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Title: Improving Safety of the Platform-Train-Interface Through Operational and Technical Mitigation Strategies

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The purpose of this study is to provide background information and examples of best practices relating to platform-train-interface (PTI) safety. The research and information obtained for this manuscript has been in association with the A-40 project funded by the Transit Cooperative Research Program (TCRP) of the National Academies. The purpose of the TCRP A-40 project is to create a manual to improve platform safety for rail modes of public transportation at the interface between the edge of the platform and the vehicle. Information has been collected via an extensive literature review, phone interviews with stakeholders, basic incident data analysis, and site visits. Research has determined that the three main factors that affect platform safety are technical aspects, operational elements, and passenger characteristics. The focus of this document is to better understand the issues and potential mitigation strategies associated with the operational and technical aspects of platform-train-interface safety.

Improving Safety of the Platform-Train-Interface Through Operational and Technical Mitigation Strategies

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Dylan Anderson, Author

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1. Introduction

Public transportation continues to be an important piece to the overall national transportation puzzle. As congestion continues to increase on the nation's roadways, commuters continue to flock to public transit as an alternative transportation mode. In particular, rail transit has been shown to provide many benefits to a regional transportation system. Often multiple modes of rail transit and bus transit will be combined to bring a commuter from a suburb to a workplace in a dense urban environment.

Safety of both passengers and employees is a major concern for transit agencies. Typical safety concerns for rail transit vary greatly depending on mode, location, climate, age of system, and various other factors. In general, the public often interact with rail transit at two primary locations. The first is at grade crossings, whether they be a pedestrian crossing or a roadway crossing. The second is at rail station platforms, which can vary from low level to high level. Passenger safety at rail stations can be a significant concern for rail transit operators. Stations can be in varying configurations such as underground, at grade, and elevated. Stations along a single route can include multiple configurations and see varying levels of passenger flows. The specific safety concerns associated with each type of station can differ significantly. Furthermore, there can be additional differing safety concerns in relation to island platforms versus side platforms and tangent versus curved track.

Specifically, one of the major concerns that rail transit agencies may have in relation to the platform involves the platform-train-interface (PTI). As the name suggests, this topic includes incidents that involve passengers having difficulties with the gap between the train and platform. In an ideal world every rail transit station would be on tangent track that is well maintained and contain an ADA compliant horizontal and vertical gap, allowing for level boarding. Furthermore, every rail transit vehicle on the system would be dimensionally consistent with self-leveling technology and contain systems that would remain reliable throughout their lifespan. However, the reality is that many systems have numerous challenges when it comes to PTI safety and achieving level boarding.

A limited amount of previous research has been conducted on this topic in various countries around the world. This previous research has been compiled into a literature review, which makes up the next section. This document also serves as the literature review for the A-40 project sponsored by the Transit Cooperative Research Program (TCRP) being undertaken by a research team at Oregon State University as well as outside contractors. The goal of the project is to develop a safety manual that can be used by stakeholders to improve safety at platform/train and platform/guideway interfaces.

For the purposes of this project, PTI safety was broken down in various sections that were determined to be relevant. This document contains a thorough literature review of previous work completed in the area of platform-train-interface safety. The next chapter contains highlights of the technical aspects of the literature review that is published in the Transportation Research Board's (TRB) 2015 Transportation Research Record (TRR). The following chapter contains a brief data analysis conducted with platform incident data received from five major transit agencies in the United States. Next, a summary of site visits to various large transit agencies in the U.S. will be provided. Additionally, a section will be provided that highlights a mitigation framework that was developed to identify mitigation strategies based on mode. Finally a summary will bring together many of the findings from the project.

2. Literature Review

2.1 INTRODUCTION

Many transit agencies and researchers recognize that platform-train-interface incidents are an important safety concern; however there has been relatively little research in this area. Incidents that involve the gap between the platform and train are not necessarily only dependent on the gap size. In fact, the literature review suggests that there may be many other contributing factors that could impact boarding and alighting safety. Various studies from around the world have considered portions of this overarching problem of gap safety in various rail transit modes. These documents have been reviewed and the pertinent information was extracted to ensure that this study could effectively address issues surrounding the platform-train-interface. The literature review is broken down into eight main sections including:

1. Technical or Engineering Factors

2. Mode Specific Considerations

3. Operational Aspects

4. Passenger Characteristics

5. Methodology of Case Studies

6. Assessing Mitigation Approaches

7. Identification of Operational Best Practices

8. Current Gaps in the Literature

2.2 TECHNICAL AND ENGINEERING FACTORS

There are many factors that can influence gap safety, one of the key concerns from the transit agencies perspective are the technical aspects. These factors range from track infrastructure and platform design to vehicle characteristics. Previous studies in New Jersey, Thailand, and Japan have addressed some of these issues and these will be discussed further in this section.

Track Infrastructure and Geometry

One of the major design aspects that can affect safety at the platform-train-interface is the gap size influenced by the track infrastructure. Different modes of rail transit often encounter different issues relating to the track on which they operate. Rail transit operations are generally divided into two different categories, exclusive track operations and shared track operations. Shared track operations include sharing the track with freight trains as well as other rail transit modes in certain instances. Commuter rail systems quite often share track with freight and thus the station platforms need to be set back further from the track to comply with freight car clearances. Light rail and streetcar operations sometimes share platforms with each other and/or buses. In these operations platforms must be designed to accommodate level boarding for various modes. Conversely, exclusive track operations involve a guideway that is reserved for a specific type of rail transit. For example, heavy rail transit operations such as those reported in the studies involving Tokyo and Bangkok generally only have to consider horizontal gaps resulting from platforms that are on curves.

Tangent and Curved Track

Curved track sections are often cited for the presence of excessive gaps in stations. Several of the studies reviewed mentioned the issues related to curved station platforms located on curved track sections (6,12,18,26). A document outlining the origins of “Mind the Gap” provides information on why these curved platforms can cause difficulties. As stated in the paper and a study from Tokyo University of Science, there are two primary classifications for stations in curves. In the first case, a station is located on the outside of a curve (concave)(18, 26). This allows the ends of the cars to be near to the platform but the center doors could have a significant gap present. The opposite is true for the second case when the station is located on the inside of a curve (convex). In this scenario the middle sections of the cars are near to the platform and ends are further away. The severity of the gap depends significantly on the rail car layout and the degree of curve in which the station is located (12). A New Jersey Transit study presents a similar conclusion in regards to stations in curves (6). The model presented by the researchers from Tokyo University of Science also takes curvature into account (26).

Gap Distance

One of the primary factors that are often associated with platform-train-interface incidents is the size of the horizontal and vertical gaps. The Americans with Disabilities Act (ADA) regulations for level boarding platforms, recommend that the horizontal gap should not exceed 3 inches and the vertical gap must be less than 5/8 inches from platform to rail car. The New Jersey Transit study focused on gap size in relation to accident rate for a portion of their report. Interestingly, the results showed that there was no clear relationship between gap sizes and frequencies of incidents. Furthermore, it was determined that in the case of New Jersey Transit stations, the maximum gaps were seen at the ends of the platforms where passengers would not often board (6).

Excessive gaps are also seen on the platforms of many commuter lines. These gaps are based on sufficient offset from edge of platform to centerline of track to allow a variety of different vehicles to utilize the track at full operating speeds (more information in Regulations and Standards section). However, an eight-inch gap leaves ample room for an object or a person to fall or trip in between the train and platform. Gaps along curved sections of track may be even larger. The degree of curvature and amount of super elevation in a curve can also impact the gap significantly. As a general rule, for every one-degree of track curvature, one inch of additional gap is required to ensure the train cars do not strike the edge while passing. A similar convention is used for superelevation with one inch of superelevation corresponding with one additional inch of vertical gap needed for safe train operations (See figure 1). (15).

Figure 1: Superelevation in Relation to Gap (15)

A boarding and alighting study conducted at Delft University of Technology also offers some insight into the effects of gap sizes. Consistent with the focus of the study, they determined that an increase in either the vertical or horizontal gap would lead to a corresponding decrease in capacity for that given door (5).

The study conducted by researchers at the Tokyo University of Science briefly considered the size of the horizontal gap and the relationship to platform safety. Based on the survey results collected from passengers on the system, the perceived impact of the horizontal gap was believed to be relatively small. This indicates that in those specific stations the passengers were not concerned with the size of the gap between platform and train in relation to their overall safety on the platform (26).

Platform Design

The platform design itself can be a significant factor that effects platform-train-interface incident frequency. The study from Tokyo University of Science places a significant focus on station design and the specific effects of various design characteristics. The model aimed to numerically relate different physical design aspects to their effect on platform safety. In total, five different platform design factors were considered for the overall model. In fact, the platform design portion of the model was weighted higher than passenger flow, train operations, and passenger profile. Two of the significant variables were the overall area of the platform and the length of narrow sections on the platform. These conclusions seem to be based on avoiding overcrowding on the platforms. Also, as previously mentioned in the track infrastructure section, stations in curves often see larger vertical and horizontal gaps.

Platform Size

Two primary factors in the Japanese study were the overall area of the platform and the length of narrow or obstructed sections on the platform. According to the study, as the area of the platform increased so did the overall safety of the platform. Conversely, as the length of the narrow sections of the platform increased the overall safety at the platform decreased. In general, it is understood that larger platforms with more standing area are safer than those that are smaller. Additionally, the study stated that island platforms and those with curves were considered to be more dangerous than single sided platforms and those that were straight (26).

The shape of the platform can have an impact on safety. The literature does not show consensus of whether island platforms or side platforms are truly safer. Some advantages that are listed for island platforms include using less right-of-way, ease of transfer between tracks for passengers, shared facilities, and potentially fewer station attendants needed. However, the island platforms can also have issues such as overcrowding when two trains are present on either side, crossing passenger flows, and overcrowding on stairs and escalators. Conversely, the side platforms can offer more standing area and eliminate the problem of crossing passenger flows. There are many factors that contribute to the selection and design of the platform. These factors are specific to the location and are generally determined by the geometric characteristics, right-of-way availability, station location, passenger load, and transferability to other modes or trains. Further research into platform type and its' relation to safety could be very useful.

Platform Height

There has been little research reported that has focused on comparing the various types of platforms with their relation to gap safety. A report published by Hulse in 2013 that details track intrusion at rail platforms mentions that there are a few differences between platform styles. According to the report, people may be more likely to enter the guideway from low-level platforms. This applies to low floor street cars and low floor light rail vehicles, and it suggests that passengers may be more comfortable standing on the edge and not giving as much thought to their safety on a low platform. As the platform height increases with respect to the track the potential for injury increases, consequently people may be more cautious around higher platforms (13).

Gap Reduction

The Long Island Rail Road has employed different strategies in relation to platform design to reduce the gap and improve safety. Although not always practical for every station, the railroad was able to physically realign a number of stations to reduce gap distance. A more universal solution comes in the form of installing wooden edge boards along the length of entire platforms (See Figure 2). These boards can be an economical solution to gap reduction (15).

Figure 2: Wooden Edge Boards Installed on Platforms (15)

Platform Condition

Multiple studies have acknowledged the importance of the platform condition in relation to safety, however the report published by the Rail Safety and Standards Board based in the United Kingdom is one of the few to make any conclusions. One of the emphases of the study includes information on the effects of weather on platform-train-interface incidents in the UK. According to the results, when the platform is wet or icy there is an associated increase in incidents by almost 5%. If the platform is both icy and wet the rate of incidents increases by nearly 20%. The results from the study also predicted an increase in incidents during the winter months as compared to the summer months (18). A study detailing safety issues on platforms on the Bangkok Mass Transit system also found through a passenger survey that people tend to be more careful when there is wind and rain present (21). Based on these results it appears that inclement weather can have a significant effect on incidents on platforms that are exposed to the weather.

Platform Light Conditions

Platform lighting is a topic that multiple studies mention but do not explore in depth. The study from New Jersey Transit indicates that their results with respect to natural lighting are inconclusive. The report cited a peak in injuries in the morning before natural light was present. However, this peak was also associated with the morning (AM) peak for commuters. Furthermore, according to the study the afternoon/evening (PM) peak injury rate was highest in the summer when natural light was present at the station. Thus, no significant conclusions could be drawn about natural lighting (6).

The study published by the Rail Safety and Standards Board also focused on natural station lighting rather than artificial station lighting (18). Consistent with the New Jersey study, no significant conclusions could be made. According to the collected data, there was a peak in incidents around 8:00 AM and 5:00 PM. The observations were made in the winter so at both times the natural daylight was either absent or very low. However, these hours also correspond with the AM and PM peak travel times for commuters. Thus it is difficult to determine whether or not the natural lighting has an effect on accident rates. During the literature review, no references were found that studied the relation of artificial lighting levels in relation to gap or platform safety (18).

Platform Clutter

The obstructions caused by amenities and general platform clutter influence the amount of "clear space" on the platform, and therefore consideration should be given to the location and density of obstacles. Examples of these include benches, station support columns, informational boards, stairs, elevators, and escalators. Many of these objects are necessary amenities, however it is the placement of these that is important for platform safety. Too many objects on the platform reduce the overall area and fixed obstructions such as stairs and escalators can contribute to narrow portions of the platform. These problems contribute to overcrowding and may cause passengers to stand too close to the edge of the platform. Additionally, special care should be taken when temporary construction or maintenance sites are set up to avoid creating potentially dangerous narrow platform sections.

Edge Warning Lights

A unique solution that could help to improve safety at the platform-train-interface is known as edge warning lights. Washington D.C. Metro uses this technique (See Figure 3). LED lights are imbedded in the edge of the platforms and spaced equally throughout the entire length of each platform. The bulbs burn at 50 percent power when a train is not approaching or in the station and flash at 100 percent power when a train is either approaching. Initially the lights were installed to alert both hearing-impaired and general riders that a train was approaching and encourage people to step back from the platform edge. The lights have been installed throughout the system and can improve safety by notifying passengers that a train is approaching and drawing further attention to the edge of the platform. The lights are color coded, for example the red LED lights are present on platforms that are along the Red Line, and amber lights are on the platforms that are in stations on the Green and Yellow Lines (6).

Figure 3: Platform Edge Warning Light Treatment on Washington D.C. METRO (WMATA)

Platform Edge Doors

Platform screen doors and platform edge doors at train or subway stations provide a physical barrier between the platform and the train. They are a relatively new addition to many metro systems around the world, some having been retrofitted to established systems.

Platform edge doors have been installed in Paris, London, and in parts of Asia to maintain physical segregation between passenger waiting on the platform and the track. Platform edge doors may be full, half or partial height platform doors. Figures 4 and 5 show half and full height platform doors.

Figure 4: Half height platform doors at Meguro Station Tokyo, Japan

Figure 5: Full platform screen doors Paris (PB Bulletin)

Platform screen doors refer to full height doors that provide full separation and can mitigate noise and ventilation problems in below grade stations. The doors have additional benefits including compliance with modern codes such as the National Fire Protection Association 130, for climate control, and faster train headways. Platform edge doors are usually required in order to implement Automatic Train Operation/Automatic Train Control. Full height platform screen doors/barriers are also used to create a smoke and fire barrier from the guideway, which is usually ventilated under separate tunnel ventilation controls and allows the station to be ventilated or air-conditioned separately from the guideway. These physical barriers can also provide increased survivability for passengers from train vehicle fires and smoke.

Half height doors, as the name suggests, only extend up to about chest height depending on the specific system. This configuration represents the most cost effective way to install platform edge doors but do not produce any climate or noise control benefits. Train noise suppression is slight if any but it does allow for ventilation between platform and guideway. One potential problem with half height doors is that a passenger could still potentially climb up over the wall and enter the guideway.

In all cases, platform edge gates/doors/barriers are used to prevent service delays that result from guideway intrusion. Multiple studies have mentioned platform edge doors as a potential method to improve safety at the platform-train-interface. The study produced by New Jersey Institute of Technology lists platform edge doors as a possible mitigation strategy to improve platform safety (6).

Bangkok Mass Transit System

A report published by Santoso and Mahadthai focuses on platform edge doors impacts on platform safety on the Bangkok Mass Transit System. According to the findings, incidents that are attributed to platform-train-interface incidents account for about 38 percent of the overall fatality risk and of that risk about 9 percent are attributed to boarding and alighting incidents. The doors have been shown to improve certain safety aspects surrounding the platform train interface but these improvements can be costly. Bangkok transit distributed a survey to passengers asking various questions on platform safety and over 75 percent of the respondents thought the installation of platform edge doors would improve safety, however; the respondents did not support the installation of the platform edge doors if the installation meant a fare increase of roughly 20 cents in US equivalent dollars. The same trend was seen for increasing the number of conductors on the platform in lieu of door installation. Based on these results it can be concluded that passengers appear to want platform edge doors for safety reasons but may be unwilling to pay more in fares to have them installed.

The loss of platform surface area for passengers to stand and move during boarding and alighting with the installation of platform edge doors was also a concern for the Bangkok transit agency. According to the Bangkok study, the presence of platform edge doors do not significantly change passenger flows during boarding and alighting, therefore, do not have a large negative impact on dwell time or overall capacity (21).

Taipei Rapid Transit Corporation

An internal case study completed by the Taipei Rapid Transit Corporation discusses the results of previous installations of platform edge doors on various rail transit lines under their jurisdiction (See Figure 6). Platform edge door installations began in 2005 and have continued periodically since that time. One of the motivations for the installation resulted from a report on the Paris subway that stated that the number of delays caused by passengers was reduced by 69 percent after the installation of platform edge doors. Initially doors that were 1.45 meters tall and 1.8 meters wide were installed. However, as more stations were equipped with platform edge doors, the heights of the doors have been reduced slightly to 1.4 meters and the width has increased to 2.1 meters to increase visibility and passenger flow. Additionally, the doors are equipped with automatic detection sensors that prevent them from closing on passengers and causing injuries. Recent successes with the platform edge doors have encouraged the Taipei Rapid Transit Corporation to continue installing the doors at heavily congested stations. The most recent set of installations at 13 additional stations will be completed in 2014, continuing to improve safety on the overall system (11).

Figure 6: Half height platform edge doors on Taipei Metro

Honolulu Rapid Rail

Platform edge doors will be installed at all of the 21 stations along the new Honolulu Rapid Rail Transit line that will operate under automatic train control. The decision to install the doors was supported by both planners and the community at large. This is largely due to the system being both elevated and automated. The half-height doors will be laminated safety glass and will run along the entire length of each platform. As observed by other systems around the world, installing the doors would be significantly cheaper if done during initial construction rather than retrofitting later. Thus the automatic doors will be installed at a price of about $27 million total for all of the platforms in the 21 stations (8).

Platform Edge Doors and Legacy Systems

One of the primary concerns that transit agencies have with platform edge doors implementation is inoperability. Many agencies operate multiple vehicle designs or models on the same lines. The differences between these vehicles with relation to the number, location and even style of doors and dimensions cause issues with docking at specific platform edge door locations. However, as stated by an American Public Transportation Association (APTA) publication on intrusion detection, if platform edge doors are feasible there can be many advantages. Some of these include faster train approach speeds, reduced noise levels, and reduced heating/cooling costs (13).

SkyTrain in Vancouver, British Columbia is a system which opened in 1986 and operates under automatic train control. There have been approximately 60 track intrusion related deaths in the past thirty years and a majority of those deaths have been suicides. However, it is important to note that at least ten of the track intrusion incidents were accidental in nature. Implementation of platform edge doors has been considered as a possible solution to these intrusion problems. One of the major obstacles that exist involves the various types of rolling stock that operate on the various lines. Currently, Mark I and Mark II cars operate on both the Millennium and Expo Lines. Unfortunately the door spacing is not consistent between the two vehicle types. Additionally, Mark III vehicles will be introduced in 2016 in conjunction with the opening of the new Evergreen Line with yet another door spacing scheme. Operating three different types of vehicles with varying door spacing would make platform screen door implementation very difficult. The Canada Line operates independently of the rest of the SkyTrain system and it may be possible to have platform edge doors at those stations. however, the high costs of installation and maintenance currently prevent platform edge door implementation (3).

Platform Edge Doors and Climate Control

One of the additional benefits of full height platform screen door installation is climate control and passenger comfort. Underground stations in Singapore have been retrofitted with full height platform edge doors to help improve safety and to reduce the costs of providing air conditioning on the platforms. The savings from this are significant and passenger comfort has improved immensely since the installation.

A variation on full height screen doors leave a slight gap between the ceiling and wall for ventilation. This option is less expensive than the full height doors and still prevents people from entering the guideway. Climate control benefits are reduced but noise suppression is still sufficient.

Platform Edge Doors and Delay

Delay is generally a major concern for most rail transit agencies when considering the reliability of a given system. It is therefore important to understand the potential effects that installing platform edge doors have on delay on a rail transit line. The feasibility report regarding installation of platform edge doors prepared for BC Transit contained a delay impact analysis that concluded that the potential delay with the platform edge doors would be less than half of the delay with the current system which is based on intrusion detection technology. One major assumption for this comparison was that the platform edge doors failed at about the same rate as that of the train car doors. Additionally, it was assumed that the intrusion detection systems would be removed and thus no delay would be encountered from those systems. The findings suggest that the platform edge doors would reduce delay significantly over the course of an average month (9). Similarly, results from installation of half height platform edge doors on Hong Kong's MTR system suggest that service interruptions due to intrusion dropped nearly 70 percent (3).

Intrusion Detection Technologies

Platform edge and track intrusion detection devices are relatively new technologies that are under consideration for transit related purposes. The technology for the platform intrusion detection systems has become more sophisticated and can be far more economical to install and operate as compared to platform edge doors. However, they do not offer a physical barrier between the edge of platform and track. Figure 7 shows one example of this technology in West Jin Sha Jiang Road Station in Shanghai, China. In this application a light curtains is used with platform screen doors to insure that passengers are not caught between the platform screen doors and the vehicle doors. One of the potential drawbacks of this technology is that the implementation of light sensors on curved platforms is difficult (13).

