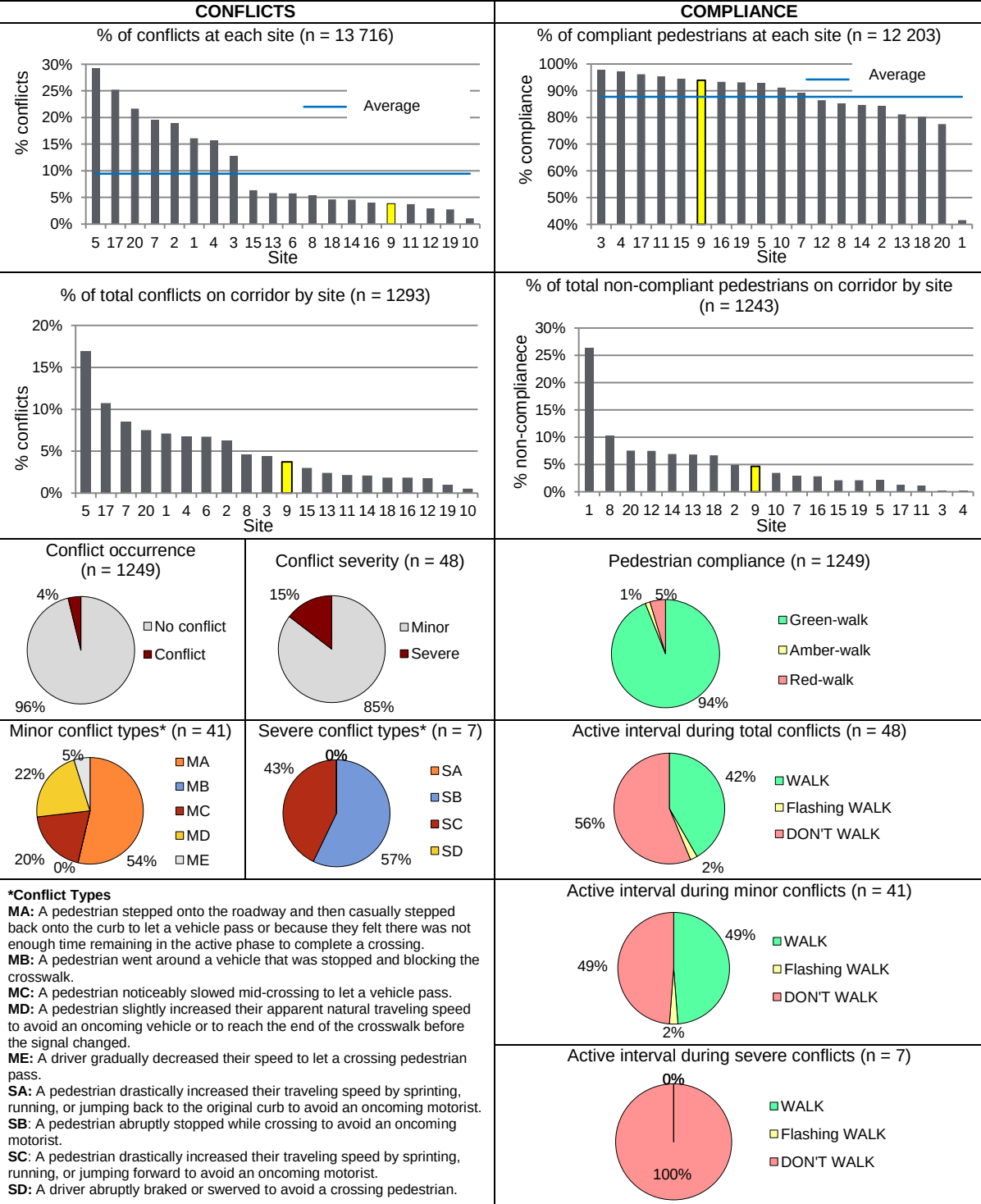
Data collection date(s) and time(s):	TR Oct 24, 9:30 – 11:30
Duration of total data collection:	2 hr
Weather:	Cloudy
Pedestrians observed:	1110