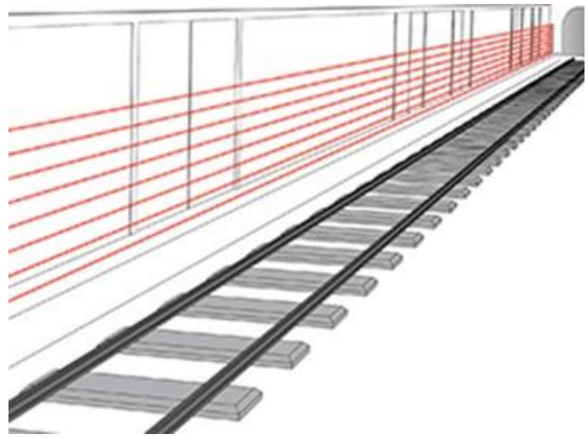

Figure 7: Light curtain and platform screen doors at the West Jin Sha Jiang Road Station, Shanghai, China

Skytrain Vancouver, British Columbia, Canada

A case study for guideway intrusion detection is derived from SkyTrain operated in the Vancouver, British Columbia. Currently SkyTrain has a basic intrusion detection that varies from lasers to metal pressure plates. The main purpose of these detection technologies is to prevent an incoming train from hitting a passenger that is on the tracks. The laser detection systems that are present on the newer lines can detect a passenger that moves too close to the platform edge and issues an audio warning of the potential danger. The second phase of the system involves lasers that can detect an object that has fallen on the track. Once detected, an alert is sent to the central control room and trains cannot enter the station until the foreign object has been cleared.

The original Expo Line still utilizes the pressure plates. This system is present on the tracks at stations and operates similar to the track laser system. If an object puts pressure on the plate it issues an alert to the central control room and does not allow trains to enter that station on that track. The system is very effective. In fact, the sensitivity is so high that a dropped wallet or aluminum can will set off the alert and stop trains. According to the same article, in May 2010 alone there were at least 80 service disruptions caused by garbage falling onto the tracks and creating false alarms. While the idea behind this intrusion detection method was sound, the operation has proven to cause many system wide delays (3).

Video Surveillance with Advanced Analytics

Video surveillance that includes advanced analytics is an emerging intrusion detection technology that is beginning to increase in popularity. Table 1 below is cited from a paper by J. Schütte that focuses on the potential of using a video based system to improve intrusion detection. Some of the primary advantages of using video over a traditional method of pressure plates or lasers involve flexibility of platform geometry and car door locations. Additionally, the video based systems should be significantly cheaper and require less maintenance. Many transit agencies currently have basic camera systems that can either be retrofitted or upgraded to accommodate the new analytics technology. The added video systems allow for incident analysis if an event were to occur along with potentially increase security at rail transit stations.

Table 1: Characteristics of Platform Protection Systems (22)

	platform doors	contact sensors	optical system (light, RADAR, LASER)	video image processing
selectivity between persons and objects	not necessary, (physical barrier)	not possible	not possible	possible; recognize and differentiate objects, persons, trains
availability and maintainability	high, proven equipment difficult to retrofit	availability limited by high number of components and false alarms (vandalism), requires extensive maintenance requires service interruption	limited by many components in dirty environment; false alarms (vandalism) electro-magnetic components critical in dirty environment requires service interruption	high availability, proven cameras, personnel intervention possible, standard cameras with high MTBF easy to repair, no interruption necessary
cost structures per platform edge	high	mean	mean	expected low
extendibility	no extended functions	no extended function	no extended function	additional functions for security

In general the system can detect guideway intrusion and passengers falling into a gap between cars if the line of sight is clear and the gap is large enough. Similar to other intrusion detection technologies, a guideway intrusion results in trains not being able to enter the station which can trigger systems delays that prevent other trains on the line from leaving stations. An additional advantage of the video imaging software is the ability to identify the size of the object and thus determine if the object is critical or simply trash blowing onto the tracks. These parameters can be customized based on transit agencies policies and needs. According to the study published by J. Schütte two cameras can cover a platform length of up to 300 feet (100 meters) in length. According to the paper there have been successful tests on three separate urban rail lines in Germany that have yielded positive results. The image processing software was able to distinguish between critical (passenger, suitcase, animal, etc.) and non-critical (trash, paper, etc.) items on the guideway and the presence of a train at the platform (22).

Los Angeles Metro

Los Angeles Metro has teamed up with a private company to install a pressure detection based system. This system uses fiber optic cable laid in the track bed that is sensitive to both movement and vibrations. If a person or another critical object is detected the system does not allow the train to enter the station. The company has also developed video analytics software similar to that which was seen in the German study discussed in the previous section. This system has been installed at select platforms for further development and testing (13).

Between Car Barriers

Between car barriers are physical barriers to prevent falls and track intrusion in the gap between vehicles at the platform. The barriers are either platform or vehicle based. This was not the specific focus of the research project; however, there is a relationship to overall platform safety. A report published by Reiss details the efforts of the Los Angeles County Metropolitan Transportation Authority to become ADA compliant with regards to between car barriers. The goal of the study was to find a station based protection system that could be universally applied in contrast to a vehicle based solution. One of the largest challenges Los Angeles faced was the large variety of vehicles operating on their lines. Currently, there are many different models of light rail vehicles (Gold, Blue, and Green lines) and heavy rail vehicles

(Red/Purple Subway Lines) operating on the system. The varying models, ages, and dimensions made it difficult to come up with an on-vehicle solution that worked for all models. Thus, after years of design and testing, a solution of platform based hinged bollards were implemented that is shown in Figure 8. The hinges were required by the California Public Utility Commission to allow passengers access to the door if the train did not stop in the proper location. The installation of the bollards even had an unanticipated positive effect for the visually impaired. According to survey responses, the trains stop so reliably that people with low vision can use the bollards to determine where the train doors will be. These devices improve safety with regards to reducing the number of incidents of falling between cars, and the bollards serve as a way finding device for passengers with visual impairments (19).

Figure 8: Bollard Between Car Barrier in Los Angeles, CA, USA

San Francisco Municipal Transportation Agency has also worked to develop a between car barrier device for their light rail vehicles. Their solution is three evenly spaced elastic bands that extend from one vehicle to the adjacent vehicle and are illustrated in Figure 9. The bands contain high tensions springs that allow them to expand up to 13 feet in length when cornering. In addition a black and yellow striped paint scheme has been utilized to bring additional visual attention to the devices and keep passengers away from the gap between vehicles (20).

Figure 9: Elastic Band Between Car Barriers in San Francisco, CA USA (20)

Vehicles

The design of the vehicle itself can impact gap safety. There is diversity in the design of rail transit vehicles between and within transit agencies. For many transit agencies they are operating different generations of vehicles on the same line. The study involving Los Angeles and between car barriers illustrates the various light rail and heavy rail vehicles that are operating in conjunction with each other (19). The article entitled “Mind the Gap” also details the efforts of the London Underground to integrate new and old rolling stock while reducing gaps (13). From a vehicle design standpoint, the significant factors include: the overall width of the vehicle, the wheel size, and the number and size of the doors (6).

Vehicle Mounted Bridge Plates

The width of the vehicle has a direct impact on the horizontal gap, and the size of the wheels and suspension system can influences the vertical gap. One of the primary vehicle mitigation strategies implemented in the United States is the use of vehicle mounted bridge plates. These bridge plates are one of the devices used to make a system ADA compliant by covering the horizontal and small vertical gaps between the train and platform. The bridge plates can also be useful for passengers that are rolling strollers or luggage aboard a rail vehicle. The presence and operation of the bridge plates largely varies with mode and vehicle model. Some vehicles are equipped with automatically operating bridge plates while others need to be activated by individual passengers. Additionally, some cars may have bridges at every door and others may only have specific doors with the plates. It should be noted that installing bridge plates on a fleet of rail cars can be quite expensive (6). An additional possible solution that Washington D.C. Metro has used is installing threshold plates on the rail vehicles below each door. These rubberized strips are meant to reduce or eliminate the gap at stations with certain horizontal gap characteristics (10).

Vehicle Doors

A primary consideration for vehicle designers and transit agencies involves determining the ideal door type and configuration for a given rail transit system. The design of the vehicle door can impact both the horizontal and vertical gap between the platform edge and the vehicle. The three most popular styles of door are plug, sliding (pocket), and folding doors.

Plug Doors

Plug doors are so named because they "plug" into the side of the vehicle when the doors close. This type of door does not take up very much room on the vehicle and allows for a tight fit with the vehicle that reduces wind entering the cars and suppresses noise. One of the primary disadvantages of plug doors is that they swing out over the platform when opening and closing. This requires extra space and therefore increases the horizontal and possibly the vertical gap between the car and the platform. In fact, the use of plug doors can make true level boarding very difficult to achieve. In general it seems that having the platform at a slightly lower height allows the doors to operate correctly without impacting the platform. Plug doors can be found on various different modes of rail transit vehicles.

Folding Doors

Folding doors are similar to plug doors in that they both swing out over the platform. They can either have two primary sections, similar to a city bus, or two sections on either side that accordion to open. In either case the doors generally protrude out over the platform when open, reducing platform space and interrupting passenger flows. The platform height in relation to the door opening height is also a concern for this configuration.

Sliding (Pocket) Doors

The sliding (pocket) door is self-contained within the rail vehicle, and it is possible to have the doors at the same level as the platform. Also, this configuration allows for wide doors spaces and quick door operation. A disadvantage of sliding doors is that the mechanisms are contained within the vehicle, and in some applications require heating. The door equipment can also take up interior space and the location of the door is restricted by the locations of windows, wheels and other special equipment.

Door size and location influences boarding and alighting capacity of rail transit vehicles. In general, the higher the number of doors the overall capacity increases regardless of door style. However, a higher number of doors reduce the seating capacity. Door sizes can also be affected by location. In general, a wider door will increase capacity and most likely safety (17).

Regulations and Standards

In reference to rules, regulations, and standards there are rather few in the United States that deal specifically with the gap between the train and platform. Specific examples of current regulations will be discussed in the following sections.

Americans with Disabilities Act (ADA)

One of the most prominent set of regulations found relating to level boarding and the platform-train-interface comes as result of the Americans with Disabilities Act (ADA) of 1990. This act requires newly built and altered rail transit platforms to comply with certain guidelines in reference to allowing access to persons with disabilities. The most relevant to the PTI is likely the level boarding gap standards. Specifically these standards can be found in 49 CFR, Subtitle A, Part 37, Subpart C, 37.42 (f). This standard requires that the horizontal gap between the vehicle and platform be no greater than 3 inches at the locations of boarding. Similarly the vertical gap cannot exceed 5/8 of an inch when the vehicle is at rest at the platform (31, 38, 40).

Association of American Railroads (AAR)

The primary rail industry trade group, the Association of American Railroads (AAR), has set dimensional standards for freight rail cars that plays an important role in shared rail transit operations. One of the primary goals of the AAR is to improve safety within the industry and the dimension standards are one portion of that mission. These standards are more commonly known as loading gauge and their primary purpose is to restrict the maximum height and width of rail cars and vehicles. Currently in the United States the most prominent loading gauges are Plate B and Plate C (See Figure 10). However it should be noted that the emergence of taller freight cars such as double stacked intermodal cars, auto carriers, and high cube boxcars has made additional standards such as Plate H and Plate K more common along certain routes. Normally in relation to accessibility and platform-train-interface, the horizontal dimensions tend to be more relevant than the vertical. Passenger cars in the United States tend not to be as wide as freight cars (10’ 8” for a typical freight car as compared to a typical Bombardier Bi-level Coach at 9’ 6”) (36, 37, 40, 41).

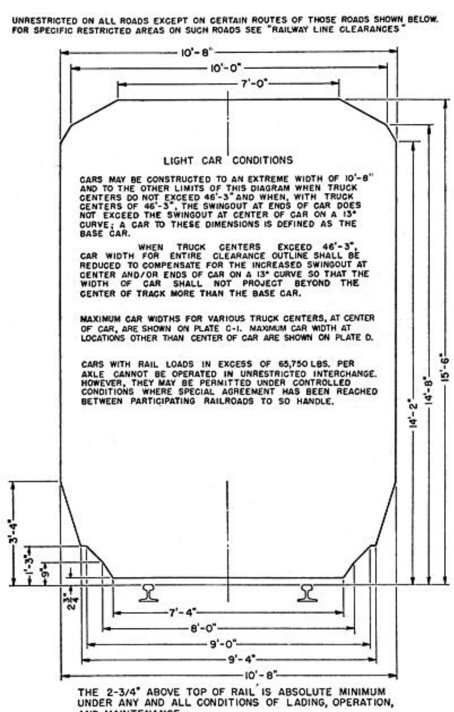

Figure 10: Association of American Railroads (AAR) Plate C Loading Gauge

State Department of Transportation (DOT) Standards

The Federal Railroad Administration (FRA) does not provide regulations or guidance on railcar clearance. However it leaves the creation of standards up to the individual states. This is often handled by the state department of transportations (DOTs). For example, in Oregon the Oregon DOT Rail Division has developed standards for rail car clearance. The standards are separated into various sections that apply to different situations. There is a section specifically that deals with passenger rail platforms. Platform height above the top of rail is the deciding factor in determining the clearance required from the centerline of the track. If the platform is no higher than 8 inches at greatest height, then the required side clearance is 4 feet 8 inches. However, if the platform is more than 8 inches but less than 4 feet above top of rail the clearance requirement becomes 7 feet 3 inches from centerline of track. Platforms that have a greater height than 4 feet are required to have the general standard clearance of 8 feet 6 inches from centerline of track. The height of the rail vehicle will dictate the height of the platform above the rail. This in turn will determine the clearance standards. It is important to note that the clearance standards do not apply to passenger sidings or gauntlet tracks that are intended only for passenger car usage. Both strategies have been employed in various parts of the country to achieve level boarding while ensuring that the legal clearances are met (42).

Other State Regulatory Agencies

It is also possible to have an additional state regulating agency. This is the case in California where the California Public Utilities Commission (CPUC) oversees common carriers such as passenger transportation. Therefore the CPUC is the agency that regulates the amount of horizontal gap required for freight car clearance. In the case of California, the regulations required by the CPUC are similar to those of Oregon. The main difference comes with which agency is in charge of regulation (43).

2.2 MODE SPECIFIC CONSIDERATIONS

Differing rail transit modes often have different platform edge safety concerns. These differences can be due to a variety of factors including differences in guideway design, platform heights, station layout, operating on shared right-of-way, vehicle size, vehicle configuration, and operating speed. Considerations related to each rail transit mode should be addressed separately when recommending potential solutions to improve safety at the platform train interface.

Heavy Rapid Rail

Based on the literature review it has been concluded that rapid rail transit generally experiences less technical problems than other rail transit modes with regards to platform train interface safety. This is because rapid rail nearly always runs on exclusive track and does not need to account for freight activity.   Often transit systems incorporate new vehicles into the fleet while continuing to operate the existing trains. Generally the new vehicles have been updated to improve safety, capacity, and/or comfort and often the layout and/or dimensions are not the same as the legacy cars. This impacts platform gap safety when the car width or floor heights change. One example of this comes from the London Underground that has experienced problems due to the integration of various styles of trains. Trains operating on the Bakerloo line are known as small profile trains and are much smaller in size than the standard profile trains that are present in other parts of the system. In fact, the small profile trains have a floor height that is approximately four and a half inches lower than the standard profile trains. This creates larger vertical and horizontal gaps when the smaller trains cross over onto the lines where standard trains operate. The platforms on these lines have level boarding for the larger trains but require a step down to board or step up to alight for the smaller trains (24).

An example of a mitigation technique used to reduce the gap for rapid rail comes from the New York City Subway System. Certain platforms on the system use movable platforms to help eliminate the horizontal gaps. Signs and audio warnings alert passengers to the moving surface and aim to make passengers aware of the movement. Even with these efforts there have been reports of people ignoring the warnings and losing their balance during operation. One potential disadvantage of moving platforms is increasing dwell times. In fact, certain platforms in New York Subway's 42nd Street Station were built initially with moving platforms to fill gaps, however the platforms were later secured in place with concrete because of the negative effects on dwell time.

The Federal Railroad Administration (FRA) manual on Managing Gap Safety also lists movable platforms as a possible solution to excessive gaps. These gap fillers are automatically moved into place when the train comes to a stop. This method can be especially effective on curves where the gap is excessive. Additionally, some operators have platforms with fold up edges that are moved out of the way when a train is not present at the station. One unusual mitigation effort uses rubber gap filler that has fingers that extend from platform. This configuration provides some fall protection and can bend if the car comes in contact with the device (10).

Light Rail and Streetcar

Many light rail and streetcar systems operate in the roadway, and the stations, which may be co-located with bus stops are part of the sidewalk. The design of the new Kansas City Downtown Streetcar system had to solve this challenge. The vehicles that were selected for this new system have ADA accessible doors in the middle section of the train but not at either end. Accordingly, the station platforms have been designed to reflect this feature. The platforms have a 14 inch from top of rail high level boarding section in the middle that is designed to align with the two doors that provide the accessible spaces on the streetcar. The middle section of the vehicle is configured to allow for maneuverability of wheeled mobility devices. At either end of the station, the platform dips down to 7 inches above top of rail or road surface which requires passengers to step up or down to get on or off the streetcar. One of the primary reasons for this design was to reduce the streetcar stations footprint in the urban environment. According to the design documents, nearly half of the station locations are space constrained by obstacles such as parking, loading zones, and driveways. Providing for level (accessible) boarding at only the middle two doors reduces the footprint significantly compared to a traditional platform that allows level boarding at all the doors. The second reason for this configuration is to allow the existing buses in Kansas City to use the stations.

This platform style is also used for the Washington D.C. streetcar at select stops (7). In Seattle the light rail vehicles and buses also share platforms (17).

One of the unique characteristics of the street running rail transit modes (light rail and streetcar) is the use of low platforms. This allows passengers and pedestrians to easily step up and down from the guideway to the platform. A lower platform reduces the severity of injury if someone were to fall, however the smaller height differential makes it easier for passengers to enter the guideway or in the case of some cities to use the platform edge as a bench. The report detailing intrusion detection technologies by Jonathan Hulse documents this and suggests that people also enter the guideway to pick up objects or to navigate around crowds. While light rail and street car vehicles generally move slower when they are operating in the street, this passenger behavior is still be considered to be an unnecessary risk (13).

Commuter Rail

Commuter rail systems in general operate using large single or bi-level vehicles on longer trip lengths with fewer station stops than heavy rail transit. In many situations commuter trains operate on shared track with freight railroad and may experience some of the most severe issues in relation to the platform-train-interface of all the rail transit modes. The combination of high platforms, various vehicle floor heights, and shared right-of-way introduces some unique factors. However, the most significant factor is due to operation on shared right-of-way. Sharing track with freight allows commuter systems to utilize existing rail infrastructure without the additional costs of installing separate track, structures, and signal systems. This also allows for shared maintenance and dispatching which can further reduce the costs to the transit agency.

Two primary considerations of shared track operation are train delay and freight car clearance standards. Most commuter railroads tend to follow Plate C standard that is set forth by the Association of American Railroads (See section on Regulations and Standards). This states that the maximum width of a car cannot exceed ten feet eight inches (10’ 8”). This results in the set back of the station platform to accommodate the dynamic envelope of the freight cars. The set back requirement insures that the platform will not be struck by passing freight cars, however it does produce a horizontal gap that exceeds the 3 inches required under ADA. Additionally, shared operations can lead to certain maintenance factors in relation to track geometry. Traditional ballasted track is subject to horizontal and vertical movement due to normal freight operations. The degree to which the track moves often depends on factors such as type of ties, size of rail, quality of ballast, sub-ballast characteristics, climate, and freight tonnage on the line. The movement can affect the track in various ways including changing the position both vertically and horizontally. This can be a significant problem with the tight gap tolerances set forth by ADA. Regular measurement and maintenance is required to ensure that gap dimensions are acceptable along the entire length of each platform. This can be both costly and time consuming. An additional possible solution could involve using concrete slab track in station areas. This potential improvement may be more expensive in the short term but involves relatively little maintenance over the long term for keeping the gap dimensions within tolerances. The solutions that a transit agency chooses to pursue depends on funds available and preferences of the partner railroad that shares the corridor (10). Many different attempts at reducing the excessive gap problem have been made by different agencies throughout the country and the world. The most successful treatment may differ for each platform along the same line. This can make a “one size fits all” solution very difficult to develop.

2.3 OPERATIONAL ASPECTS

Transit operations in addition to the design of the platform and vehicles can contribute significantly to the safety at the platform-train-interface.

Train Operations

Door Open Schemes

From the operations perspective, one of the methods of improving gap safety is to manage door opening and closing procedures and increasing the dwell time. This is especially important during times when there is significant congestion and slow passenger flows. One specific factor that should be considered with respect to dwell time is adjusting the door closing times. The incident data analysis shows that door closing procedures may contribute to platform vehicle incidents. Additionally, as stated in the New Jersey Transit study, rail vehicles could be configured to only open certain doors at specific stations to avoid larger gaps (6). A potential disadvantage of this strategy is passenger confusion with regards to which doors will actually be opening. An additional possible concern with operations involves the number of trains that arrive and leave a given station. Predictably, more passengers on a platform can lead to more opportunities for incidents. Having multiple trains use the same platform can contribute to an increase in injury potential (6).

Another management tool that was utilized was to adjust train positioning to reduce excessive gaps. At certain platforms the train stopping location is adjusted so that fewer doors experienced significant gaps. For example, cars were “zoned” at specific platforms so that only doors with a safe gap distance would open. While this eliminated many of the excessive gaps, it created longer dwell times and greater passenger inconvenience for boarding. The alternative to train positioning was to increase the number of platform conductors during peak periods at many of the stations with gap problems to provide assistance to passengers during boarding (15).

Trains By-Passing Stations

The Federal Railway Administration Manual on Managing Gap Safety discusses potential factors on train operations that can affect gap safety. There are some operations such as express service where trains bypass a station at a high speed. In this case, the horizontal gaps need to be larger to ensure that the train does not strike the platform when passing by. Additionally, the manual suggests that railroads develop door opening policies and strategies for stations that have excessive gaps. This would be particularly important on platforms that are in curves as there may be significant gaps that are present. This requires different door opening schemes for each platform. If this is the case, communication to passengers on which doors will be available would be important (10).

Railroad Track, Station, and Car Maintenance

The Federal Railway Administration manual on Managing Gap Safety brings attention to the importance of proper maintenance of the track, stations, and cars to ensure the gap is minimized. One example the document listed involves careful consideration of platform maintenance and improvements. Regular attention should be given to the platform edge to ensure that the surface remains sturdy and the gap is minimized. In addition, track maintenance can have a large effect on gap distances. Regular use by passenger and freight trains can cause track geometry and position to change frequently. Regular inspections should be conducted to ensure that changes in alignment, cross level, and curvature do not increase the gap distance or cause the cars to come in contact with the platform (10). Vehicle or car maintenance is also an important factor in the overall safety scheme. Failures with various components such as wheels, trucks, and self-leveling systems can cause excessive gap issues. The vehicle suspension system controls the vertical and to a certain extent the horizontal gaps.

Public Relation Campaigns and Information Systems

From the TCRP A-40 webinar and various stakeholder surveys it has been determined that public relations campaigns can improve safety. The importance of educating passengers and employees about platform safety was emphasized quite frequently in discussions and surveys. Effective techniques include automated announcements on trains and platforms, safety videos, posters, and placards. In addition, one transit agency has emphasized the importance of creating a robust "safety culture" to reduce incidents.

Dumb Ways to Die

One unique idea that was employed by Metro in Melbourne, Australia involved the creation of an Internet based video ad campaign and mobile application entitled "Dumb Ways to Die". Through the use of humor and rather graphic images of animated characters dying in what were determined to be stupid ways, the message is conveyed that people should be careful around railroad tracks and stations. While this specific video might not be appropriate for all audiences, the use of humorous videos to convey safety messages could be potentially very effective on transit users.

A similar effort was undertaken by various airline companies recently in efforts to have passengers pay closer attention to the preflight safety briefings. Indications suggest that using humor is more effective than traditional briefings (14).

One of the most recognized public relation campaigns in relation to the platform-train-interface is “Mind the Gap” from the London Underground. The London Underground is over a hundred years old and many stations have large vertical and horizontal gaps(12). Railway systems in the United States have slightly modified this statement for their own public relation campaigns.

Managing the Gap

The Federal Railway Administration manual on Managing Gap Safety has many suggestions for public awareness. The manual encourages the use of audio announcements, signs, posters, brochures, information on ticket stubs, videos, and seat dropped material. One interesting twist on a simple audio announcement involved using celebrities to convey the messages. The example cited came from the airport in Las Vegas. The theory is that more people would pay attention to a voice they recognize from a TV show or movie (10).

Audio and Visual Announcements

The Japanese case study also included information systems in the model regarding gap safety. The two main factors considered were the presence of both visual announcements and auditory train approaching announcements. Stations that did not have either visual or auditory announcements were rated lower in terms of safety than those that included warnings. Another interesting point that was briefly stated in the report was the standardization of pictograms and signage throughout a country. Having consistent warnings regardless of mode and system could improve gap safety across the country (26).

The Long Island Rail Road and New Jersey Transit Rail both have placed an emphasis on public relations in order to improve safety relating to gap injuries. The Long Island Rail Road has stenciled “Watch the Gap” on the edge of many platforms along with red painted warning sections that draw extra attention to the areas of the platform where doors open as shown in (See Figure 11) (6). Several rail transit agencies have aggressive ad campaigns that include posters, placards posted on trains and in stations, brochures, audio announcements both on train and on platform, visual warnings via electronic signs, and a detailed safety video posted online that details the danger of the gap (15).

Figure 11: "Watch the Gap" and Red Painted Warning Markings on Long Island Platform (15)

Transit Agency Employee Training and Safety Culture

Employee training can be one effective way to reduce the number of platform-train-interface injuries. Employee training should focus on recognizing the risk factors associated with platform train incidents such as crowding, people with disabilities, age, and people who are carrying luggage. Additionally, the employee should be briefed on situations and locations where these injuries are most likely to occur (6).

The Federal Railway Administration report on Managing Gap Safety suggests that each type of employee get specific training that pertains to their duties in relation to safety. For example, train crew and conductors should be trained in platform monitoring, look back procedures, and monitoring door openings and closings. Maintenance crews should be trained to recognize features on the platform, track, and cars that could potentially increase the gap. Other employees that should receive training include station personnel, station supervisors, station security officers, and railroad police (10).

Beyond employee training, McElveen suggests that it is necessary to create a sustainable safety culture at a transit agency to overtime improve employee safety behavior and reduce incident possibilities. According to the McElveen, transit agencies should evaluate their own safety culture through both internal and external surveys and assessment. It is important to consider employees at all levels, as safety should be just as important for front line employees as upper management. A true safety culture should consider the views, beliefs, and attitudes towards work and the organization as a whole.

Changing culture at any big organization can be very difficult depending on the magnitude of the change. Often, there are two primary methods that are considered for influencing change within an organization. The first is where the agency suddenly makes a change. Examples of this type of change could be from a new technology being introduced or as the result of an incident. The changes come swiftly and are often not well received and require rather quick adaption. The preferred method, when time allows for it, is known as evolutionary change. As the name suggests this type of change comes slowly over time. It allows employees to adapt to the change at slow and simple rate that encourages participation. As the program progresses the impacts of the changes can be tracked and the culture properly instilled among employees. Incremental step programs have been shown to improve retention and have improved employee attitudes.

It is important that a transit agency be able to define their safety culture and furthermore be able to measure it. How and what a transit agency might measure will likely vary from system to system. McElveen goes on to suggest that the metrics that will be measured should be valued by a large variety of stakeholders both within the agency and externally as well. Potential examples of internal employees include upper level managers, front line employees, engineering, and safety related employees. External stakeholders could include passengers, contractors, and the community at large. From an internal perspective having a variety of employees provide input on development of the safety culture will improve the transition between what is currently in place and the goal. If upper level management develops the plan without considering the individual needs of the large variety of stakeholders, the result will likely involve pushback from those employees.

Successful development and implementation of a new safety culture should be an iterative process with a variety of sources of input. When considering the new plan, clear goals should be established and steps to achieve these goals should be laid out with a designated timeline. Intermediate goals and specific steps and actions should be listed to ensure greater organization. It may be necessary to create an overall plan that is supplemented with more focused plans that involve the various stakeholder groups. Doing this will allow a global perspective and help employees better understand where they fit within the overall agency safety culture. Safety culture can be a powerful tool that can improve both the reliability and safety for both passengers and employees of a transit agency.

Railroad Hazard Analysis Process

The Federal Railway Administration strongly recommends that passenger railroads work to develop a hazard analysis plan as part of the hazard management process. The plan should be highly structured and ensure that all potential hazards are identified, inventoried, analyzed, and then mitigated at the earliest possible opportunity. According to the detailed appendix that was included with the Managing Gap Safety report there are four main categories to consider for the hazard analysis; people, procedures, equipment/facilities, and environment. For a hazard management plan to truly be effective it should be constantly updated and be created during the design phase for a new transit system. A regular review of safety concerns should be laid out within the plan and also should be conducted whenever a gap related incident occurs. In addition, there should be a review of current mitigation measures at a regular interval.

Hazard Identification Process

The hazard identification process involves studying all the factors that could result in a passenger injury caused by the gap between the train and platform. These range from passenger characteristics to vehicle and track features. The identified hazards are then assigned a criticality level. The scale is from one to four, with one being a catastrophic outcome (death, shutdown of system, or severe environmental impact) to four (less than minor injury, minimal system damage, or inconsequential environmental impact).

The next step examines the potential level of frequency for the identified hazards. This scale uses letters from A to E, with A defined as an event that is likely to occur frequently (once a week) and E representing a very unlikely or improbable event (less than once in every 10 years). A risk matrix can be created from these two metrics to asses each identified hazard. An example that the Federal Railway Administration used in the report can be seen in Table 2. This matrix paired with the suggested actions table that can be seen in Table 3 can be used to determine the level of action for each hazard. A mitigation strategy can begin to be developed that aims to reduce the severity or the frequency of incident occurrences. The hazard is then reevaluated with the risk matrix and suggested response table to determine if a satisfactory improvement was made. This process generally takes place on a worksheet that can be later referenced to determine effectiveness for different approaches (10).

Table 2: Risk Matrix for Hazard Analysis (10)

	Hazard Categories			
Frequency of Occurrence	**I Catastrophic**	**II Critical**	**III Marginal**	**IV Negligible**
A – Frequent	1A	2A	3A	4A
B – Probable	1B	2B	3B	4B
C – Occasional	1C	2C	3C	4C
D – Remote	1D	2D	3D	4D
E – Improbable	1E	2E	3E	4E

Table 3: Suggested Actions for Identified Hazards (10)

Risk Matrix Hazard Category	**Suggested Action**
1A, 1B,1C, 2A, 2B, 3A	Unacceptable, eliminate hazard
1D,2C,2D,3B,3C,4A,4B	Undesirable, upper management decision to accept or reject risk
1E,2E,3D,3E	Acceptable with management review
4C,4D,4E	Acceptable without review

2.4 PASSENGER CHARACTERISTICS AND CONDITIONS

Passenger characteristics include people of different age, gender, cultural backgrounds, with limited mobility and sensory capabilities. Other characteristics include whether they are frequent travelers and if they are traveling with children or luggage. Passenger conditions such as being suicidal, intoxicated, or distracted may also contribute to incidents such as tripping and falling.

User Characteristics

Age

The age of the passenger is a factor reported in both the New Jersey Transit study and the Rail Safety and Standards Board studies (6,18). Findings from both investigations seem to suggest that there is a significant difference in injury rates based on age. Specifically, the Rail Safety and Standards Board study focused on passengers less than 16 years of age. They found that people in this age group had a higher accident rate proportional to the number of total passengers in that category (18). The New Jersey study broke the age categories down a bit further and put children under the age of ten and a 10-20 year old segment into separate categories. According to their results, children under the age of ten were at a very high risk for a boarding or alighting gap accident. However, the percentage of injured was reduced for those in the 10-20 year old category. Based on the data presented from both studies, it can be concluded that children have a higher risk for platform incidents (6). Both studies cite reasons such as size, physical capabilities, distraction, and lack of experience with transit as possible reasons for this.

Elderly passengers also have a very high number of incidents relative to the number of total travelers. Both studies found that people over the age of 50 had a significantly higher chance of a platform accident as compared to middle-aged passengers. The Rail Safety and Standards Board study found the over 50 year old category to have the highest magnitude of gap related incidents (18). The New Jersey Transit Study also found this age group to have the most platform incidents (6).

Gender

According to both the New Jersey and Rail Safety and Standards Board studies, females tend to have a higher risk of injury for gap related incidents. Based on the results published by the New Jersey Department of Transportation, 69% of the gap related injuries on New Jersey Transit involved women (6) . The Rail Safety and Standards Board report had similar results with approximately 63% of the total boarding and alighting platform incidents involving female passengers. However, one of the possible reasons listed for this was that perhaps women are more likely to report a platform accident (18).

One interesting difference between the New Jersey and British studies occurs when both age and gender are accounted for. The New Jersey study found that in the younger age category, 0-10 years old, there was a 20% difference in the number of injuries between male and female (6). The report published by Rail Safety and Standards Board found there to be little difference in the youth category between males and females. One of the reasons cited for this was minimal difference gender is attributed to children's footwear. Both reports did agree that for people over 50, a larger percentage of women were report to be injured. Women's footwear was one of the reasons cited for women having an increased injury rate (6,18). Specifically involving women who tend to wear high heeled shoes that could contribute to instability while boarding or alighting (18). Additional reasons mentioned by the New Jersey study involved women pushing strollers and the distraction of small children. Both factors were determined to have a small effect during the observational studies (6).

Tourists

Multiple studies suggest that familiarity with rail transit may have an effect on platform train related incidents. In general, accident rates tend to peak during the morning and afternoon peak for the working age group (30-40 years old). These travelers would likely be regular passengers and the increase in number of injuries may be due to more people present on the platform. However, it has also been suggested that midday injuries may be due partly to inexperienced riders. Confusion due to unfamiliarity with rail transit operations and procedures could cause distractions while boarding or alighting (6). The Rail Safety and Standards Board study also cites an increase in injuries during the summer months to an influx of tourists. According to the report, tourists are likely be less experienced with specific rail stations and may be less aware to the risks associated with boarding and alighting (18).

Luggage

In Bangkok passengers that were travelling to and from an airport were more likely to have luggage that could lead to boarding or alighting issues (21). This conclusion was backed up by the study done at Delft University of Technology in relation to boarding times with luggage (5). According to the findings, the presence of luggage can decrease the boarding or alighting capacity by up to 25 percent. Not only can the luggage be a problem for the owner but other passengers who are trying to move about the train and station (5).

User Conditions

Disruptive Behavior

The Federal Railway Administration Manual on Managing Gap Safety discusses the issues related to passenger behavior. According to the report, disorderly conduct or disruptive behavior can increase the risk of a gap accident to the offender and those in the surrounding area. A similar conclusion was drawn about unmonitored children, although they present a greater risk to themselves as opposed to others. The manual suggests that it is the duty of both the conductors and station personnel to prevent these unsafe behaviors. Mitigation efforts for these problems would be addressed in employee training (10).

Intoxication

Intoxicated passengers have significantly higher accident rates as compared to the general population. According to the Rail Safety and Standards Board study males are more than twice as likely to be involved in a boarding or alighting accident, and other types of incidents while intoxicated. In the British report, approximately 6 percent of the overall boarding and alighting incidents involve intoxicated passengers. Furthermore it was reported that these incidents are most likely to occur Thursday through Saturday evenings with a peak at 11:00 PM. The data showed that between the hours of 9:00 PM and 12:00 AM the accident rate involving intoxicated passengers is twice that of sober passengers (18).

The researchers at Tokyo University of Science also found intoxication to be a significant factor contributing to platform injury rates. In fact it was one of the highest weighted variables present in their model on platform safety (26). The Bangkok Mass Transit System also recognized the potential safety issues caused by intoxicated passengers. According to the findings from a passenger survey, the majority of people suggested that they thought intoxicated passengers should not be allowed to ride the trains (21). This is contrary to many of the “designated driver programs” that are provided by North American transit agencies.

Distracted Passengers

Distracted passengers have been an issue that has been cited by multiple studies and was brought up extensively at the workshops (23, 25).

Personal Electronic Devices

Cellphones and MP3 players have essentially made many passengers blind and deaf according to a study on intrusion prevention technology. These distractions greatly affect people’s ability to recognize an approaching train or judge a gap distance (13). The New Jersey study did not find cellphone use to be highly significant based on people talking on the phone because of excessive noise on the platform (6).

However, since the New Jersey report was published in 2009 there is evidence that the use of smart phones has increased dramatically. The Wireless Association, conducted a survey in 2014 and reported that smart phone market share has more than tripled from December of 2009 through December of 2013 (4). The primary distraction measure for a smart phone would likely not be a phone conversation but rather texting, email, Internet, music, or application use.

Research has not been conducted into the relationship of cell phone use and platform train interface safety. Some of the results of recently completed studies on distracted pedestrians are relevant (23, 25). Researchers at the University of Alabama tasked college students with talking on the phone while trying to cross a street with simulated traffic. The students were exposed to varying levels of complexity with respect to the phone conversations. After the trials it was concluded that talking on the phone distracted pedestrians significantly regardless of the complexity of the conversation. Interestingly it seemed that the individuals were able to recognize the visual clues but would often miss certain key elements that would allow them to make safe decisions to cross the street (25).

An additional study also completed by the University of Alabama team goes on to make the comparison between pedestrians that were not distracted, talking on the telephone, texting, and listening to music. According to their results, texting and listening to music led to a higher level of distraction than simply talking on the phone, and this implies that talking on the phone, texting, and listening to music increase the level of distraction when crossing the street and can lead to an increase in dangerous behavior (23).

These studies were not conducted in relation to passengers using personal electronic devices on the platform, however it could be hypothesized that similar distraction characteristics exist. It would be reasonable to conclude that cellular telephone use will increase the likelihood of possible injury due to distraction.

Cultural Variations and Congestion

Passenger crowding can have a significant effect on boarding and alighting safety. As noted by Hulse, platform congestion can vary significantly from location to location. Cultural variations can also influence whether passengers form orderly lines on the platform or tend to cluster near to the door locations. Higher levels of congestion were determined to increase injury possibilities at the platform-train-interface (13). Crowded conditions are often seen on the Bangkok Mass Transit System, particularly at transfer stations during the morning and evening peak times. Based on passenger surveys, crowded platforms were seen as a significant factor that contributes to injuries in stations (21). Crowding was also found to have a large negative effect on safety in Japanese railway stations (26).

The boarding and alighting experiment conducted at Delft University of Technology looked at passenger crowding characteristics as it related to dwell times. Intuitively, as the density of passengers increased on both the train and platform, the speed in which they were able to board or alight decreased (5). The Federal Railway Administration report on Managing Gap Safety also concluded that as the level of crowding increased, so did the risk of a gap related incident. This was found to be true for those stations with well managed gaps as well as those platforms that suffered from excessive gaps (10).

Incident Characteristics

Gap versus Non-Gap Related Incidents

One very important distinction with platform-train-interface injuries is the difference between those that involve the gap and those that do not. In general, non-gap injuries are far more prevalent on most rail transit systems. For example, only about 25% of the total injuries from 2005 to 2008 on New Jersey Transit actually involved the gap. The other injuries involve other factors such as falling onto the tracks (no train present), slips, trips, or falls around the platform (6).

The report published by Rail Safety and Standards Board also makes a distinction between gap related injuries and non-gap related injuries. The study specifically divided the data up between boarding and alighting incidents versus non-boarding and alighting incidents. Non-boarding and alighting injuries primarily occur when a passenger is struck by a train entering or leaving a station or result from a fall from the platform when no train is present. Throughout the report there are statistics given for both injury categories. In general, based on the data collected there are many more fatalities that occur with non-boarding and alighting incidents as compared to boarding and alighting incidents. However, there is a higher percentage of fatalities and weighted injuries for boarding and alighting incidents (12%) than for non-boarding and alighting incidents (8%) (18).

Boarding versus Alighting

Transit agencies are often interested in the difference in risks between boarding and alighting at a station. A study performed in 2008 by Winnie Daamen, Yu-Chen Lee, and Paul Wiggenraad at Delft University of Technology in the Netherlands suggests that boarding and alighting behavior differ based on various characteristics of both the station and the vehicle. The study involved looking at factors that affect both boarding and alighting times, alighting headways were found to be shorter than boarding. Reasons for this are attributed to the queuing patterns near doors, gap size, and presence of luggage (5).

Faster alighting times could contribute to the higher percentage of alighting injuries (52% of overall) reported by the Rail Safety and Standards Board (18). It is hypothesized that the faster pace contributes to less control that result in more incidents. The study also states that alighting incidents account for more than twice the injury severity potential as compared to boarding incidents. Two listed possible causes of this involved a greater distance to fall from train to platform and/or lack of objects to grab on to regain balance (18). In contrast to the Delft study, the New Jersey Transit study found that more injuries occurred during the boarding phase as opposed to alighting (66% of overall incidents) (6).

Time of incident

The New Jersey study examined the relationship of the time of incident and other characteristics such as age or gender. The data showed that by age injuries were most likely to fall in the following times:

By Age:

- Young children: midday (10 AM-3 PM), the PM peak (3 PM-7 PM) or PM non-peak (7 PM-12 AM)
- 30-40 year olds; the AM peak (7 AM-10 AM) or PM peak (3 PM-7 PM)

By Gender:

- Men:
    - Distributed throughout the day with slight peak in PM and PM Non-peak hours,

    - Monday, Wednesday, and Sunday
    - January through March and July through September
- Women:
    - AM and PM Peak
    - Tuesday, Thursday, Friday, or a Saturday
    - April to June and October to December

The report published by Rail Safety and Standards Board also had results concerning time of day and gap related injuries. These findings however were not broken down by age and gender. Interestingly, the results from the report suggest that the incident rates are highest in the off peak times of day (midday) and the PM peak. There is also a small increase in injuries at 8:00 AM. The early morning peak differs from the New Jersey study as it seems to suggest that the peak periods do have increased risks for injuries relating to the platform train interface. When considering days of the week, it appears that the number of injuries is somewhat consistent throughout the week and decrease on the weekends quite dramatically. This is likely due to fewer travelers on rail transit networks on the weekends (18).

2.5 METHODOLOGY CASE STUDIES

New Jersey

Platform safety studies often involve a series of surveys, transit operator incident data, and/or field observations. The New Jersey Transit case study utilized both New Jersey Transit Rail safety data and observational surveys in various stations. The safety data allowed the researchers to relate various passenger characteristics to external factors like time, gender, and age. The number of gap related incidents versus non-gap incidents could also be separated and related to the same external factors.