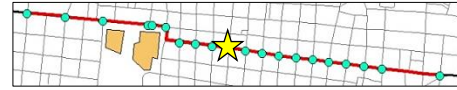
Site 9 (Avenida Segunda & Calle 8)



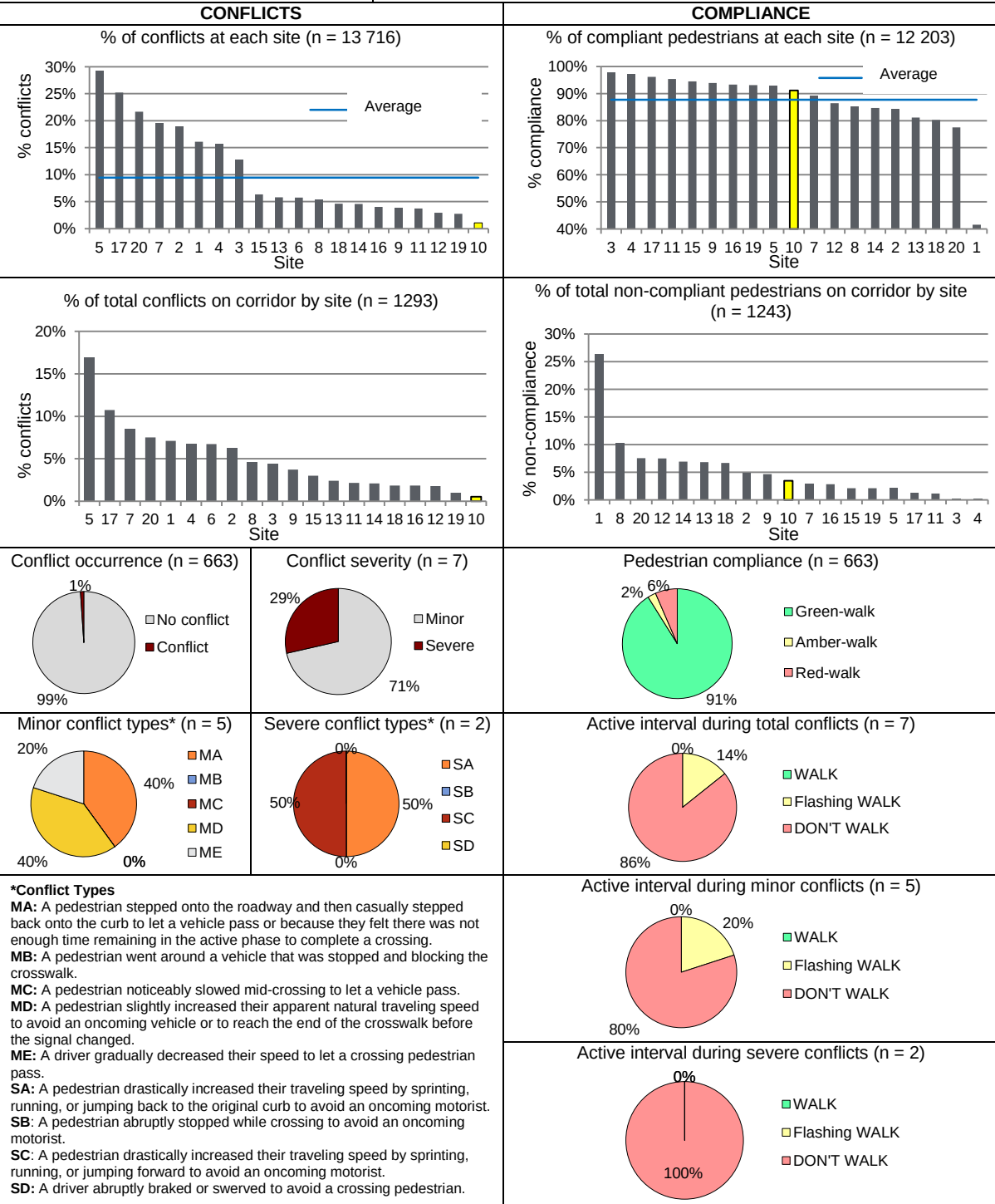
Data collection date(s) and time(s):	T Nov 5, 10:20 – 11:15
Duration of total data collection:	0.9 hr
Weather:	Sunny 30
Pedestrians observed:	1249