The main goals of the site visits were to record the total number of boarding and alighting passengers, note how many of the passengers looked down while boarding or alighting, and the presence of a distractor such as luggage, stroller, small child, or cell phone. One of the major issues encountered by data collectors included having too many boarding and alighting passengers. When congestion was high it became difficult to see the passengers and accurate observations were not possible. However, overall 1,212 observations were made at the four stations. Various conclusions about gender and distractions were made from the compiled data (6). The final product of this data analysis was a series of plots and a few tables of data. The graphical results and the descriptions allowed accident trends to be easily observed. The report also summarized results of passenger observational surveys that were conducted at five stations that reported a higher frequency of gap incidents.

Bangkok Mass Transit System

The case study from the Bangkok Mass Transit System used passenger surveys to determine what aspects passengers perceived to contribute most to platform-train-interface incidents. To develop the survey, the researchers conducted a literature review and observed passenger behavior at two busy platforms. For the actual safety related questions, the questionnaire was set up to represent a passenger's feeling towards a specific safety aspect. One of the specific questions of interest for this study revolved around the possible installation of platform screen doors. This information was presented in two pie charts to better show the responses. The results showed that most people wanted the doors to be installed but without an increase in fare (21).

Japan Study- Analytical Hierarchy Process

The case study involving platform safety of railways in Japan numerically modeled safety to allow risk assessment comparison between stations. The primary goals were to identify specific safety weaknesses at stations and evaluate the effects of potential mitigation strategies. Initially an exhaustive list of concepts relating to station safety was created. From that overall list, evaluation factors were selected for the model that could be quantifiable and were thought to have a significant impact on station safety. These factors were then categorized into four groups; platform structure, passenger flow, train operation, and passenger profile.

The Analytical Hierarchy Process was used to evaluate the individual factors to determine both major and minor factors that contributed to platform safety. For each of the four major factors listed previously, there were up to five minor factors included that related to station safety. To determine the weights of each factor, a survey was distributed to station staff, train company officials, and passengers. Data that contained a range of values (crowding, length, width, etc.) was broken into five groups and assigned a number score based on percentile of the observed data. Discrete variables (platform shape, clarity of indicators for train direction, etc.) were assigned values based on professional opinion.

Comprehensive safety scores were developed for a total of 28 platforms at 10 different stations belonging to seven different railway companies in Tokyo. The distribution of stations and platforms were chosen in relation to the number of incidents and to achieve a balance between the various companies. Data was collected from the respective stations through observation and paired with data that was provided by the railway companies. In total 16 data points were collected for each platform with each representing a safety factor. Each factor was then assigned a score based on the previously established standards. The raw scores were then multiplied by the weighting factors and a platform comprehensive score was produced.

Horizontal bar graphs were chosen to display the resulting scores for each factor so they may be directly compared to each other. A similar graph allowed the various platforms to be compared as well. These visuals allowed researchers to determine which aspects were most critical in terms of safety hazards at specific platforms. Another interesting feature of the model was the ability to predict impacts to safety based on the manipulation of a given factor. For example, if the overall platform area was increased it would be possible to measure how much safer that improvement would make the platform. This tool could be useful to both researchers and railway operators (26).

2.6 ASSESSING MITIGATION APPROACHES IMPLEMENTED WORLDWIDE

Introduction

A survey of technical gap mitigation solutions that are implemented worldwide was performed. A summary of the most promising solutions is outlined in the following sections. Transit agencies are considering automatic train control operations to improve headways to manage congestion. In addition, the advances in analytics are providing more options for intrusion detection and management. These new technologies include platform edge doors and advanced video surveillance with analytics for intrusion management. Also, Cooperative Research Centre (CRC) for Rail Innovation based in Brisbane, Australia, has released a report that has outlined some of the current and newly patented designs of platform gap closing solutions for rail transit platforms (30).

In North America most commuter rail systems share track with freight railroads. This introduces increased horizontal and vertical gaps between the commuter rail car and the platform. In addition, the floor height of the commuter car can vary if an operator is using both single level and bi-level rolling stock or different generations of rolling stock. The vertical and horizontal gaps between the vehicle and platform need to be bridged to create accessible boarding. The examples to be discussed include gauntlet track, moving platforms, platform fixed boards, onboard and automatic gap fillers and sliding ramps.

Gauntlet Track

A gauntlet track is a parallel track to the main track that is used to bring a train closer to the platform to reduce horizontal gaps. It runs the length of the platform with two switches for the train to come on and off the main track. It should be noted that a gauntlet track is not a traditional siding track where the passenger train moves to a new track with full track spacing. Rather the switches move the train to an offset track that features one rail between the existing rails and one slightly outside. Freight trains have wider lateral dimensions than passenger trains, and the dynamic envelope resulting from the sway of the vehicles requires that the platform is set back from the edge of rail to accommodate the freight train. When a passenger train uses the same track, there is a large horizontal gap between the car and the platform. To resolve this problem, gauntlet tracks are used to mitigate the gap between the platform and a passenger train.

Westside Express Service Portland, Oregon

The use of a gauntlet track is one solution to solve mixed operation problems with regards to horizontal gap distances. One example of this method comes from the Westside Express Service (WES) commuter train operated by the Tri-County Metropolitan Transportation District of Oregon (Trimet) in Portland, Oregon (See Figure 12). The 14.7 mile long corridor has five stations and operates on shared track with a regional freight railroad. The Oregon Department of Transportation required a clearance distance of seven feet and three inches (7' 3") from centerline of the track to the edge of the station platform. During the project development phase it was determined that the car widths for the proposed diesel multiple unit trains were only 10 feet and 10 inches wide (5' 5" from centerline to edge of vehicle). Thus, in order to comply with the Americans with Disabilities Act regulations of a maximum three-inch (3") horizontal gap, a solution was needed. Several options were considered such as mini-high platforms, motorized platform extensions, manual platform extensions, and gauntlet tracks. The gauntlet track was selected as the preferred alternative.

The developed gauntlet track consists of two switches 466 feet apart (point of switch to point of switch) with a platform length of 146 feet. These switches move the commuter train approximately one foot and eight inches closer to the platform while allowing freight trains to remain the legal distance. With this shift, the horizontal gap is reduced from one foot and ten inches down to two inches, respectively. This gap is fully compliant with the Americans with Disabilities Act regulations. Based on the success observed with the Westside Express Service in Portland, more applications of gauntlet tracks are suggested for similar areas with mixed rail operations (16). A report published by the Federal Railroad Administration entitled Managing Gap Safety also suggests gauntlet tracks as a potential solution to the excessive gap problem (10). It should be noted that New Jersey Transit also currently has a gauntlet track in operation at Union Station on the Raritan Valley Line (1).

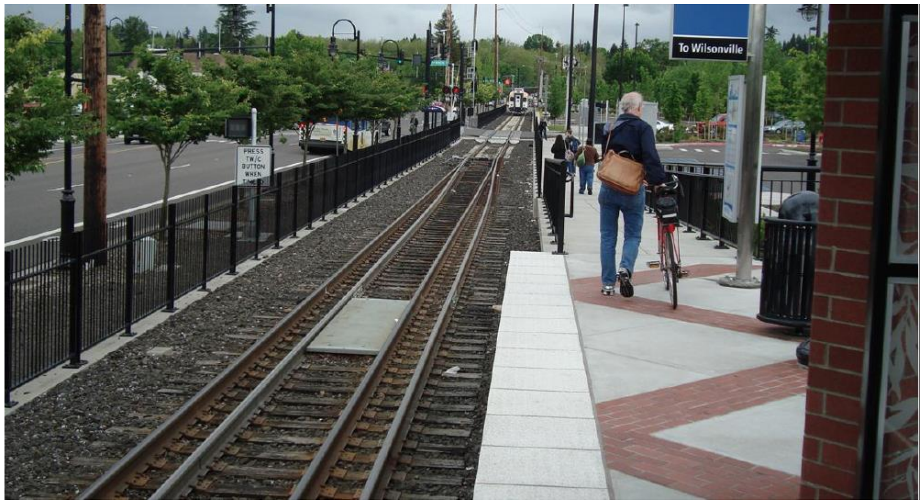

Figure 12: Gauntlet Track at WES commuter rail station in Portland, OR (16)

Moving platform –Amtrak, United States

A concept has been developed by Amtrak to reduce the horizontal gap between the passenger train and the platform on tracks that see both passenger and freight traffic. A section of the platform moves horizontally towards the passenger train door section to allow passengers to board. New York City Transit (subway) has a few operating movable platforms also. Some have been removed or secured in place with concrete due to the large increase in dwell time and potential injury possibilities. Figure 13 shows a picture of this new concept developed by Amtrak.

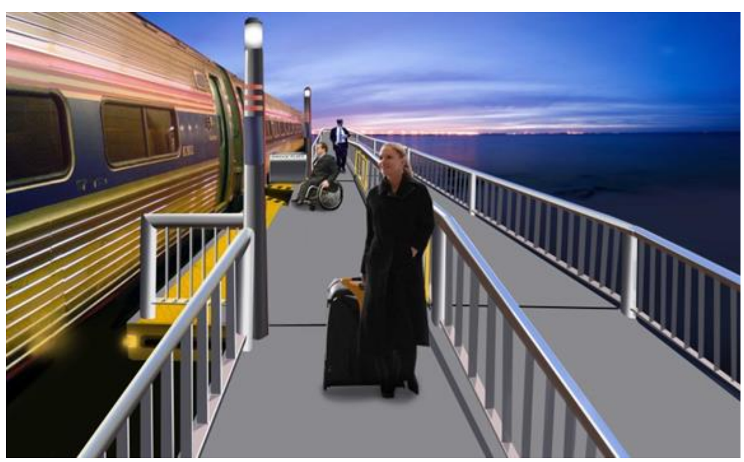

Figure 13: Moving Platform Concept by AMTRAK (RVAAC Committee)

Platform Fixed Gap Boards

On existing platforms used by legacy rolling stock, a horizontal gap may exist when new rolling stock is introduced. In this case, fixed boards that are attached to the platform are added for the sections where the door positions are. This can only be achieved if a train consist always has the same vehicle configuration with predetermined or predictable door locations. There is the potential that the boards are applied to the whole length of the platform, however this will create other challenges for freight train operation. In Figure 14, the fixed platform boards are used on the commuter train system in Ottawa that operates on exclusive track that is no longer used for freight operations. The boards were initially designed to move up and down, but currently they are always down.

Figure 14: Fixed Platform Board on the OC Transpo Commuter System in Ottawa, Canada

Onboard Automatic and Manual Gap Fillers

Newer commuter and light rail trains running on older tracks or those sharing tracks with freight trains can provide car based automatic or manually operated gap fillers. These are small ramps that slide in and out from under the doors when the doors are closed. The automatic board slides out when the train comes to a complete stop before the door opens and retracts when the doors are closed prior to departing. The manually operated boards will deploy when a customer pushes a button on the inside or outside of the train while stopped at a platform. These technologies often require exemption provisions, however they are often very simple devices with manual operation by a member of the train crew.

It is important to note that on most systems the doors must be shut for the gap fillers to operate. Thus this can increase dwell time if the doors must cycle shut to deploy the ramp if the button is pushed after the doors have been initially opened. However, the automatic operated ramps have not shown to increase dwell time. In both cases the ramps can be present at all doors or designated locations throughout the train. This solution can be applied to various types of rail transit with varying gap distances (See Figure 15).

Figure 15: Automatic Gap Filler Shown on a German LRT

A variation of an automatic gap filler is shown in Figure 16. To mitigate horizontal and vertical gaps, in particular for metro/subway operations, a swing-out gap bridge, based onboard the car, has been developed and is applied successfully on all Metro cars in the city of Vienna, Austria. The system works only for small horizontal and vertical gaps and is placed under each door. The system is applied when doors are closed.

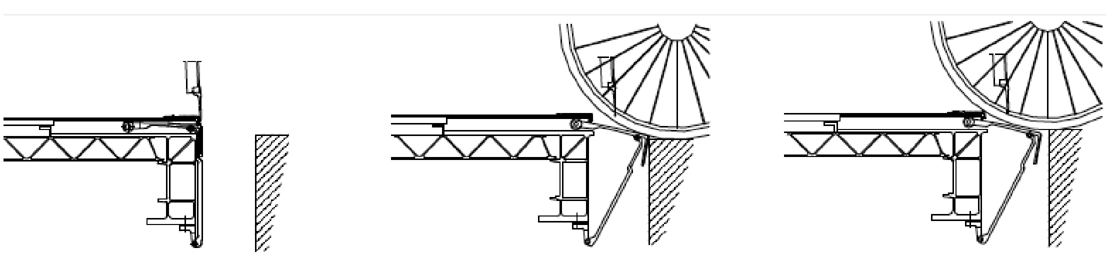

Figure 16: Onboard Automatic Swing Out Gap Bridge (Bombardier for Vienna Metro

Sliding Ramps

A sliding ramp can mitigate both horizontal and vertical gaps and works particularly well for passengers using mobility devices where the car floor is higher than the platform. The length of the platform typically exceeds the width of tactile platform edge strips and thus does not interfere with a mobility device's wheels of the tactile strip. The ramp is located above the accessible car door and slopes back into the car. Its deployment may have an impact on dwell times. These ramps are mainly used on trams, light rail, commuters, and some intercity trains where the vertical gap does not exceed 3 inches. Figure 17 shows a side view of a sliding ramp.

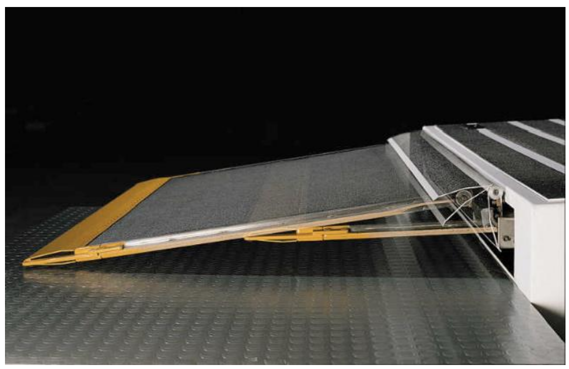

Figure 17: Sliding Ramp (Bombardier)

Raised or Partially Raised Platforms

Figures 18 and 19 show a platform in the Vauxhall Station of the London Underground that has been partially raised to reduce the vertical gap between the platform and the vehicle. In addition the overhead sign indicates the location of the accessible door.

Figure 18: Partially Raised Platform at the London Underground Vauxhall Station

Figure 19: Accessible Door Location Marking on Raised Platform Edge and Overhead Placard Showing Location of Accessible Door

Despite the raised platform there is still a significant vertical gap between the platform and vehicle that would not meet the ADA standards in the United States. Figure 20 shows passengers exiting a vehicle at the Vauxhall station.

Figure 20: Passengers Exiting Train at Raised Platform in Vauxhall Station

In addition to the raised platform at Vauxhall Station, there are barriers to reduce intrusion by passengers at the end of the platform (See Figure 21).

Figure 21: Barriers to Reduce Passenger Intrusion at the End of the Platform

2.7 IDENTIFICATION OF OPERATIONAL BEST PRACTICES

Platform Safety

There are several different strategies that can be used to reduce the potential for track intrusions from the platform:

- Active intrusion methods – these includes physical barriers such as doors and high railings, etc.
- Passive intrusion methods - these include environmental features such as:
    - Signage and environmental graphics
    - Material differentiation – such as platform striping, changes in color, texture, and design cues that intuitively lead passengers to the proper waiting and boarding locations

Transit agencies may also implement the use of separate electronic intrusion detection systems that alert train control and security staff that a track intrusion has occurred.

All transit agencies must engage in public outreach programs that educate the public about safe use of their particular modes of transportation. This outreach program will provide the basic framework for understanding the interaction between the vehicle and the rider. This also includes the need for a suicide prevention program.

Suicide Prevention

A report that was released from the Mineta Transportation Institute at San Jose State University focuses on rail suicides on commuter and metro rail systems in the United States. The report starts by reviewing the numbers of suicides that relate to rail public transportation in the United States. It states that in the period of 2003 to 2008 there were roughly 30 suicides per year on 48 total systems. By comparison, in the year 2010 alone there were over 38,000 suicides around the country. Thus it can be concluded from this report that rail public transportation related suicides make up a very small percentage of the overall suicide problem in the United States. While these numbers are certainly small, it does not mean that transit agencies should ignore suicides as a problem all together.

Suicides are quite costly to a transit agency and a local community. Transit agencies are often limited in their resources and should strategically focus available resources to prevent suicides on the system. The report suggests that transit agencies let the community at large be responsible for determining the motivations for suicides and creating overall prevention programs. However the transit agencies should be involved with the process where these programs intersect with the railroad. The report suggests that an example of this would be to include signs or telephones that access a local suicide crisis hotline (see Los Angeles Metro example). Furthermore, the transit agency could partner with the community to determine locations that are at a higher risk for suicides. Specific projects could then be identified at these locations and a cost-benefit analysis could be conducted to determine which projects could see the most improvement. When projects are implemented, the transit agency should keep records of the costs associated and safety improvements. The report suggests that even if a careful cost-benefit analysis is conducted there may be very few cases when the projects will make sense to complete for the sole purpose of suicide prevention. This mainly stems from the relatively few incidents that are seen on rail transit systems. However, if suicide prevention projects align with overall system improvements the likelihood of project approval and funding would be higher.

Previous research has indicated that the most common locations for suicide on a rail transit system tends to be near at grade crossings or rail platforms. Thus efforts to limit access and improve security at these locations could be an effective way to reduce the number of suicides on a system. Again, with suicides being a relatively rare occurrence, these projects will likely need to be combined with general improvements to prove economic benefit. Specific methods that can be employed at a station platform have been discussed throughout this report. However some common examples include platform screen doors, intrusion detection, and suicide hotline signs posted in and around stations (14).

A specific example of the suicide hotline posters was discussed at the workshop and during interviews transit agencies. Los Angeles Metro (LA Metro) mentioned the use of suicide crisis line placards on platforms and at grade crossings (See Figures 22 and 23). According to the sources at LA Metro the large increase in number of calls into the hotline suggests that the campaign is seeing success.

Figure 22: Crisis Line Placard at Level Grade Crossing (LA Metro)

Figure 23: Crisis Line Placard at the End of the Platform (LA Metro)

Public Relations

A number of transit agencies have instituted public relations and marketing campaigns to engage the public to develop a culture of safety and security. The programs at the basic level include signage and information brochures. Ongoing communication and passenger education can also improve safety. In Philadelphia, several initiatives have been applied that are shown in Table 4.

Table 4: SEPTA Public Relations Initiatives (Source: Metro Magazine, May 15-19, 2013)

–Operation Lifesaver presentations to a variety of school and community groups
–Monthly Safety Blitz programs - Safety Officers visit passengers at the railroad
–Safety Awareness Day (first was held 2013 May 1)
–Conduct such campaigns regularly
–Conduct at locations known to be potentially hazardous

Public relations materials developed in Australia, Philadelphia, Chicago and New York include videos to discourage guideway and track intrusion. Table 5 includes links to these videos.

Table 5: Links to Websites that Discourage Intrusion

Australia: http://dumbwaystodie.com/
Philadelphia: Make the Safe Choice; http://www.septa.org/safety/safe-choice.html
Chicago: It's not worth your Life: Stay off the Tracks http://www.transitchicago.com/assets/1/misc_images/Rail_Safety_Campaign_Car_Cards_FINAL_September2013.pdf
New York City: http://web.mta.info/nyct/safety/

2.8 GAPS IN THE LITERATURE

The literature and related research studies on the interface between the train and platform has been limited. The most recent studies are based on automatic train control systems and the introduction of platform edge doors. As a result of the data analysis activities, several gaps in the literature have been identified; lighting at the edge of platform and vehicle doors, acoustics, platform design, and passenger behavior.

Lighting

Two studies examined the natural levels of light but failed to make solid conclusions on how lighting levels really affect platform safety (6, 18). There is a need to understand how ambient light levels impact passenger's ability to identify and properly traverse the gap between the platform and train. Specifically there is a need to study the effects of various types and levels of lighting.

Acoustics

Examination of acoustics of transit platforms is also needed. Ambient noise levels can have large impact on people with low vision and can also increase the stress level of people in a crowd. It is not known whether excessive noise on a platform could contribute directly to platform type injuries.

Platform design

Many of the platform studies have focused on high level platforms used for either commuter rail or heavy rail operations. There is a need to examine some of the differences in platforms safety between high platforms and low platforms. In addition to platform height and width, it is important to study platform configuration. The study from the Tokyo University of Science discusses the differences between center island and side platforms. Further study is needed of fundamental station design and the different risks attributed to platform configuration.

Curved Platforms

Multiple studies have mentioned the effects of having a platform on a curve and the relation to the horizontal gap. However, these studies have not focused on the safety effects of vertical gaps and sloped vehicles resulting from any associated super elevation that is present in most curves. A vehicle cross slope complicates the boarding and alighting task particularly for people who use wheelchairs, walkers, pushing a stroller, or wheeling luggage. The incident data is sparse, however it would be interesting to determine if there are any impacts of super elevation on boarding and alighting incidents.

Passenger Behavior

Previous studies have briefly mentioned the possible issues that are attributed to distracted passengers. The previous reasons cited involved things such as presence of children, handling luggage, talking on a cell phone, and pushing of a stroller. Personal electronic devices such as smart phones continue to increase their market share, and anecdotal information has indicated that hand held devices are an increasing safety hazards for passengers boarding or alighting from a train. The impact of these mobile devices on passenger safety should be studied further to determine the actual safety impact.

3. Platform Edge Detection and Protection Effects on Platform-Train-Interface Safety

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3.1 ABSTRACT

The purpose of this study is to provide background information and examples of best practices relating to platform-train-interface (PTI) safety. This manuscript was adapted from a literature review that was undertaken as part of the Transit Cooperative Research Program (TCRP) project A– 40 that aims to improve platform safety for rail modes of public transportation. The findings come from an extensive literature review, transit operator safety data, input from two workshops, and interviews with various stakeholders. Specifically, information was gathered from transit operators, station designers, station builders, car builders, and accessibility equipment manufacturers. The background research has shown that platform safety is primarily effected by technical factors, operational aspects, and passenger characteristics. This paper identifies possible issues and best practices for the technical design aspects of platform edge safety. It was determined that certain factors are universal between modes and can be grouped together. However, the research suggests that each mode has many factors that should be considered separately when determining potential mitigation strategies. The second part of this paper considers each mode separately.

3.2 INTRODUCTION TO PLATFORM-TRAIN-INTERFACE SAFETY PROBLEMS

Many transit agencies and researchers recognize that the platform-train-interface (PTI) accidents are an important safety concern, however there has been relatively little research in this area. Incidents that involve the gap between the platform and train are not necessarily only dependent on the gap size. In fact literature review suggests that there may be many other contributing factors that could impact boarding and alighting safety. Various studies from around the world have considered portions of this overarching problem of gap safety in various rail transit modes. These documents have been reviewed and the pertinent information was extracted to insure that this study could effectively address issues surrounding the platform-train-interface. This paper is based on research that is currently being undertaken as part of the Transit Cooperative Research Program (TCRP) A-40 project. The objective of this research is to develop a manual for practitioners to improve safety at rail public transportation platform/train and platform/guideway and roadway interfaces. The research should assist transit agencies to prevent and minimize incidents and improve safety. This research focuses on rail transit but may include Bus Rapid Transit systems where car/bus floors are level (or near level) with their platform. This paper focuses on the platform train interface (PTI).

3.3 SIGNIFICANT ISSUES

Geometry and Size

One of the major design aspects that can affect safety at the platform-train-interface is the gap size influenced by the track infrastructure. Different modes of rail transit often encounter different issues relating to the track on which they operate. Rail transit operations are generally divided into two different categories, exclusive track operations and shared track operations. Shared track operations include sharing the track with freight trains as well as other rail transit modes in certain instances. Commuter rail systems quite often share track with freight and thus the station platforms need to be set back further from the track to comply with freight car clearances. Light rail and street car operations sometimes share platforms with each other and/or buses. In these operations platforms must be designed to accommodate level boarding for various modes. Conversely, exclusive track operations involve a guideway that is reserved for a specific type of rail transit. For example, heavy rail transit operations such as those reported in the studies involving Tokyo and Bangkok generally only have to consider horizontal gaps resulting from platforms that are on curves.

The use of a gauntlet track, is one solution to solve mixed operations problems with regards to horizontal gap distances. One example of this method comes from the Westside Express Service (WES) commuter train operated by TRIMET in Portland, Oregon (see Figure 1). The 14.7 mile long corridor has five stations and operates on shared track with a regional freight railroad. The Oregon Department of Transportation (ODOT) required a clearance distance of seven feet and three inches (7’ 3”) from centerline of the track to the edge of the station platform. During the project development phase it was determined that the car widths for the proposed diesel multiple unit trains were only 10 feet and 10 inches wide (5’ 5” from centerline to edge of vehicle). Thus, in order to comply with the Americans with Disabilities Act (ADA) regulations of a maximum three inch (3") horizontal gap, something had to be done. Various suggestions such as mini-high platforms, motorized platform extensions, manual platform extensions, and gauntlet tracks were considered. In the end the gauntlet track was selected as the preferred alternative. The gauntlet track consists of two switches roughly 466 feet apart (point of switch to point of switch) for a platform length of 146 feet. These switches move the commuter trains approximately one foot and 8 inches closer to the platform while allowing freight trains to remain the legal distance. With this shift, the horizontal gap is reduced from one foot and 10 inches down to two inches, respectively. This gap is fully compliant with the ADA regulations. TRIMET estimated that an installation of a gauntlet track for a platform length of 146 would be about $650,000 including materials, signal work, and installation costs. Based on the success observed with WES in Portland, more applications of gauntlet tracks could be suggested for similar areas with mixed rail operations *(1)*. A report published by the Federal Railroad Administration (FRA) entitled Managing Gap Safety also suggests gauntlet tracks as a potential solution to the excessive gap problem *(2)*. It should be noted that New Jersey Transit also currently has a gauntlet track in operation at Union Station on the Raritan Valley Line*(3)*.

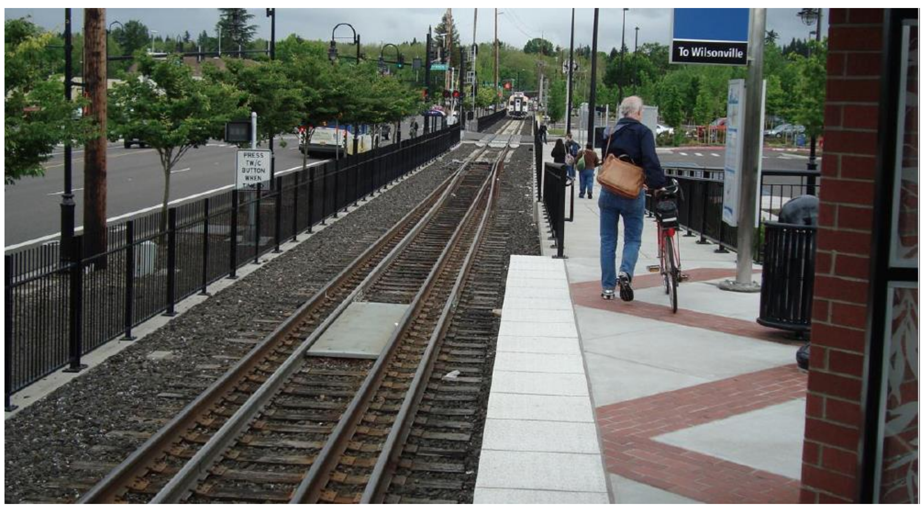

Figure 1: Gauntlet Track at Station in Portland, OR (Ken Kirse).

Another reason often cited for the presence of excessive gaps are stations in curved track sections. Numerous studies mention the problems related to curved station platforms located on curved track sections and the challenges that come with them. A document outlining the origins of "Mind the Gap" offers some information on why these curved platforms can cause significant problems. As stated by that paper and a study from Tokyo University of Science, there are two primary classifications for stations in curves. In the first case, a station is located on the outside of a curve (concave). This allows the ends of the cars to be near to the platform but the center doors could have a significant gap present. The opposite is true for the second case when the station is located on the inside of a curve (convex). In this scenario the middle sections of the cars are near to the platform and ends are further away. The severity of the gap depends significantly on the rail car layout and the degree of curve in which the station is located*(4)*. The New Jersey Transit study presents a similar conclusion in regards to stations in curves*(5)*.

Two additional significant factors in the study from Japan were the overall area of the platform and the length of narrow or obstructed sections on the platform. According to the results, as the area of the platform increased so did the overall safety of the platform. Conversely, as the length of the narrow sections of the platform increased the overall safety at the platform decreased. These conclusions seem to make sense from the perspective of avoiding overcrowding issues. In general, it is understood that larger platforms with more standing area are safer than those that are smaller. Additionally, island platforms and those with curves were considered to be more dangerous than single sided platforms and those that were straight *(6)*.

As previously mentioned, the platform shape could potentially have an effect on safety. Unfortunately it seems that there is not a general consensus of whether island platforms or side platforms are truly safer. Some advantages that are listed for island platforms include using less right-of-way, ease of transfer between tracks for both passengers and trains, shared facilities, and potentially fewer station attendants needed. However, the island platforms can also have issues such as overcrowding when two trains are present on either side, crossing passenger flows, and overcrowding on stairs and escalators. Conversely, the side platforms can offer more standing area and eliminate the problem of crossing passenger flows. There are many factors that contribute to the selection and design of the platform. These factors are specific to the location and are generally determined by the geometric characteristics, right-of-way availability, station location, passenger load, and transferability to other modes or trains. Further research into platform type and its' relation to safety could be very useful *(7)*.

Platform Clutter

The obstructions caused by amenities and general platform clutter influence the amount of "clear space" on the platform, and therefore consideration should be given to the location and density of obstacles. Examples of these include seats, station support columns, informational boards, stairs, elevators, and escalators. While many of these objects are necessary on a platform, the placement of these can be crucial to platform safety. Too many objects on the platform reduce the overall area and fixed obstructions such as stairs and escalators cause there to be narrow portions on the platform. These problems lead to overcrowding and involve passengers standing too close to the edge of the platform. Additionally, special care should be taken when temporary construction or maintenance sites are set up to avoid creating potentially dangerous narrow platform sections *(7)*.

Between Car Barriers

One issue that emerged during background research on the platform-train-interface was barriers between cars to prevent track intrusion. This was not the specific focus of the research project, however there is a relationship to overall platform safety. A report published by Reiss details the efforts of the Los Angeles County Metropolitan Transportation Authority (LACMTA) to become ADA compliant with regards to between car barriers (BCBs). The goal of the study was to find a station based protection system that could be universally applied in contrast to a vehicle based solution. One of the largest challenges LACMTA faced was the large variety of vehicles operating on their lines. Currently, there are many different models of light rail vehicles (Gold, Blue, and Green lines) and heavy rail vehicles (Red/Purple Subway Lines) operating on the system. The varying models, ages, and dimensions made it difficult to come up with an on vehicle solution that worked for all models. Thus, after years of design and testing, a solution of platform based hinged bollards was implemented (See Figure 2). The hinges were required by the California Public Utility Commission (CPUC) to allow passengers access to the door if the train did not stop in the proper location. The installation of the bollards even had an unanticipated positive effect for the visually impaired. According to survey responses, the trains stop so reliably that people with low vision can use the bollards to determine where the train doors will be. So not only do they improve safety with regards to reducing the number of accidents of falling between cars, they can also be used as way finding devices for visually impaired passengers *(8)*.

Figure 2: Bollard Between Car Barrier in Los Angeles, CA.

San Francisco Municipal Transportation Agency (SFMTA) has also worked to develop a between car barrier device for their light rail vehicles. The solution came in the form of three evenly spaced elastic bands that extend from one vehicle to the adjacent vehicle (see Figure 3). The bands contain high tensions springs that allow them to expand up to 13 feet in length when cornering. In addition a black and yellow striped paint scheme has been utilized to bring additional attention to the devices and keep passengers away from the gap between vehicles *(9)*.

Figure 3: Elastic Band Between Car Barriers in San Francisco, CA.

Safety data collected from several transit agencies and input from the project workshops suggest that between car injuries are indeed a problem. There were numerous cases reported from transit agencies that involved low vision and distracted passengers. This seems to suggest that between car protection should be provided when a gap exists between two cars or vehicles. Solutions to this could come in many forms including the previously discussed bollards that LACMTA has implemented or the elastic bands used in San Francisco. Additional possibilities may include using an alternative car based protection system such as chains or plastic paddles that extend from each car or vehicle.

Edge Warning Lights

A unique solution that could help to improve safety at the platform-train-interface is known as edge warning lights. The most prominent application of this technique is in the Washington D.C. Metro (See Figure 4). LED lights are imbedded in the edge of the platforms and spaced equally throughout the entire length of each platform. The bulbs burn steady at 50 percent power and flash at 100 percent when a train is either approaching or currently in the station. Initially the lights were installed to alert both hearing-impaired and general riders that a train was approaching and encourage people to step back from the platform edge. The lights were successful in this regard and have been installed throughout the system. In theory the lights can improve safety by notifying passengers that a train is approaching and drawing further attention to the edge of the platform. Additionally, the lights are color coded to reflect which line the train is operating on. For example the red LED lights are present on platforms that are along the Red Line. Amber lights are on the platforms that are in stations on the Green and Yellow Lines *(5)*

Figure 4: Edge Warning Light Treatment on Washington D.C. Metro.

Platform Screen Doors (PSD)

Multiple studies have mentioned platform screen doors (PSD) as a potential method to improve safety at the platform-train-interface. Automated train operations and driverless train operations are also motivations for implementing PSD.

Platform screen door design is largely dependent on location and transit system preference. There are three primary configurations for platform screen doors used around the world. Full height doors have the advantage of being able to contribute to climate control and essentially ensures that no one can enter the guideway until the train is present. In underground stations the full height doors must satisfy fire and life safety standards. Most full height door systems leave a slight gap between the ceiling and wall for ventilation. This option is often less expensive than the full height doors and still prevents people from entering the guideway.

One of the additional benefits of platform screen door installation is climate control and passenger comfort. Underground stations in Singapore have been retrofitted with full height PSDs to help improve safety and to reduce the costs of providing air conditioning on the platforms. The savings from this are significant and passenger comfort has improved immensely since the installation. For both at grade and above grade platforms half height barriers/doors are more common than full height (See Figure 5). As the name suggests, they only extend up to about chest height depending on the specific system and are sometimes also known as half height platform safety gates. This configuration represents the most cost effective way to install platform screen doors but does not produce any climate control benefits. Train noise suppression is slight if any but it does allow for ventilation between platform and guideway. One potential problem with half height doors is that a person could still potentially climb up over the wall and enter the guideway *(13)*.

The study produced by New Jersey Institute of Technology lists PSDs as a possible mitigation strategy to improve platform safety *(5)*. Additionally, the report published by Santoso and Mahadthai actually focuses on PSDs effects on platform safety on the Bangkok Mass Transit System (BMTS). According to the findings, accidents that are attributed to the platform-train-interface (PTI) account for about 38 percent of the overall fatality risk and of that risk about 9 percent specifically deal with boarding and alighting incidents. The doors have been proven to improve certain safety aspects surrounding the PTI but that improvement can come at a high cost. When BMTS distributed a survey to passengers asking various questions on platform safety, over 75 percent of the respondents thought the installation of PSDs would improve safety. However, if the installation meant a fare increase of roughly 20 cents in US equivalent dollars, the PSDs lost much of their support. The same trend was observed for increasing the number of conductors on the platform in lieu of door installation. Based on these results it can be concluded that passengers appear to want PSDs for safety reasons but are unwilling to pay more to have them installed. Additionally, according to the BMTS study, the presence PSDs do not significantly disturb passenger flows during boarding and alighting and thus do not have a large effect on dwell time or overall capacity *(10)*.

One of the primary concerns that transit agencies may have with regards to PSD implementation could be interoperability. Many agencies operate multiple designs or models of the same mode of vehicle. The differences between these vehicles with relation to the number, location and even style of doors and dimensions causes issues with docking at specific PSD locations. However, as stated by an APTA (American Public Transportation Association) publication on intrusion detection, if PSDs are feasible there can be many advantages. Some of these include faster train approach speeds, reduced noise levels, and reduced heating/cooling costs *(11)*.

An internal case study completed by the Taipei Rapid Transit Corporation also makes some conclusions as a result of previous installations of PSDs on various rail transit lines under their jurisdiction (See Figure 5). Platform screen door installations began in 2005 and have continued periodically since that time. One of the motivations for the installation came from a report on the Paris Subway stating that the number of delays caused by passengers was reduced by 69 percent after the installation of PSDs. However, installation was a slow process in Taipei and it took months to do a single station based on lack of available time to work due to efforts to minimize effects on normal operations. Initially doors that were 1.45 meters tall and 1.8 meters wide were installed. However, as more stations were equipped with PSDs, the heights of the doors have been reduced slightly to 1.4 meters and the width has increased to 2.1 meters to increase visibility and passenger flow. Additionally, the doors are equipped with automatic detection sensors that prevent them from closing on passengers and causing injuries. Recent successes with the PSD's have encouraged the Taipei Rapid Transit Corporation to continue installing the doors at heavily congested stations. The most recent set of installations at 13 additional stations will be completed in 2014, continuing to improve safety on the overall system *(12)*.

Figure 5: Half Height Platform Screen Doors on Taipei Metro.

Delay is generally a big concern for most rail transit agencies when considering the reliability of a given system. It is therefore important to understand the potential effects that installing platform screen doors could have on delay on a rail transit line. The feasibility report regarding installation of platform screen doors prepared for BC Transit contained a delay impact analysis that concluded that the potential delay with the platform screen doors would be less than half of the delay with the current system. One major assumption for this comparison was the assumption that the platform screen doors failed at about the same rate as that of the car doors. Additionally, it was assumed that the intrusion detection systems would be removed and thus no delay would be encountered from those systems. The findings suggest that the PSD's would reduce delay significantly over the course of an average month *(14)*. Similarly, results from installation of half height PSDs on Hong Kong's MTR system suggest that service interruptions due to intrusion dropped nearly 70 percent *(13)*.

Platform screen doors will be installed at all of the 21 stations along the future Honolulu Rapid Rail Transit line. The decision to install the doors was supported by both planners and the community at large. This is because the system is both elevated and automated. The half-height doors will be laminated safety glass and will run along the entirety of each platform. As observed by other systems around the world, installing the doors would be significantly cheaper if done during initial construction rather than retrofitting later. Thus the automatic doors will be installed at an estimated cost of about $27 million total for all of the platforms in the 21 stations *(15)*. In automated metro operations, the cost of platform screen doors is offset by the savings in labor over ten years (*16*).

Intrusion Detection Technologies

Platform edge and track intrusion detection devices are a relatively new technologies that are under consideration for transit related purposes. The technology for the platform intrusion detection (PID) systems has become more sophisticated and can be far more economical to install and operate as compared to PSDs. However, they do not offer a physical barrier between the edge of platform and track. One example of this technology is in Yong-In, South Korea. A series of light curtains are employed to detect when a person comes within 12 inches of the edge of a platform when no train is present. If detected, an automated public address message is triggered and an alert is sent to the dispatchers at central control. While this specifically does not address gap problems it could potentially be modified to detect passengers falling into excessive gap areas. One of the potential drawbacks of this technology is implementation of light sensors on curved platforms is difficult *(11)*.

A case study for guideway intrusion detection is derived from SkyTrain operated in the Vancouver, British Columbia. Currently SkyTrain has basic intrusion detection that varies from lasers to metal pressure plates. The main purpose of these detection technologies are to prevent an incoming train from hitting a passenger that is on the tracks. The laser detection systems that are present on the newer lines can detect a passenger that moves too close to the platform edge and issues an audio warning of the potential danger. The second phase of the system involves lasers that can detect an object that has fallen on the track. Once detected, an alert is sent to the central control room and trains cannot enter the station until the foreign object has been cleared.

The original Expo Line still utilizes the pressure plates. This system is present on the tracks at stations and operates similar to the track laser system. If an object puts pressure on the plate it issues an alert to the central control room and does not allow trains to enter that station on that track. The system is very effective. In fact, the sensitivity is so high that a dropped wallet or an aluminum can will set off the alert and stop trains. According to the same article, in May 2010 there were at least 80 service disruptions caused by garbage falling onto the tracks and creating false alarms. While the idea behind this intrusion detection method was sound, the operation has proven to cause many system wide delays *(13)*.

3.4 MODE SPECIFIC CHALLENGES

Each specific rail transit mode experiences different problems in relation to platform edge safety. These differences can be due to a variety of factors including differences in guideway design, platform heights, station layout, operating on shared right-of-way, vehicle size, vehicle configuration, and operating speed. Problems related to each rail transit mode should be considered separately when recommending potential solutions to improve safety at the platform train interface (PTI).

Heavy Rapid Rail

Rapid rail transit generally experiences less technical problems than other rail transit modes with regards to PTI safety. This is because rapid rail systems nearly always operate on exclusive track and they do not need to accommodate freight activity or other modes such as buses. One of the major challenges for rapid rail can be attributed to varying vehicle sizes and configurations. Often transit systems incorporate new vehicles into the fleet while continuing to operate the older vehicles. Generally the new vehicles have been updated to improve safety, capacity, and/or comfort and therefore the layout and/or dimensions can vary slightly from the legacy cars. This can be a significant problem if the car width or floor heights change slightly. One example of this problem is encountered in the London Underground which has experienced problems due to the integration of various styles of trains. Trains operating on the Bakerloo line are known as small profile trains and differ in size from the standard profile trains that are present on other parts of the system. In fact, the small profile trains have a floor height that is approximately four and a half inches lower than the standard profile trains. This creates problems when the smaller trains cross over onto the lines where standard trains operate. The platforms on these lines have level boarding for the larger trains but require a step down to board or step up to alight for the smaller trains *(17)*.

Another additional problem with rapid rail transit comes from the legacy systems and in particular those that are underground. Initially these systems were laid out to serve the maximum number of passengers but often this was often done by sacrificing favorable geometry. Many of the stations are located in curves and present some serious issues with excessive gaps both vertically and horizontally *(4)*.

The FRA manual on Managing Gap Safety lists movable platforms as a possible solution to gap issues. These gap fillers are automatically moved into place when the train comes to a stop. This method can be especially effective on curves where the gap is excessive. Additionally, some railroads have platforms with fold up edges that are moved out of the way when a train is not present at the station. One unusual mitigation effort uses a rubber gap filler that has fingers that extend from platform. This configuration allows some fall protection and can bend if the car comes in contact with the device *(2)*.

One example of a mitigation technique used to reduce the gap for rapid rail is shown in the New York City Subway System. Certain platforms on the system use movable platforms to help eliminate the horizontal gaps. Signs and audio warnings alert passengers to the moving surface and aim to make passengers aware of the movement. Even with these efforts there have reports of people ignoring the warnings and losing their balance during operation. One potential disadvantage of moving platforms is increasing of dwell time. In fact, certain platforms in New York Subway's 42nd Street Station were built initially with moving platforms to fill gaps. However, the platforms were later secured in place by concrete because of the effect on dwell time at the platforms *(7)*.