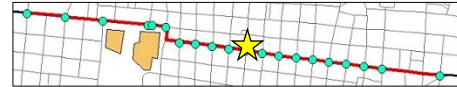
Site 10 (Avenida Segunda & Calle 6)



Data collection date(s) and time(s):	W Nov 6, 9:45 – 10:15
Duration of total data collection:	0.5 hr
Weather:	Sunny 30
Pedestrians observed:	663

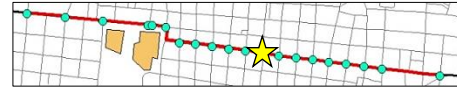


Site 11 (Avenida Segunda & Calle 4)

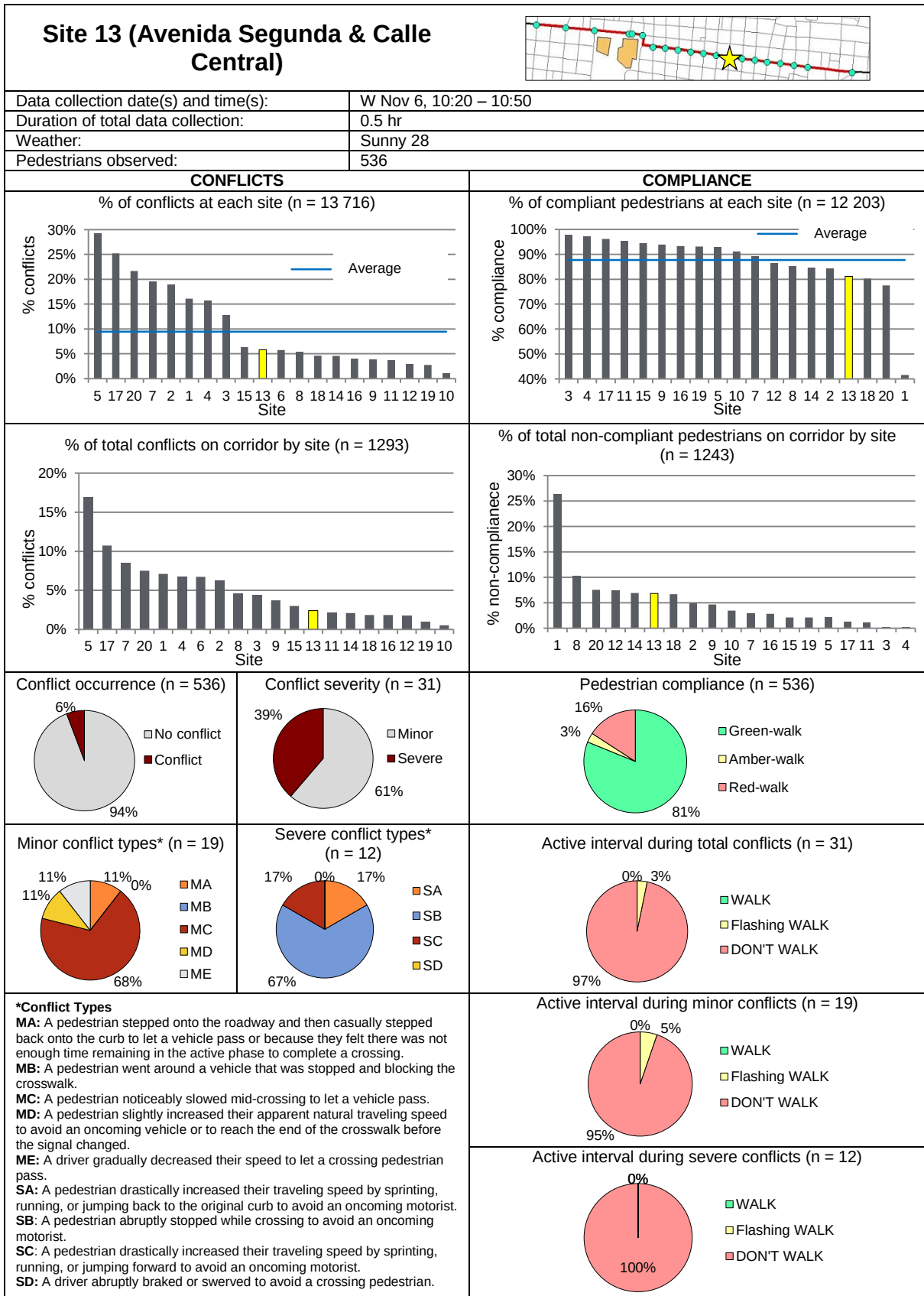


Data collection date(s) and time(s):		M Oct 28, 10:10 – 10:50	
Duration of total data collection:		0.7 hr	
Weather:		Sunny 20	
Pedestrians observed:		748	
CONFLICTS		COMPLIANCE	
% of conflicts at each site (n = 13 716)		% of compliant pedestrians at each site (n = 12 203)	
% of total conflicts on corridor by site (n = 1293)		% of total non-compliant pedestrians on corridor by site (n = 1243)	
Conflict occurrence (n = 748)	Conflict severity (n = 28)	Pedestrian compliance (n = 748)	
Minor conflict types* (n = 23)	Severe conflict types* (n = 3)	Active interval during total conflicts (n = 28)	