Light Rail and Streetcar

One of the unique characteristics of the street running rail transit modes (light rail and streetcar) is the use of low platforms. This can be a problem because people can easily step up and down from the guideway to the platform. A lower platform reduces the severity of injury if someone were to fall, however the smaller height differential makes it easier for passengers to enter the guideway or in the case of some cities to use the platform edge as a bench. The report detailing intrusion detection technologies by Jonathan Hulse confirms this and goes on to suggest that people would be very willing to enter the guideway to pick up an object or navigate around crowds. While light rail and street car vehicles generally move slower when they are operating in the street, this passenger behavior is still be considered to be an unnecessary risk *(11)*.

Commuter Rail

Commuter rail may experience some of the most severe issues in relation to the platform train interface of all the rail transit modes when level boarding is present. It should be noted that many commuter rail systems in the United States operate low level platforms that require passengers to climb or descend steps on the rail vehicles to board and alight. These stairs introduce additional safety concerns but are not the focus of this study. However, the combination of high platforms, various vehicle heights, and shared right-of-way introduces some unique challenges. The most prominent issue from that list is often considered to be operation on shared right-of-way. Sharing track with freight allows commuter systems to utilize existing rail infrastructure without the additional costs of installing track, structures, and signal systems. This also allows for shared maintenance and dispatching which can further reduce the costs to the transit agency. One potential downside of shared operations results from freight car clearance standards. Most commuter railroads tend to follow Plate C standards that is set forth by the Association of American Railroads (AAR). This states that the maximum width of a car cannot exceed ten feet eight inches (10' 8"). Thus when a station is designed for commuter rail, the platform is set back to ensure that the edge is beyond of the dynamic envelope of the freight cars. While this guarantees that the platform will not be struck by passing cars, it often introduces an excessive gap (beyond 3 inches per ADA requirements) for boarding commuter trains *(7)*.

Additionally, shared operations can lead to certain maintenance issues in relation track position and geometry. Traditional ballasted track is subject to movement due to heavy freight operations. The degree to which the track moves often depends on factors such as type of ties, size of rail, quality of ballast, sub-ballast characteristics, climate, and freight tonnage on the line. The movement can affect the track in various ways including changing the position both vertically and horizontally. This can be a significant problem with the tight gap tolerances set forth by ADA. Regular measurement and maintenance is required to ensure that gap dimensions are acceptable along the entire length of each platform. This can be both costly and time consuming. An additional possible solution could involve using concrete slab track in station areas. This potential improvement could be costly as well but involve relatively little maintenance for keeping the gap dimensions within tolerances. The solutions that a transit agency chooses to pursue depends on funds available and preferences of the partner railroad that shares the corridor *(2)*. Transit agencies throughout the country and the world have made attempts to correct the excessive gap problem. The most successful solutions may vary between each platform along the same line. This can make a "one size fits all" solution very difficult to develop. One of the newer techniques that has emerged is known as a gauntlet track. This treatment was discussed in detail in a previous section. It should be noted that currently both Portland's West Side Express Service (WES) and NJ Transit's Raritan Valley Line have at least one operational gauntlet track section *(7)*.

3.5 OTHER CONSIDERATIONS

This paper has focused specifically on the technical design aspects of the platform, however it should be noted that safety at the platform-train-interface (PTI) involves additional factors as well. The two primary additional considerations are transit operations and passenger characteristics. Previous studies by New Jersey Institute of Technology and the Rail Safety and Standards Board (RSSB) out of the United Kingdom have focused extensively on passenger characteristics in relation to PTI safety. Some major findings include that children and those passengers over the age of 50 often have a higher risk of injury. Also, distracted and intoxicated passengers are much more likely to be injured or killed than those who are aware of their surroundings *(5, 20)*.

Operational factors also can have a significant effect on passenger safety. From the TCRP A-40 webinar and various stakeholder surveys it has been determined that one of the biggest operational factors that can improve safety is public relations campaigns. The importance of educating passengers and employees about platform safety was emphasized quite frequently in discussions and surveys. Effective techniques include automated announcements on trains and platforms, safety videos, posters, and placards. One unique idea that was employed by Metro in Melbourne, Australia involved the creation of an internet based video ad campaign entitled "Dumb Ways To Die". Through the use of humor and rather graphic images of animated characters dying in what were determined to be stupid ways, the message is conveyed that people should be careful around railroad tracks and stations. While this specific video might not be appropriate for all audiences, the use of humorous videos to convey safety messages could be potentially very effective on transit users. A similar effort was undertaken by various airline companies recently in efforts to have passengers pay closer attention to the preflight safety briefings. Indications thus far seem to suggest these methods are better than traditional briefings *(7)*.

3.6 CONCLUSIONS AND DISCUSSION

A number of technical design factors that are related to platform-train-interface (PTI) safety have been discussed based on stakeholder input and an extensive literature review. From the background information available some useful conclusions could be made. As previously discussed, platform size and shape can have a significant impact on safety. In general, as the size of the platform increases the possibility of crowding is reduced and thus overall safety improves. It was also determined that straight platforms present fewer problems in relation to horizontal gaps than curved platforms. It should also be noted that curved platforms are more often a problem on legacy systems and not recently constructed lines. Certain gap mitigation technologies have started to be used more frequently, and these include; gauntlet tracks, movable platforms, and rubberized platform edges. In each case, the gap fillers need to be approved by the host railroad for compatibility. Which technology is employed is largely a function of mode type and specific platform characteristics. Through the literature review and interviews it was found that horizontal gaps tend to present more significant problems than vertical gaps between the platform and train. It has also been determined that gaps between cars or vehicles can be a serious safety problem to both visually impaired and distracted passengers.

Intrusion prevention and detection has also been identified as an important factor in relation to PTI safety. The most effective method of prevention is the implementation of platform screen doors (PSDs) on the platform edge. Ideally PSDs would be installed on new platforms, as there are often technical challenges and high costs associated with retrofitting doors on existing platforms. Furthermore, it was found that passengers were generally against the PSDs if it meant that there would be a fare increase. Intrusion detection is another potentially important technology that continues to be explored. Laser based detectors on both the edge of platforms and on the track have been identified as a new technology for intrusion detection. Continued development and additional research is needed to improve these systems.

It should be further emphasized that platform-train-interface (PTI) safety issues are mode specific and potential solutions for each mode can vary greatly. Heavy rail has issues that are derived from passenger behavior. Light rail and streetcar have challenges related to sharing platforms with other modes. Commuter rail generally encounters the most technical problems that related to PTI safety with shared freight operations. Gap filling technology continues to be on the forefront of commuter rail safety. While the technical design aspects are important to PTI safety, passenger characteristics and operational aspects must also be considered. Extensive public outreach campaigns and employee training should be undertaken to improve awareness of potential safety issues that relate to the platform-train-interface. In specific passenger distraction and intoxication are two significant problems that should be addressed by transit operators.

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3.8 REFERENCES

1. Kirse, K. *TriMet's WES Commuter Rail Use of Gauntlet Track For Level Boarding*. Tri-County Metropolitan Transportation District of Oregon. http://www.apta.com/ mc/rail/previous/2010/Presentations/TriMet-WES-Commuter-Rail.pdf. Accessed July 22, 2014.

2. Federal Railroad Administration Office of Safety FRA Approach to Managing Gap Safety. 2007.

3. Braunstein, A. New Jersey Transit Raritan Line. http://www.nycsubway.org/wiki/New_Jersey_Transit_ Raritan_Line. Accessed July 23, 2014.

4. Horne, M. *Mind the Gap*. This is the Metadyne Website. 2014, pp. 1–6. Accessed July 2, 2014.

5. Daniel, J. R., Rotter, N. G., & Nichnadowicz, V. F. *Customer Behavior Relative to Gap Between Platform and Train* (pp. 1–79). New Jersey Institue of Technology, Newark, NJ, 2009.6.

6. Yamada, S., Terabe, S.. & Kasai, M. Safety Performance Measures for Railway Stations. In *TRB 93rd Annual Meeting Compendium of Papers*, No. 14-1868, Transportation Research Board of the National Academies, Washington, D.C., 2014.7.

7. Hunter-Zaworski, K. *Workshop and Web Conference Report on "Improving Rail Transit Safety at Platform/Train, Platform/Guideway, and Platform/Roadway Interfaces".* 2014.

8. Reiss, S., Lozano, R., Cannell, M., Puglisi, D., & Mitchell, L. *Successful Implementation of Station Platforms Between Car Barriers*. Transportation Research Board of the National Academies, Washington, D.C., 2014, pp. 2-8.

9. Rose, P. *Between-car Barriers Enhance Safety on Muni Metro*. San Francisco Municipal Transportation Agency. http://www.sfmta.com/ko/news/press-releases/between-car-barriers-enhance-safety-muni-metro. Accessed July 24, 2014.

10. Santoso, D. S., & MahadthaI, S. *How Safe is the Rail Platform? A Study of Bangkok Mass Transit System (BTS*). Eastern Asia Society for Transportation Studies. Retrieved from http://easts.info/on-line/proceedings/vol9/PDF/P233.pdf. Accessed July 20, 2014.

11. Hulse, J. *Intrusion Detection and Prevention Technologies available to Rail Transit*. 2014. Delcan Corportation, Kingston, Ontario, Canada. Presented at the 2013 APTA Rail Conference.

12. *Guidance Safeguards for Passengers Waiting on Platforms-Platform Screen Doors and Track Intrusion Detection System*, 1–2. Taipei Rapid Transit Corporation. http://english.trtc.com.tw/fp.asp?fpage=cp&xItem=1056659&ctNode=27510&mp=122032. Accessed July 22, 2014.13.

13. Chan, K. (2014). *Are Glass Sliding Platform Edge Doors Feasible for Skytrain Stations? Vacncity Buzz*. Retrieved from http://www.vancitybuzz.com/2014/04/glass-sliding-platform-screen-doors-feasible-skytrain-stations/. Accessed July 23, 2014.

14. *Feasibility Study for Implementation of Platform Edge Door System*. British Columbia Transit. December 16, 1994.

15. *Ensuring Rail Passenger Safety*. Honolulu Authority for Rapid Transit (HART). Retrieved from http://myemail.constantcontact.com/News-from-the-Honolulu-Rail-Transit-Project.html?soid=1102697428056&aid=Hx5Y3V3IrQE. Accessed July 25, 2014.16. Nelson, D. *Automated Metro Operations: Challenges and Opportunities.* Transportation Research Board of the National Academies, Washington, D.C., 2013, pp. 1-12.

17. Smiler, S. *Easy Access. City Transport*. City Transport. Retrieved from http://www.citytransport.info/Access.htm#Train. Accessed July 8, 2014.18. Davis, R., and L. Olson. *Technical Memorandum*. 2014, pp. 1–8.

19. *Modern Streetcar Vehicle Guideline.* American Public Transportation Association (APTA). APTA Standards Development Program. Washington, D.C., 2013.

20. RSSB. *Interface between Station Platforms, Track and Trains Interface between Station Track and Trains Platforms, Issue record*. 2010, pp. 1–34.

4. TCRP A-40 Platform-Train-Incident Data analysis

4.1 INTRODUCTION

The data and information collected during the interviews of transit agencies, car builders, and consultants were evaluated. The trends from the data threads are summarized in the following sections.

4.2 INCIDENT DATA

The safety officers at numerous key transit agencies in the United States were contacted for incident data pertaining to platform-train-interface (PTI) incidents. This data is very sensitive, and it took weeks to months to obtain. To protect the identities of the transit agencies that willingly provided valuable incident data, each transit agency was assigned a letter will be referred to by that name.

Many attempts were made to obtain data from other large operators but no data was acquired. Several transit agencies that operate light rail transit systems indicated that they did not have incidents related to the platform-train-interface. Commuter rail data was available from the National Transit Database (NTD) but did not contain detailed incident characteristics or descriptions.

The data received from the transit agencies did not have enough incidents to conduct a detailed statistically significant analysis, however it was possible to see trends in the data that was provided. In addition, follow-up phone interviews were also conducted for clarification of incident data items that were not clear. Each transit agency was asked to provide data that specifically dealt with Platform Train Interface (PTI) incidents. However, only transit system A kept detailed incident data that was exclusively related to PTI and/or gap related incidents. The remaining transit agencies submitted data that was mixed in nature and required separation to focus on PTI type incidents. For the purposes of general PTI incident data analysis, PTI type injuries were defined as incidents that occurred while boarding or alighting a rail transit vehicle. Specifically the focus was on slips, trips, falls, and passengers that became stuck in the gap between train and platform. Passenger incidents that involved being hit by closing doors were separated from PTI related incidents due to many agencies classifying the incidents separately. Also, due to the technical nature of the project, incidents relating to passengers that became injured due to illness while boarding or alighting were omitted. This decision was made primarily because only one of the five transit agencies actually detailed the nature of the illness in relation to the PTI incident. Furthermore, it was determined that medical related incidents such as passing out or feinting were not a function of platform or train design.

The raw data received from each transit agency varied greatly. It was quickly discovered that each transit agency had their own methods, standards, and processes for reporting incidents on the system. This included a variety of employees responsible for filing a report for an incident occurrence even within a given transit agency. The reporting was handled by many different employees including but not limited to train operators, station attendants, conductors, safety officers, and transit police. Thus the amount of detail that was included within each incident description varied greatly by each individual's training and work load. It should also be noted that while certain incident reports made note of the employee responsible for the report content, others did not.

With respect to each incident recorded by a given transit agency, certain information was consistent between agencies while other information fields were not considered by some. Table 6 summarizes the information that each transit agency collects for each incident on the system. These information fields represent only the data received and do not necessarily represent the incident data collection methods of the agency as a whole. As can be seen, there is a vast difference between the amount information each transit agency collects for a given incident. All of the transit agencies tend to record the same basic information (date, time, location, etc.) but certain systems go further to record very specific data. These additional details are very useful when trying to identify trends that can lead to PTI type injuries. Some examples of these useful additional details could include which leg received the injury, age of passenger involved in the incident, tangent versus straight track, and measurement of both horizontal and vertical gaps. It could be important to note that among all of the transit agencies the length and content of the incident description section tended to vary significantly, even within an agency. Thus when detailed descriptions were available, additional specific data could be pulled from the description. However these specific details were not recorded consistently enough to identify patterns in many cases. Also, important to note is that while there might be 18 different characteristics that could be recorded for a given incident on transit system A, often there were numerous fields that were left blank.

Table 6: Incident Information Recorded for Each Transit Agency

Information Recorded for Each Incident on Studied Transit Systems				
Transit System A	Transit System B	Transit System C	Transit System D	Transit System E
Date	Date	Transit Mode Type	Time	Station
Time	Time	Incident Type	Date	Date
Rush Hour	Line Color	Location	Station	Time
Division	Station	Date	Incident Type	Accident Description
Subdivision	Direction	Time	Dispatch Summary	Escalator
Direction	Nature of Injury	Incident Description		Name of Patron
Location	Incident Description			Gender
Trouble Car #				Age
# of Car on Train				Handicap
Male or Female				Hospital (Yes/No)
Age Group				Police Case No.
Entering/Exiting				
Injuries (True/False)				
Medical Attention (True/False)				
Tangent or Curve				
Horizontal Gap Measurement				
Vertical Gap Measurement				
Summary of Incident				
From Description:	**From Description:**	**From Description:**	**From Description:**	**From Description:**
N/A	Gender	Gender	Gender	Age
			Age	

4.3 DATA ANALYSIS AND ASSESSMENT:

It is important to frame the analysis in context. Table 7 is derived from data from the 2013 National Transit Database and individual transit agency recorded incident data. It shows the relative sizes of the systems on a yearly basis that were analyzed. Also displayed in the table is the number of PTI related incidents as compared to the number of overall incidents reported on each system. The final rows contain the number of PTI related incidents that are normalized on the basis of passenger revenue miles, train revenue miles, and number of unlinked passenger trips on each system. This allows for a more objective comparison of the systems as opposed to judging solely based on number of incidents alone. As can be seen in Table 7, transit system D while seeing relatively few PTI related incidents for the data collection period, actually has the highest rate of PTI incidents on the basis of unlinked passenger trips (boardings). This proves that the frequency of PTI related incidents is not necessarily just based on number of passengers that ride a given rail transit system.

One challenge that was raised by many of the transit agencies in the workshop and web conference was that of uncontrolled passenger behavior resulting in suicide. However, with the exception of transit system A, the data sets received did not indicate a significantly high number of suicides. In fact, one system reported no suicides at all for the data collection period.

Table 7: Comparison of the Five Systems that Provided Incident Data Analyzed for Project

PTI Incident Rates / **Annual System Miles (2013)**	**Transit System A**	**Transit System B**	**Transit System C**	**Transit System D**	**Transit System E**
Passenger Revenue Miles	344,975,317	69,046,006	75,884,600	7,884,786	65,652,045
Train Revenue Miles	37,908,349	8,945,014	11,569,883	1,955,280	8,945,014
Unlinked Passenger Trips	2,656,476,693	229,113,934	273,828,461	21,198,687	126,546,495
Average Number of PTI Incidents/Year	161	72	1	9	42
Percent PTI Incidents of Total Incidents	N/A	8%	5%	4%	15%
Year Range for PTI Data Collected	2013	2013-2014	2010-2013	2013-2014	2013-2014
Not Otherwise Classified Injuries (NTD 2013)	5067	466	292	102	752
PTI Incidents/ 10 Million Passenger Revenue Miles	**5**	**10**	**0**	**11**	**6**
PTI Incidents/ 10 Million Train Revenue Miles	**42**	**80**	**1**	**46**	**47**
PTI Incidents/ 10 Million Unlinked Passenger Trips	**1**	**3**	**0**	**4**	**3**

4.3 IDENTIFYING FACTORS WHICH CORRELATE BETWEEN INCIDENTS AND INTERFACE CHARACTERISTICS:

As previously mentioned, it was possible to compile the data received from the five different transit agencies and look for trends. Discussions with transit agencies and the initial analysis of data indicated that the analysis needed to be separated by mode: street level transit such as light rail transit and streetcars, heavy urban rail, and commuter rail that operate of shared track. However it should be noted that all five transit agencies that submitted data for the assessment provided only heavy rail incidents. When follow up questions were asked to the agencies it was determined that some did not operate other forms of rail transit while others did but did not have issues with the PTI. Through the interviews with transit agencies it has been determined that heavy rail tends to see far more PTI related incidents when compared to street running types (LRT and Streetcar). As previously mentioned, detailed commuter rail incident data was not able to be obtained to better understand the prevalence of PTI related incidents with this mode.

The incident data analysis from all five transit systems are summarized in the following sections. At an aggregate level, the data from transit systems B, C, D, and E is shown in Table 8 and 9. As previously mentioned, transit system A only provided information on PTI related incidents and thus other forms of incidents were not available. Table 8 shows a comparison of the number of incidents, while Table 9 shows a comparison of the proportion of incidents for each agency in percentage.

Table 8: Comparison of Incident Type Prevalence from Four Transit Agencies

	Transit System B	**Transit System C**	**Transit System D**	**Transit System E**
Incident Type	**# of Incidents**	**# of Incidents**	**# of Incidents**	**# of Incidents**
Closed in Door	31	19	9	69
Slipped and Fell	275	14	58	107
Gap/Platform interfaces	73	5	9	42
Intoxication	32	4	4	5
Injured by Escalator/Stairs	352	52	159	10
Attempted or Successful Suicide	2	3	0	0
Involved Wheelchair	7	0	3	10
Struck by Train	0	0	2	7
Fell into Guideway/Right-of-Way	79	0	0	22
Total	**852**	**97**	**244**	**272**

Table 9: Comparison of Incident Type Prevalence from Four Transit Agencies

	Transit System B	Transit System C	Transit System D	Transit System E
Incident Type	**% of Total**	**% of Total**	**% of Total**	**% of Total**
Closed in Door	4%	19%	4%	25%
Slipped and Fell	33%	14%	24%	39%
Gap/Platform interfaces	8%	5%	4%	15%
Intoxication	4%	4%	2%	2%
Injured by Escalator/Stairs	41%	51%	65%	4%
Attempted or Successful Suicide	0%	3%	0%	0%
Involved Wheelchair	1%	3%	1%	4%
Struck by Train	0%	0%	1%	3%
Fell into Guideway/Right-of-Way	9%	1%	0%	8%
Total	**100%**	**100%**	**100%**	**100%**

Transit System A

Transit system A provided a very detailed dataset that focused solely on PTI related incidents. With additional details available, a specific analysis of factors that affected PTI frequency was possible. A brief summary of the analysis has been provided in the following section. In addition to the raw data, an interview with the safety officers at transit system A was also conducted to answer questions and clarify unclear data.

Transit System A Data Summary (January 2013 – December 2013)

- Majority of incidents occurred during boarding 68% as opposed to alighting 32%.

Table 10: Number of Incidents Entering versus Exiting

Entering vs. Exiting		
Entering	82	68%
Exiting	38	32%
Total # of Incidents	120	100%

- Majority of incidents involved female passengers (61%). It was discussed during the follow up interview that female passengers may be more likely to report an incident than a male passenger. Also, there was talk of women's footwear potentially playing a part. It was theorized that high-heeled type footwear could have potential negative effects on a passenger's stability when boarding or alighting.

Table 11: Number of Incidents Male versus Female

Male vs. Female		
Male	49	39%
Female	78	61%
Total # of Incidents	127	100%

- More gap injuries were recorded on tangent or straight track as opposed to curved or curve transitions. It should be noted that during the interview it was stated that there are many more tangent platforms than curved, thus proportionally the curved/transition platform incidents may be more common relative to total number of platforms of that configuration. The exact number of curved and tangent platforms was not available from the transit agency.