*Conflict Types MA: A pedestrian stepped onto the roadway and then casually stepped back onto the curb to let a vehicle pass or because they felt there was not enough time remaining in the active phase to complete a crossing. MB: A pedestrian went around a vehicle that was stopped and blocking the crosswalk. MC: A pedestrian noticeably slowed mid-crossing to let a vehicle pass. MD: A pedestrian slightly increased their apparent natural traveling speed to avoid an oncoming vehicle or to reach the end of the crosswalk before the signal changed. ME: A driver gradually decreased their speed to let a crossing pedestrian pass. SA: A pedestrian drastically increased their traveling speed by sprinting, running, or jumping back to the original curb to avoid an oncoming motorist. SB: A pedestrian abruptly stopped while crossing to avoid an oncoming motorist. SC: A pedestrian drastically increased their traveling speed by sprinting, running, or jumping forward to avoid an oncoming motorist. SD: A driver abruptly braked or swerved to avoid a crossing pedestrian.		Active interval during minor conflicts (n = 23)	
		Active interval during severe conflicts (n = 3)	

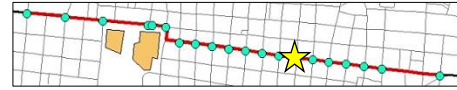
Site 12 (Avenida Segunda & Calle 2)



Data collection date(s) and time(s):		W Nov 6, 9:20 – 9:40
Duration of total data collection:		0.3 hr
Weather:		Sunny 28
Pedestrians observed:		784
CONFLICTS		COMPLIANCE
% of conflicts at each site (n = 13 716)		% of compliant pedestrians at each site (n = 12 203)
% of total conflicts on corridor by site (n = 1293)		% of total non-compliant pedestrians on corridor by site (n = 1243)
Conflict occurrence (n = 784)	Conflict severity (n = 23)	Pedestrian compliance (n = 784)
Minor conflict types* (n = 18)	Severe conflict types* (n = 5)	Active interval during total conflicts (n = 23)
*Conflict Types MA: A pedestrian stepped onto the roadway and then casually stepped back onto the curb to let a vehicle pass or because they felt there was not enough time remaining in the active phase to complete a crossing. MB: A pedestrian went around a vehicle that was stopped and blocking the crosswalk. MC: A pedestrian noticeably slowed mid-crossing to let a vehicle pass. MD: A pedestrian slightly increased their apparent natural traveling speed to avoid an oncoming vehicle or to reach the end of the crosswalk before the signal changed. ME: A driver gradually decreased their speed to let a crossing pedestrian pass. SA: A pedestrian drastically increased their traveling speed by sprinting, running, or jumping back to the original curb to avoid an oncoming motorist. SB: A pedestrian abruptly stopped while crossing to avoid an oncoming motorist. SC: A pedestrian drastically increased their traveling speed by sprinting, running, or jumping forward to avoid an oncoming motorist. SD: A driver abruptly braked or swerved to avoid a crossing pedestrian.		Active interval during minor conflicts (n = 18)
		Active interval during severe conflicts (n = 5)

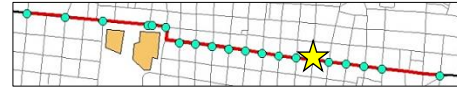


Site 14 (Avenida Segunda & Calle 1)



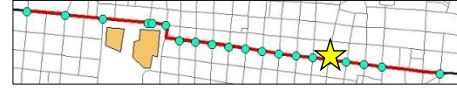
Data collection date(s) and time(s):		M Oct 28, 10:10 – 10:50	
Duration of total data collection:		0.7 hr	
Weather:		Sunny 20	
Pedestrians observed:		592	
CONFLICTS		COMPLIANCE	
% of conflicts at each site (n = 13 716)		% of compliant pedestrians at each site (n = 12 203)	
% of total conflicts on corridor by site (n = 1293)		% of total non-compliant pedestrians on corridor by site (n = 1243)	
Conflict occurrence (n = 592)	Conflict severity (n = 27)	Pedestrian compliance (n = 592)	
Minor conflict types* (n = 26)	Severe conflict types* (n = 1)	Active interval during total conflicts (n = 27)	
*Conflict Types MA: A pedestrian stepped onto the roadway and then casually stepped back onto the curb to let a vehicle pass or because they felt there was not enough time remaining in the active phase to complete a crossing. MB: A pedestrian went around a vehicle that was stopped and blocking the crosswalk. MC: A pedestrian noticeably slowed mid-crossing to let a vehicle pass. MD: A pedestrian slightly increased their apparent natural traveling speed to avoid an oncoming vehicle or to reach the end of the crosswalk before the signal changed. ME: A driver gradually decreased their speed to let a crossing pedestrian pass. SA: A pedestrian drastically increased their traveling speed by sprinting, running, or jumping back to the original curb to avoid an oncoming motorist. SB: A pedestrian abruptly stopped while crossing to avoid an oncoming motorist. SC: A pedestrian drastically increased their traveling speed by sprinting, running, or jumping forward to avoid an oncoming motorist. SD: A driver abruptly braked or swerved to avoid a crossing pedestrian.		Active interval during minor conflicts (n = 26)	
		Active interval during severe conflicts (n = 1)	

Site 15 (Avenida Segunda & Calle 3)