Table 12: Number of Incidents Tangent versus Curved Track

Tangent vs. Curve Track		
Tangent	63	65%
Curve/Trans	34	35%
Total # of Incidents	97	100%

- Track configuration A had 76% of the incidents and Track configuration B saw the remaining 24%. Discussion with transit system A staff clarified that vehicles used in configuration A are smaller and are 105.5 inches wide while the vehicles on configuration B are larger with a width of 120 inches. According to the interview, these types of cars are normally segregated and do not operate on shared track. However configuration A cars do operate on configuration B tracks occasionally leaving an excessive gap. Configuration B vehicles do not operate on configuration A track as there would not be sufficient clearance.

Table 13: Number of Incidents by Track Division

Track Configuration (A or B)		
Configuration A	96	76%
Configuration B	31	24%
Total # of Incidents	127	100%

- The majority of injuries fell into the "Adult" age category. It should be noted that it is reasonable to conclude that the majority of passengers using the system are in the "adult" age category. However, data was not provided on the general age demographic profile of the transit system. Transit system A predefined the age categories within their incident dataset and thus the number of each was simply totaled to fill in Table 14.

Table 14: Number of Incidents by Passenger Age Grouping (Transit Agency Defined)

Age of Injured Passenger		
Child	15	25%
Adult	40	67%
Elderly	5	8%
Total # of Incidents	60	100%

- PTI related incidents were divided up equally between peak and non-peak times. However, it appears that the afternoon peak sees a slightly higher number of incidents as compared to the morning peak. Similar to age category, Peak and Off Peak were defined by transit system A and thus time ranges were not established by the research team.

Table 15: Number of Incidents by Time of Day

Injury Time of Day		
AM Peak	35	22%
PM Peak	44	28%
Off Peak	80	50%
Total # of Incidents	159	100%

- There is a slight increase in gap incidents during summer months (July, August, and September) but overall gap injuries appear to be consistent throughout the year. The number of PTI incidents on a monthly basis can be seen in both table and graph form in Table 16 and Figure 24.

Table 16: Number of Incidents by Month of Year

Month of Injury		
Months	**Number**	**%**
Jan	7	4%
Feb	11	7%
Mar	16	10%
Apr	14	9%
May	13	8%
Jun	13	8%
Jul	19	12%
Aug	17	11%
Sept	15	9%
Oct	12	7%
Nov	12	7%
Dec	12	7%
Total	**161**	**100%**

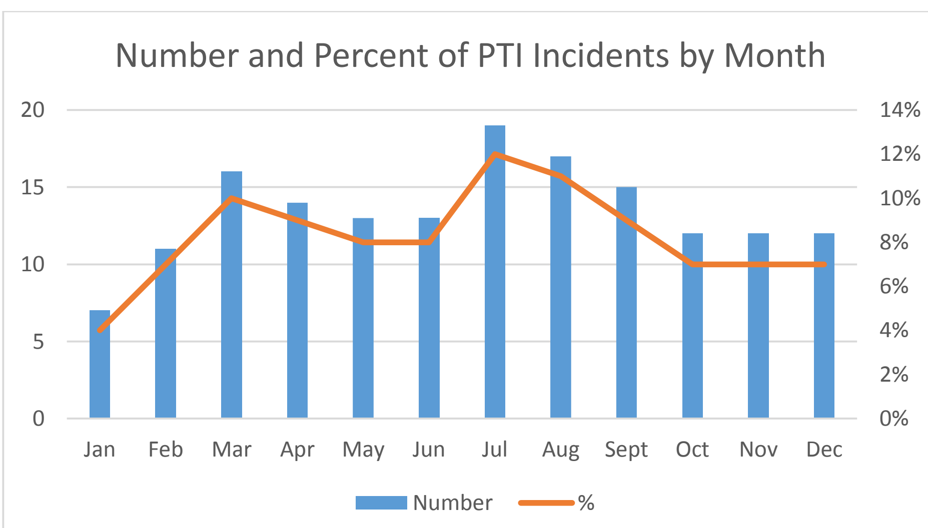

Figure 24: Seasonal Variation of Incidents Reported by Transit System

Other Transit System A Data Notes

For the recorded incidents, it appears that the right and left leg are equally likely to be involved in a gap incident. Despite a high ridership, only one wheelchair and one stroller incident were recorded. Through reading the detailed incident summaries it was determined that many passengers involved with gap incidents cited overcrowding or pushing as being instrumental in causing the event. During the interview with transit system A staff there was also discussion on whether some of the incidents occurred when passengers stepped out of the vehicle temporarily to provide more room for alighting or boarding passengers. For these type of incidents, the most common scenario involved the incident occurring when the passenger took the initial step out of the vehicle and not while re-boarding the train.

Transit System B

Transit system B also provided an extensive dataset that included general platform incident data from November 2013 through early October 2014. A summary of the various incident types can be seen in Table 17. Transit system B reported a high number of PTI related incidents in terms of both number and proportion to other incident types on the system. The frequency on a per passenger basis also is high as reported by Table 8. Of the 852 total incidents, 73 involved the platform train incidents. Furthermore, from the descriptions provided it seems that many people are actually falling or slipping into the gap between the train and platform as opposed to just tripping over the gap. Upon further analysis, it appears that over 50 percent of the platform incidents occur on one single line. It could be important to note that this line is made up of underground, at grade, and elevated stations. The majority of the incidents occur during the middle of the day (9:00 AM to 4:00 PM) followed closely by the PM Peak period that was designated as trips between 4:00 PM and 7:00 PM. It appears that both men and women were equally as likely to be injured due to a platform incident. However, it should be noted that nearly 25 percent of the incidents did not specify a gender.

The most common injuries seen by transit system B were general slips or falls on the platform not related to boarding or alighting. Additionally, another prevalent incident type included injuries sustained on escalators or staircases. One unique trend seen in the data provided by transit system B was the number of passengers who fell into the guideway. It was the third most common incident that occurred within the dataset. Despite the high number of guideway intrusions, there appeared to be no passengers struck by a train and none were listed as successful or attempted suicide.

In the data received from transit system B, there were people that complained about getting caught in the vehicle doors while boarding or alighting but this was reported in only 4 percent of the incidents. While this is not counted as a PTI incident specifically, it could be reasonable to hypothesize that door closing regimes could impact passenger behavior in relation to boarding and alighting. Another interesting observation involves the prevalence of intoxicated passengers. The data indicates that four percent of the incidents identified that alcohol played a significant role. It should be noted that intoxication is not always reported in incident data.

Table 17: Transit System B Recorded Incident Data by Type

Incident Type	Number of Incidents	% of Total Incidents
Closed in Door	31	4%
Slipped and Fell	275	33%
Gap/Platform	73	8%
Intoxication	32	4%
Injured by Escalator/Stairs	352	41%
Attempted or Successful Suicide	2	0%
Involved Wheelchair	7	1%
Struck by Train	0	0%
Fell into Guideway/Right-of-Way	79	9%
Total	**852**	**100%**

Transit System C

The number and type of platform related incidents for transit system C can be seen in Table 18. The data used for this analysis was a subset of incident data provided by transit system C ranging from incidents that occurred as far back as 2010 and as recent as 2014. As can be seen in Table 18, the most common incident at the platforms involves injury from escalators. These type of incidents are not within the project scope but should be mentioned.

Table 18: Transit System C Recorded Incident Data by Type

Incident Type	Number of Incidents	% of Total Incidents
Closed in Door	19	20%
Slipped and Fell	14	14%
Gap/Platform (PTI)	5	5%
Intoxication	4	4%
Injured by Escalator/Stairs	52	54%
Attempted or Successful Suicide	3	3%
Involved Wheelchair	0	0%
Struck by Train	0	0%
Fell into Guideway/Right-of-Way	0	0%
Total	**97**	**100%**

The next most common injury results when passengers get struck or caught during the door-closing phase. This type of incident is seen in data received from transit systems A, C, and D also. Door closing regimes were seen as potential influential factor in PTI type injuries. When the doors are closing and a passenger wishes to board or alight the focus is diverted from where the passenger is stepping to avoiding the closing doors. This could cause a passenger to more readily trip over or fall into the gap between the train and platform.

Based on the incident descriptions, slips and falls appear to be related to platform conditions whether they are environmental (wet, icy, etc.) or physical condition (uneven pavement, cracks, etc.). Of the reported PTI type incidents at transit system C, only one involved a passenger getting stuck between the platform and train. The remaining injuries involved tripping or falling while exiting or entering the train. Interestingly, the numbers of intoxication related incidents were quite low, although this condition is not always reported. Lastly, the number of attempted or successful suicides was also very low.

Transit System D

Table 19 includes data received from transit system D that involved incidents on the rail systems in which they operate from August 2013 to August 2014. Consistent with the trend seen by transit system C, transit system D seems to have more escalator/stairway incidents than any other incident type.

Table 19: Transit System D Recorded Incident Data by Type

Incident Type	Number of Incidents	% of Total Incidents
Closed in Door	9	4%
Slipped and Fell	58	24%
Gap/Platform (PTI)	9	4%
Intoxication	4	2%
Injured by Escalator/Stairs	159	65%
Attempted or Successful Suicide	0	0%
Involved Wheelchair	3	1%
Struck by Train	2	1%
Fell into Guideway/Right-of-Way	0	0%
Total	**244**	**100%**

The most common demographic for this type of injury tended to be elderly females. However passengers of all age ranges reported this type of injury. Many passengers also slipped or fell either on the platform itself or inside the train during braking. From incident descriptions, it was determined that the majority of the platform related slips and falls were related to the environmental or platform condition. Interestingly, the number of passengers impacted by the closing of the doors on transit system D was relatively few as compared to the other incident types. In fact, a passenger was just as likely to be struck by a closing door as trip or fall into a gap. Similar to the data from transit system C, only one passenger physically got caught between the train and platform. It should be noted that intoxication was not a very significant factor that was reported by transit system D. Other interesting conclusions involve a few passengers getting struck by entering or exiting trains but no reported attempted or successful suicides. This statistic was verified by a phone call to the transit agency. Lastly, there were very few wheelchair related incidents identified within the dataset.

Transit System E

The preliminary incident data from transit system E is shown in Table 20. Transit system E compiled a table of aggregated platform incidents in addition to the raw incident data that was provided. While this table was helpful in getting a quick look at the varying numbers of incidents by type, it was discovered through careful analysis of incident descriptions that there were occasionally errors in reporting PTI type injuries. Thus when Table 20 was prepared by transit system E there were incidents that were related to the PTI that were not included. Table 21 has included the incidents seen in Table 20 as well as the additional incidents that were discovered through analysis of the incident descriptions. It is important to note that there were many medical related issues and these were not recorded due to lack of relevance to PTI type incidents.

Table 20: Aggregated Platform Train Incident Data from Transit System E

Station Operation[1]	**Report Period**	**Comparison Period**
	February 2013 to August 2014	February 2012 to August 2013
Guideway	13	12
Platform	124	98
Train Operations		
Boarding	28	19
Alighting	23	17
Struck by Doors Boarding	13	25
Struck by Doors Alighting	23	26
On –Board Accident	136	97
Other	16	13
Gap Falls	17	13

[1] Only relevant incident data reported. Passengers who were sick were not included in the analysis.

Table 21 shows that there were just over 270 incidents that were recorded and were considered relevant to this project. Out of any system that general incident data has been received, transit system E seems to have the highest number of Gap/Platform incidents by percentage at roughly 15%. However, when number of passenger miles are considered as shown by Table 8, transit system E does not seem to have a significant problem relative to the other systems. The incidents that were recorded for this study were only those that involved passengers that were slipping or falling and not those that were suffering from a medical condition such as seizure, heart attack, or passing out. Similar to the other systems, slipping and falling on the platform was a very common incident type. Descriptions suggested this was due to running for a train and encountering slippery or wet conditions. The second most common incident type reported were passengers getting caught in closing doors. This seems to be a trend with many systems. In the transit system E data set, there seems to be more passengers that get struck by the doors when they are alighting as opposed to boarding. This is also a trend that is seen with Gap/Platform incidents. According to the reported data for transit system E, passengers are more likely to trip over or fall into the gap when alighting than when boarding. Further investigation with the transit agency should be conducted to better understand why these types of incidents are occurring. There were a few incidents involving passengers falling into the guideway, however crowding or pushing was not listed as a major cause for most of them. The incident data also included a number of wheelchair related incidents but very few that involved the gap. It should be noted that the area served by transit system E serves a larger proportion of people who use wheelchairs. The last data item that was noted was passengers who were struck by the train. According to incident descriptions, intoxication did play a role in at least a few of these incidents.

Table 21: Transit System E Recorded Incident Data by Type

Incident Type	Number of Incidents	% of Total Incidents
Closed in Door	69	25%
Slipped and Fell	107	39%
Gap/Platform	42	15%
Intoxication	5	2%
Injured by Escalator/Stairs	10	4%
Attempted or Successful Suicide	0	0%
Involved Wheelchair	10	4%
Struck by Train	7	3%
Fell into Guideway/Right-of-Way	22	8%
Total	**272**	**100%**

4.4 GENERAL TRENDS SEEN BY ALL TRANSIST SYSTEMS IN STUDY

There are certain trends that can be seen amongst the transit agency's incident reports. Escalators and stairs tend to be a source of many of the platforms incidents but are outside the scope for this project. General slips and falls on the platform or within the vehicle tend to be far more common that platform-train-interface type injuries. Within the platform-train incidents, the most common injury involves falling while boarding or alighting from the train. Passengers getting caught in doors are also somewhat common and should be investigated further. Especially considering this incident type could lead to a more serious incident. Attempted or successful suicides, while a problem, do not seem to have significant impacts in the data the team received.

4.5 IDENTIFICATION OF TECHNICAL ELEMENTS

The interviews and incident data indicated that that the technical elements such as platform design and vehicle design were mode specific. For discussion purposes there are three categories: street level operations, heavy rail transit, and commuter rail transit.

Street Level Transit

Light rail transit and streetcar transit systems are often classified as street level or mixed operations. In general many of these systems also have low-level platforms that are 14 inches above the top of rail for approximate level boarding with low floor vehicles. It should be noted that many of the older Light Rail systems have high floor vehicles with on board steps, or some have high floor platforms and share many of the characteristics of heavy rail transit. In general light rail and streetcar transit consists are single, two car and up to four car trains.

Trends were observed through the interview process that indicated there were very few platform vehicle incidents at low level platforms such as those used in light rail or streetcars. Interviews with the platform designers indicated that street stations that were shared with bus operations were a challenge when the streetcar or Light Rail vehicles did not have center door access. For systems with center doors on the streetcar or Light Rail vehicle, a mini high or raised platform provided accommodation of both bus and rail vehicles. Although outside the scope of this project, a number of agencies did indicate that grade crossings near light rail transit stations had pedestrian crossing incidents. Other comments that did not show up in incident reports, but were indicated in the interviews include people sitting on the edge of the platform, or people crossing through the guideway from one platform to another despite posted placards warning people not to do this. As previously mentioned, many transit agencies indicated that they do not have problems with PTI type injuries.

Heavy Rail Transit

Heavy rail transit in general operates on exclusive right of way that is fully grade separated from the street network with high-level platforms, and has trains with more than four cars. Heavy rail transit is almost always electric powered with either overhead catenaries or third rail power.

Interviews with urban rail transit systems indicated that the common incidents tend to be general slips and falls on the platform not relating to the platform-train-interface. Many urban rail systems have small horizontal and vertical gaps between the vehicle and platform. With the exception of the data from a few systems, very few gap related incidents were reported or documented. A common thread for this mode were incidents related to passengers coming in contact with closing doors, and in a few instances, coming in contact with the side of the train as the train was accelerating out of the station.

Commuter Rail

Commuter Rail is a passenger rail system that often shares the track with freight operations and may operate with either an overhead catenary system or a diesel locomotive set up in a push-pull configuration. In commuter rail operations the platforms may be low or high, however most of the systems require mechanical ramps, bridging plates or lifts to bridge the horizontal and vertical gaps. The horizontal gap is due to the need to provide clearance for the freight rail cars that are often wider. The literature review outlined the challenge of commuter rail operators and mitigation treatments for the horizontal and vertical gaps but no incident data was obtained for this mode of service.

Vehicle Design

The main issues raised by the vehicle manufacturers that were interviewed were related to the door design. The interviews with vehicle builders did indicate mixed reactions with the requirement for the passenger door to remain shut when deploying a ramp, or bridging plate. Two of the manufacturers indicated that not requiring the door to be closed during deployment would reduce dwell times, however other vehicle manufacturers were supportive of the current requirement. Transit agencies interviewed also emphasized the safety concerns associated with allowing the doors to be open during ramp deployment. In the interview it was indicated that even if door open operation was available, the agency would not utilize this feature.

The American Public Transportation Association Standard for Powered Exterior Side Door System Design for new Passenger (Train) Cars, provides the minimum requirements for powered exterior side door systems.[1] There were at least two vehicle manufacturers that mentioned design elements concerning the sensitive edge on the door to prevent people being caught in the doors. There are systems that permit passengers to manually push the doors 2 to 3 inches apart and this automatically prevents the train from moving. Other door edge systems are called “leash sensitive” and these systems are designed to prevent people with service animals having the animal and person on opposite sides of the door.

Human Factors Elements

Incidents related to suicides and intoxicated passengers were significant concerns for some of the stakeholders during transit agency interview activities across all modes of rail transit operations. A number of transit agencies have conducted research projects on the use of platform edge protection systems as a possible mitigation strategy. LA Metro has placed placards that list the suicide crisis line phone number at platform edges and grade crossings. Caltrain and Philadelphia have launched active suicide prevention campaigns through information on their websites and public outreach programs. It is important to note that according to the data received by the five different agencies, suicide does not appear to be very prevalent. However when consideration is given to the cost to both the transit agency and those passengers and employees involved, the issue is still important. Universally, the transit agencies do not publicize these types of incidents in order to reduce “copycat incidents” and have developed management plans to manage service interruptions caused by these incidents.

None of the incident data that was provided included enough detail on passenger footwear, but in the interviews with several of the operators indicated that women’s footwear such as high heels could be contributing factors, but this was not documented in the incident reports and the data analysis was not able to support or refute these observations.

[1] APTA PR-M-S-18-10

The literature review and interviews also indicated that distracted passengers who are texting and talking on cell phones might contribute to platform incidents, however the data collection forms used by the transit agencies do not document this characteristic.

The data did indicated that pushing and crowding may also have been contributing factors, while this was documented in many of the incident descriptions there is no consistent measure that defines "pushing or crowding".

Other human factors items included people falling on to the guideway either intentionally or accidentally. This type of incident was reported in all the data sets that were analyzed. The frequency was very low, but the costs of each incident in terms of operator stress and lost travel time are very high.

There were sporadic incidents across all the incident data sets of people in wheelchairs falling on to the tracks. There were no trends in the data, however, it was reported that the passengers lost control of their wheelchairs.

Real Time Passenger Information and Communication Strategies

Several large transit systems such as London, New York and Chicago have developed extensive public information and education strategies warning passengers to "Mind the Gap". These transit agencies also have public information in a variety of media to tell passengers not to retrieve items such as cell phones that drop onto the track.

During the workshop and web conference participants from various transit agencies have recommended that a closer partnership with rail operators be formed to create a modified division the "Operation LifeSaver" program to address the needs of rail transit operators. Traditionally this program focuses on grade crossing incidents, but the stakeholders also suggested that platform safety should also be addressed. SEPTA (Southeastern Pennsylvania Transportation Authority) has an Operation Lifesaver program that is mainly targeted at pedestrians trespassing on the tracks. This transit agency has presented the Operation Lifesaver program to thousands of people throughout the region including students, seniors, law enforcement officials, bus operators, and others. Each presentation is tailored to the specific audience and includes a slide show, video and question-and-answer session.[2]

[2] http://www.septa.org/safety/lifesaver/

5. TCRP A – 40 Southern California Site Visit Report

After an extensive literature review, phone interviews with stakeholders, and basic incident data analysis was performed, site visits to key selected transit agencies in the United States were conducted. The agencies were selected by the TCRP A-40 project panel and many considerations were taken into account including type of modes operated, availability of transit agency staff, geographic location, number of incidents, and size of the system. While extensive background research was conducted on each agency chosen for a site visit, often the outcomes from the visits revealed additional best practices and issues that were not previously identified in the research. The main focus of the site visits were to highlight best practices seen at various agencies around the United States. A basic summary of the site visits is contained in the following sections.

LOS ANGELES METROPOLITAN TRANSPORTATION AUTHORITY (LOS ANGELES, CALIFORNIA)

Los Angeles County Metropolitan Transportation Authority (LA Metro) operates two heavy rail lines and four light rail lines in Los Angeles County, California. In total the six lines total nearly 88 miles and encompass 80 stations with average weekday boarding of approximately 350,000 passengers in 2013. The Red and Purple lines are traditional heavy rail transit operations operating primarily underground. The four light rail lines (Blue, Expo, Gold, and Green Lines) operate on a variety of right-of-ways ranging from grade separated to street running. The vehicles used on the heavy rail system are fairly consistent, however the light rail vehicles vary by line with respect to manufacturer and operations. Even though LA Metro operates both heavy and light rail, the mitigation solutions employed by the agency were fairly consistent between the modes. This may be due to consistent high platform height throughout both the light rail and heavy rail operations (39 inches from top of rail to platform surface). There were no low level platforms on the system.