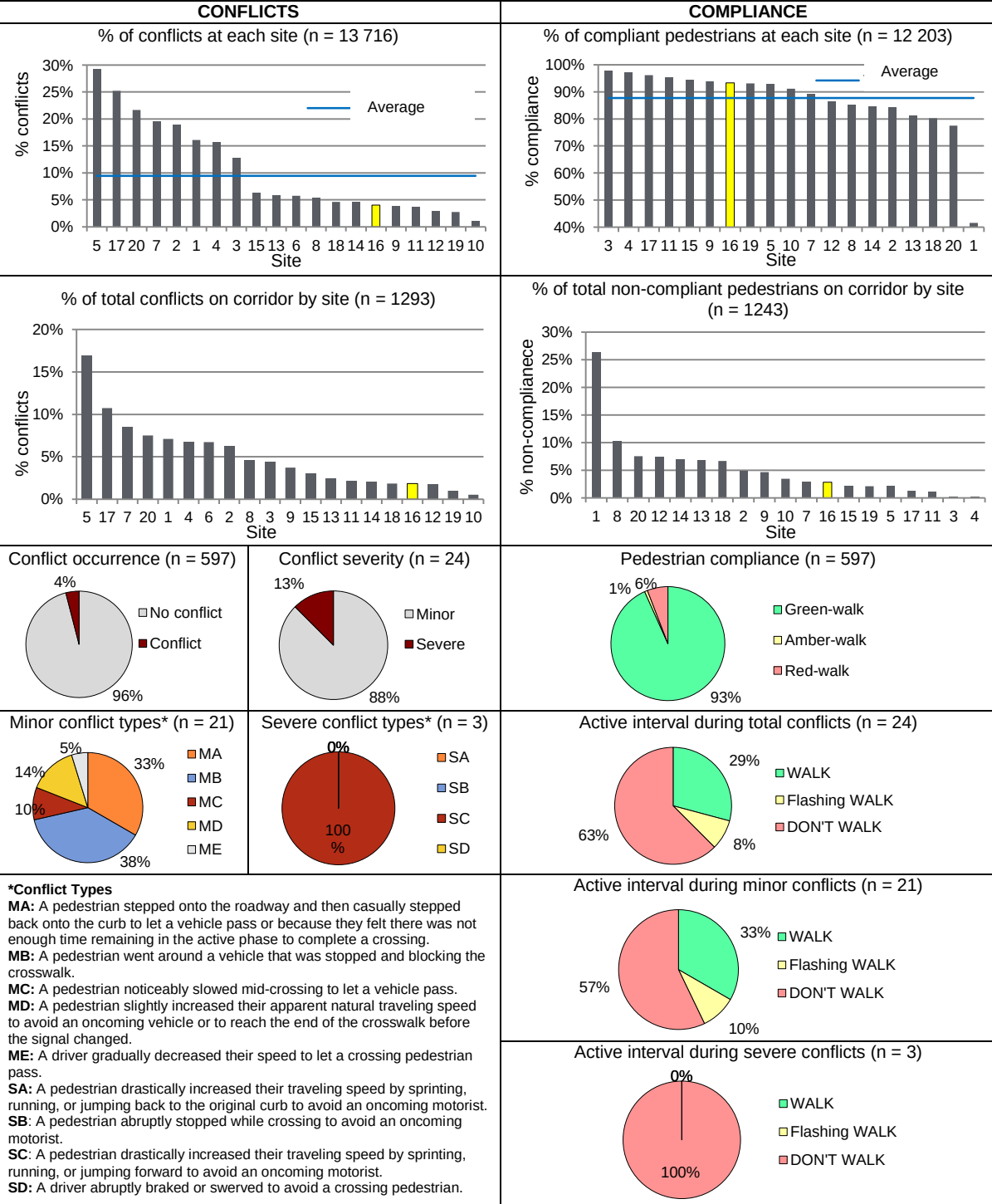


Data collection date(s) and time(s):		TR Nov 14, 9:25 – 9:50																																																																																			
Duration of total data collection:		0.4 hr																																																																																			
Weather:		Cloudy 22																																																																																			
Pedestrians observed:		616																																																																																			
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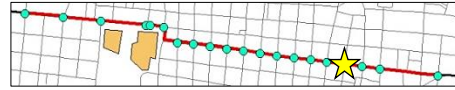
Site 16 (Avenida Segunda & Calle 5)



Data collection date(s) and time(s):	TR Nov 14, 9:50 – 10:20
Duration of total data collection:	0.5 hr
Weather:	Cloudy 22
Pedestrians observed:	597

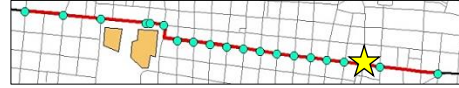


Site 17 (Avenida Segunda & Calle 7)



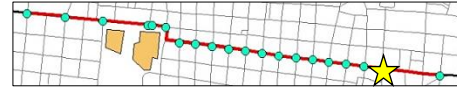
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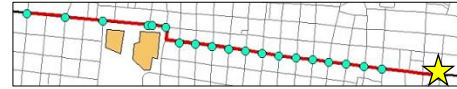
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Total Pedestrians Observed at All Sites*



Duration of total data collection:

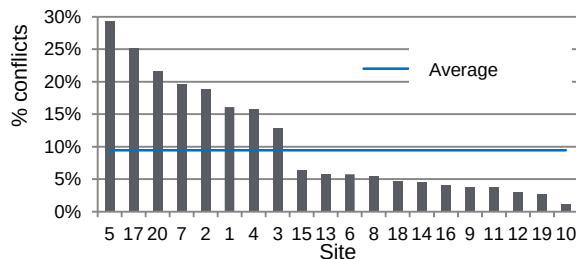
23.25 hr

Pedestrians observed:

13 716

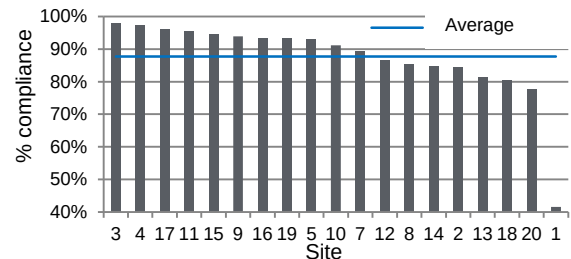
CONFLICTS

% of conflicts at each site (n = 13 716)

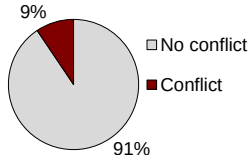


COMPLIANCE

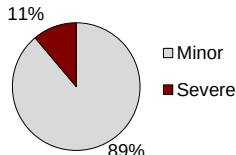
% of compliant pedestrians at each site (n = 12 203)



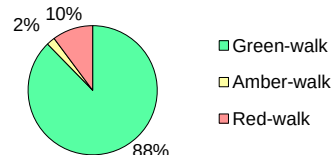
Conflict occurrence
(n = 13 716)



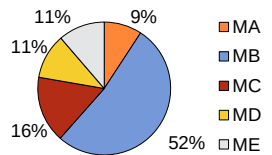
Conflict severity (n = 1293)



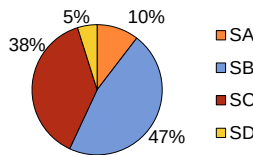
Pedestrian compliance (n = 12 203*)



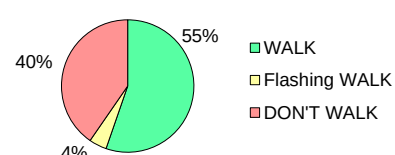
Minor conflict types**
(n = 1149)



Severe conflict types**
(n = 144)



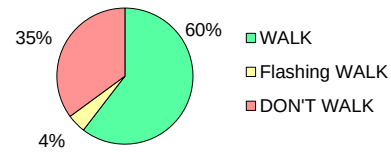
Active interval during total conflicts (n = 1206*)



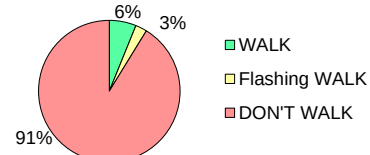
**Conflict Types

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Active interval during minor conflicts (n = 1092*)



Active interval during severe conflicts (n = 114*)



* no compliance data for intersection 6