Platform Bollards

One of the innovative ideas that was developed at LA Metro was a unique method for protecting the gap between transit vehicles. In both heavy and light rail operations there is a gap between vehicles. Initially car based protection methods were considered and implemented. However they were soon dismissed due to the complexity introduced to the system and potential for injury. Working with an outside consultant and the California Public Utilities Commission (CPUC), a platform based solution was developed and implemented. As can been seen in Figure 25, a series of bollards that are hinged at the base are fixed directly to the platform to alert passengers of the between vehicle gap. The bollards were installed at all of the heavy rail and light rail platforms. During the visit, it was noticed that passengers tended not to stand in the areas near the bollards presumably due to the fact that they knew the doors would not fall there when the train stopped. An important thing to note is that the bollard placement is independent of door spacing and only relies on vehicle lengths. Many transit operators operate different generations of vehicles that often result in different door configurations. The bollards are able to be used as long as the vehicle lengths are consistent.

Figure 25: LA Metro Between Car Barrier Platform Based Bollards

Platform Edge Extenders

LA Metro underwent an internal audit for ADA compliance and voluntarily added platform extenders on any platforms that did not comply with the horizontal gap standards. The solution that was developed was an "L" shaped aluminum angle that was attached to the edge of the platform. The angle piece was pretreated with slip resistant yellow paint (See figure 26). According to LA Metro staff, the platform vehicle gaps are inspected on a monthly basis to ensure ADA compliance and to preform preventative maintenance. Based on the agencies estimates, the aluminum extenders have lasted more than 10 years without needing to be replaced.

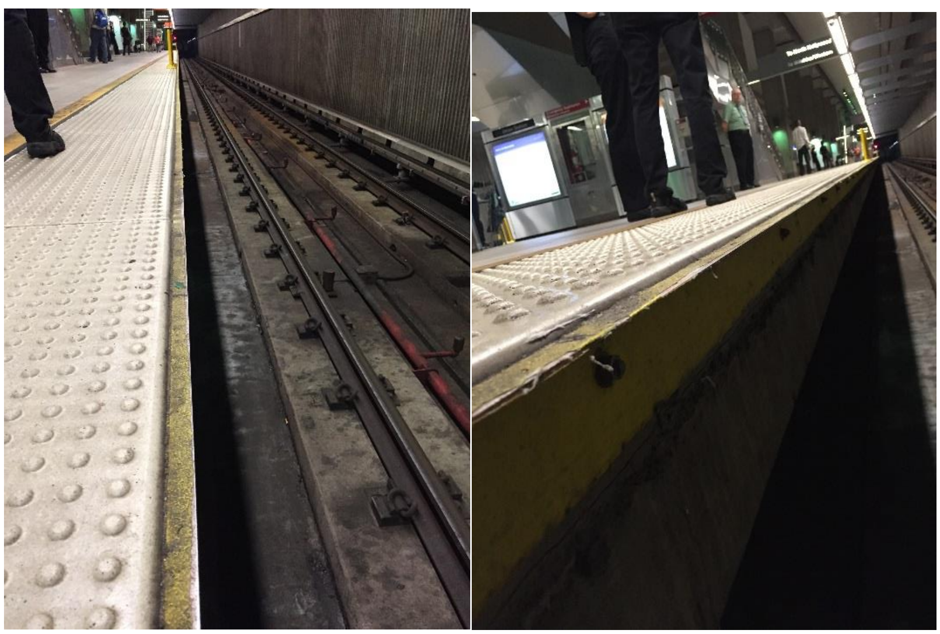

Figure 26: Platform Edge Extenders (LA Metro)

Tactile Door Position Markers

In compliance with ADA regulations there is a tactile edge warning strip along the entire length of the platform. LA Metro went one step further by introducing horizontal tactile bars at the locations at which doors open on a platform (See figure 27 and 28). These strips or bars allow both passengers with low vision and those that are able to see to locate where the doors will be when the train stops. Based on observations during the visit it was determined that passengers tended to congregate near these strips. One potential fallback in applications for this technology comes from transit agencies that operate mixed vehicle consists involving inconsistent door locations. Also, the train needs to stop in a predictable location each time. It is important to note that LA Metro has only placed the strips at one or two locations for each platform at this time, and it was generally to identify the doors on the vehicle in the middle of the consist.

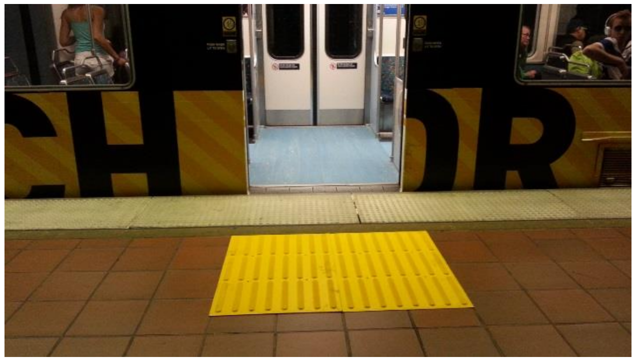

Figure 27: Detectable Bars at Open Door Locations (LA Metro)

Figure 28: Second View Detectable Bars at Open Door Locations (LA Metro)

Extended Door Thresholds

In addition to the platform based solutions the heavy rail vehicles on the Red and Purple lines have extended door thresholds to reduce the gap (See figure 29). All the vehicles operated by LA Metro are equipped with self-leveling suspensions systems that ensure that the train height does not significantly vary during boarding.

Figure 29: Extended Door Thresholds (LA Metro)

Track Geometry Stabilization

LA Metro has many stations that have track directly fixed to concrete slabs, however there are certain stations on the light rail lines that contain ballasted track in the stations. One issue with ballasted track in stations is the tendency for the track to shift laterally. LA Metro has developed two primary solutions to combat the lateral movement. On the Blue Line, metal anchor strips are fixed to every fourth tie and extend down in the ballast to the subgrade. On the green line old rail is cut up and placed longitudinally between the ends of the ties and edge of platform. Both of these methods, according to LA Metro, have reduced the amount of lateral movement on the track.

Outreach and Public Engagement

From an operations perspective, LA Metro has come up with innovative outreach programs to improve safety at the many stations they operate. Educating the public on the safety concerns surrounding rail transit has been a high priority and it is accomplished in a variety of different ways. There is a community relations manager for each line that is charge of coordinating public outreach on their line. LA Metro regularly sends personnel out into the community to educate citizens that live or work within a one and a half mile range of the alignment and stations. The focus often is divided up by special interests such as school children, homeowners, or the elderly that are transitioning out of driving personal vehicles. The transit agency also has invested heavily in the development of promotional material that encourages safe use of the transit system. Most of these materials are developed and produced in house. Safety messages are conveyed through a variety of means including but not limited to flyers, pamphlets, radio ads, television ads, internet videos, presentations, and a dedicated safety website (See figure 30). Online Programs Offered by LA Metro for Rail Transit Safety Education

Figure 30: Online Programs Offered by LA Metro for Rail Transit Safety Education

One of the unique programs seen at LA Metro is using safety ambassadors at designated stations to encourage safe behavior. The program utilizes retired rail transit and bus operators at select stations for 6 hour shifts. They tend to be located near the entrances of stations and in locations where there is high potential for conflict. The safety ambassadors often work in pairs and are given whistles and safety vests to promote an official look. The ambassadors also make important observations about ways LA Metro can improve safety at stations and near grade crossings. Since the program has started the number of safety ambassadors has increased dramatically and the program has been deemed highly successful (44).

SAN DIEGO METROPOLITAN TRANSIT SYSTEM (SAN DIEGO, CALIFORNIA)

The San Diego Trolley is a light rail system that operates primarily in the San Diego metro area. The system consists of 53 stations spread out on three lines (Blue, Green, and Orange) that total just over 53 miles. The overall system sees an average of approximately 120,000 boardings on a given weekday. The train consists typically operate in three car configurations with modern low floor and partial-level boarding cars on either end and an older generation car in the middle. The older generation car in the middle is a high floor configuration with steps required to enter or exit the vehicle. The older vehicles uses bi-fold style plug doors and the newer ADA accessible vehicles have sliding plug doors. The ADA accessible cars on the ends offer near level boarding with the assistance of a vehicle based ramp or bridging plate on either end of the vehicle. The center doors do not offer level boarding. According to MTS, the eventual plan is to phase out the older generation cars and have three car train consists that allow level boarding on all vehicles. However with approximately 40% of the fleet consisting of high floor vehicles that have 15 years or more useful life remaining, this will take time.

The platforms on the line are considered to be low with the platform surface being only eight inches above top of rail. The lower platform height was implemented to achieve clearance standards set forth by the California Public Utilities Commission (CPUP) for mixed-use corridors. Currently there is freight traffic that is temporally separated on the Blue Line, Orange Line, and Green Line. With a standard 14 inch high platform the track centers through the platform would have to be set back 7 feet 6 inches. With a standard vehicle width of 8 feet 8 inches, the gap would be more than 13 inches with the onboard ramp fully deployed and a 3 feet 2 inch gap at the doors without ramps. However with an 8 inch platform height the required set back is only 4 feet 10 inches. This leaves a 4 inch horizontal gap that is easily covered by the ramp. The ramp would be required to comply with ADA as it exceeds the 3 inch limit.

Truncated Dome Detectable Warning

One issue many transit operators face is ensuring that the vehicle based ramp rests flat on the platform surface with the presence of the truncated domes of the detectable edge warning strip. San Diego MTS submitted a Request for Equivalent Facilitation to the FTA for the modified detectable warning strip at the edge of the low level platforms. Thus the standard 24 inch wide detectable warning strip now contains a 7.59 inch clear space that contains no domes. As can be seen in figure 31, when the ramp is deployed the edge of the ramp rests within this clear space. The beginning of the clear space is about 17 inches from the edge of the platform with 6 inches being the edge of the curb containing the “Stand Behind” line and 11 inches being the truncated domes of the detectable edge warning strip. After the clear space there is another 5 inches of truncated domes before returning to normal flat platform surface (45).

Figure 31: Detectable Warning Edge that Accommodates Bridging Ramp (San Diego MTS)

Door Location Markers

Similar to Los Angeles Metro, San Diego MTS adopted the horizontal bars that are perpendicular to the platform edge to denote boarding locations (See figure 32). Furthermore, MTS placed signs that contained both lettering and braille to denote the location and direction of the train directly behind the bars for passengers with low vision. MTS also works with local organizations that advocate for people who are blind or have low vision to educate this community on using the trolley in a safe manner.

Figure 32: Door Location Bars and Sign for Low Vision and Blind Passengers (San Diego MTS)

Between Car Warning Placards

According to the staff at San Diego MTS, the between car barrier incidents are not a significant problem. Reasons cited by the agency included education, use of a low platform, and coupler placards that warn passengers of the dangers of trying to walk over the couplers (See figure 33). According to MTS the placards on the vehicles now discourage passengers from walking through the coupler area.

Figure 33: Between Car Warning Placards Located on the Couplers (San Diego MTS)

Intrusion Detection

San Diego MTS does not currently employ intrusion detection on platforms, however they have invested in a detection system for the tunnel that runs under the campus of San Diego State University (SDSU). The agency utilizes a laser based intrusion detection system that is briefly disabled when the train enters or exits the tunnel. If the system detects an intruder, an audio announcement is automatically played that warns the intruder to leave. SDSU campus security and MTS dispatchers are also automatically notified of the intrusion. If detected, the wayside signal system will permit a train to enter the tunnel but will only allow a reduced speed. Cameras are used to verify intrusion and can allow dispatchers to more accurately assess the situation.

Safety Culture

One of the main topics raised by the staff at San Diego MTS was the importance of safety culture. According to the employees, San Diego Trolley has been run like a freight railroad from early on. Many of the upper level managers began their careers with freight railroads and thus the focus has been to put safety above all other priorities. The team also emphasized the importance of adopting a safety culture from the top to the bottom of an organization. This implies that the upper level management should be leading by example to ensure the entire organization puts safety first. One of the ways cited for improving safety culture at the organization was developing both pride and loyalty to the system. This is accomplished through giving all employees responsibility so that they make take ownership of what they contribute to the agency. This in turn leads to pride and loyalty to the system which encourages improvement in both safety and operations. Furthermore, the safety, operations, and maintenance departments meet regularly to discuss issues that arise on the system. According to MTS, having the three departments working closely together as opposed to working in silos improves productivity (46).

NORTH COUNTY TRANSIT DISTRICT (OCEANSIDE, CALIFORNIA)

North County Transit District (NCTD) operates both commuter rail and light rail on separate right-of-ways. The commuter rail operation (Coaster) operates 41 miles between Oceanside and San Diego, California serving eight stations. The Coaster currently utilizes bi-level cars that do not attempt to achieve level boarding, but use mini high platforms and on board ramps to meet ADA compliance. The light rail operation known as the Sprinter consists of a 22 mile line with 15 stations that have approximately 8,000 boarding per weekday. The Sprinter is able to achieve level boarding on the diesel multiple unit (DMU) rail transit vehicles. The Sprinter shares characteristics with both light rail and commuter rail but it is officially considered to be a light rail operation reporting to the FTA. For example, the spacing of stations are consistent with many light rail operations but the headways and shared operations resemble a commuter system. Additionally, the operator stated that the DMU vehicles acquired for the Sprinter were designed for commuter rail operations with longer distances between stations and fewer stops.

Shared Use Track-Gangways

After the daily revenue service for the Sprinter has been completed, a shortline freight operator runs multiple trains along the tracks. The presence of freight operations require clearance standards set forth by the California Public Utilities Commission (CPUC) to be met. Normally this would introduce an excessive gap between the train and platform. However in this case the NCTD utilizes 14 foot wide metal gangways that line up with the doors of the vehicles (See figure 34). The gangways have a standard 24 inch detectable warning strip on the edge and also employ the horizontal bars to identify boarding locations. The gangways rest in the down position during the day and are hydraulically retracted at night after revenue service. This allows the gap between the train and platform to be covered to meet ADA standards while permitting freight service along the line. The gangways are remotely operated by train dispatchers in the central control room. Once all gangways have been confirmed to have been lifted via a system display and platform security cameras, the freight trains are allowed to proceed onto the territory. In addition, after revenue service has finished the gangways are tied into the wayside signals. If a gangway has not successfully been lifted the signal will remain red, not permitting entry into the block.

Figure 34: Gangways on Share Use Track (NCTD)

The use of the hydraulically powered gangways is a creative solution to the shared use right-of-way issues that many commuter rail operations see. According to the agency, the gangways do not malfunction often and have been an economic solution to gap filling. What little gap remains after the use of the gangways is covered by a vehicle based ramp that extends from the bottom of the door threshold. The use of these technologies has eliminated issues with gap related incidents, according to the transit agency.

Platform Edge Fences or Railings

Platform edge fences or railings along the entire lengths of the platforms except at the designated door locations (See figure 35). These simple fences channelize passengers to the designated boarding locations and protect the edge from a fall at non-boarding locations. According to NCTD, the light rail train operators do not have problems stopping at platforms within the limits set forth by the 14 foot wide gangways.

Figure 35: Platform Edge Fencing and Geometric Stabilization (NCTD)

Track Geometry Stabilization

As can be seen in figure 35, the Sprinter's stations have ballasted track and are subject to lateral track shift. This is particularly a concern with the mixed freight operations. NCTD has attempted to correct this issue by placing wood ties in between the station wall and the end of every fourth tie. This can be seen in figure 35 between the left station wall and left track (47). According to NCTD this method has been successful in preventing movement.

6. Mitigation Framework

Figure 36 provides an overall look at the mitigation framework that was developed to aid stakeholders in quickly identifying appropriate mitigation strategies based on mode. With regards to platform-train-interface (PTI) safety, the issue has been broken down into two primary components; operational aspects and technical factors. The separation of the two components represents a significant difference in mitigation strategies. Technical mitigation strategies is further broken down by mode to highlight both the similarities and differences between modal mitigation strategies. Operational mitigations have been determined to largely be independent of mode. Each mitigation flow chart will be discussed in further detail from the top down. The technical mitigation strategies have been discussed in detail in previous sections. This section serves primarily to highlight certain applications and not give specific details on technologies.

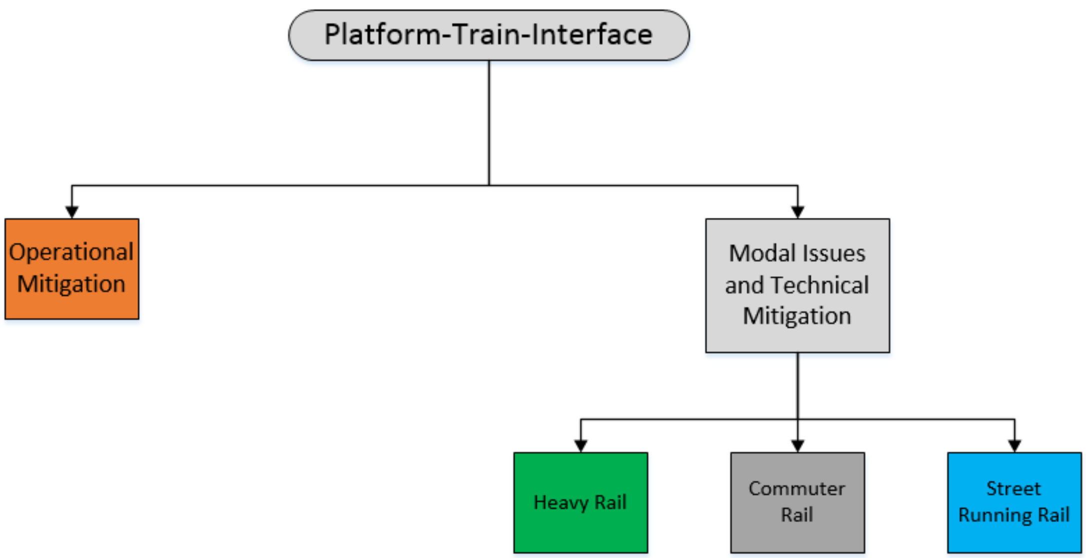

Figure 36: Top Level Mitigation Framework

HEAVY RAIL TRANSIT MITIGATIONS

Figure 37 contains the mitigation flow chart for heavy rail transit. It is important to note that track and platform geometry can play an important role in the severity of PTI type incidents. However, based on field visits and interviews with transit operators it was determined that mitigation strategies themselves can be largely independent of geometry. Beyond track geometry, issues were divided into major categories; those that dealt with between car incidents and those that involved that gap between train and platform. Between car barriers were discussed in detail in previous sections, however on the flow chart it denotes that the potential mitigation strategies can be either vehicle based or platform based. In heavy rail applications the mitigations traditionally tend to be vehicle based.

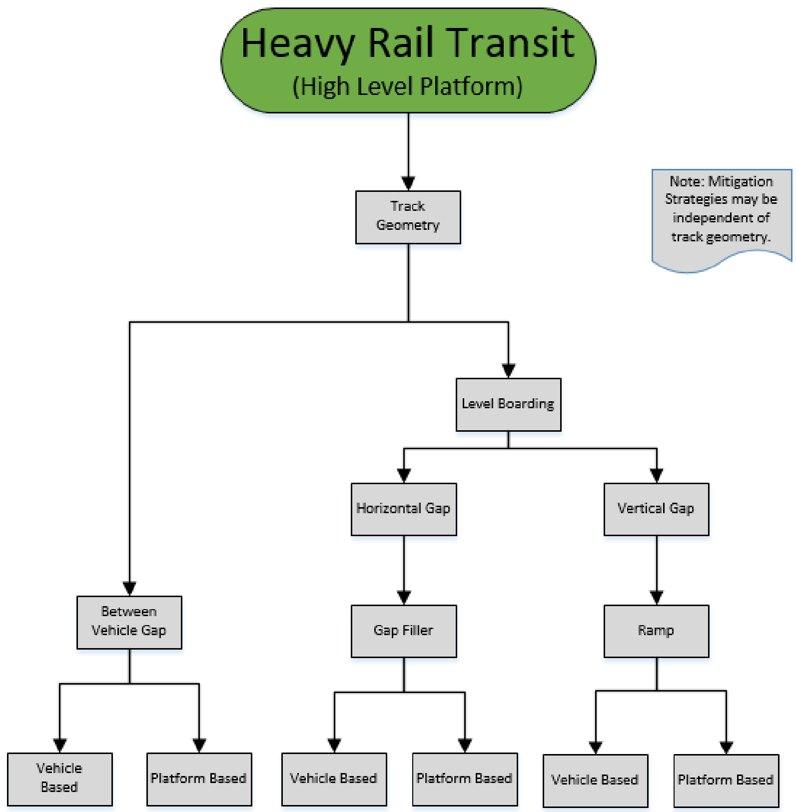

Figure 37: Heavy Rail Transit Mitigation Framework

The primary scope of the TCRP A-40 project deals with rail transit that strives to achieve level boarding. All of the transit agencies that operated heavy rail transit that were interviewed or visited, either comply with or have a goal to comply with ADA regulations for level boarding. In general, PTI type issues can either be due to an excessive horizontal gap or vertical gap. The primary solutions suggested for horizontal gaps tend to be using a gap filler. The platform based gap fillers come in many forms and can be anything from wood to rubber to aluminum. The most common vehicle based gap filler that addresses horizontal gaps is the extended door threshold. With vertical gaps on heavy rail systems the primary mitigation strategy are manually operated ramps. These ramps are either located on the platform or are stored onboard the train. The ramps must be operated by a conductor or station attendant.

STREET RUNNING RAIL TRANSIT

The primary mitigation strategies for street running rail transit can be seen in Figure 38. These strategies are very similar to those of heavy rail transit with two significant differences. Both technologies have potential issues with passengers falling into the gap between vehicles. However, light rail and streetcar systems have yet to come up with an effective vehicle based between car barriers that actually prevent passengers from falling into the gap. The current technologies focus on passenger awareness more so than providing a physical barrier. Aside from providing platform edge fencing (see NCTD in site visit section) the platform based technologies also only focus on awareness. Heavy rail vehicles have been using a metal based barrier since the early 20th century.

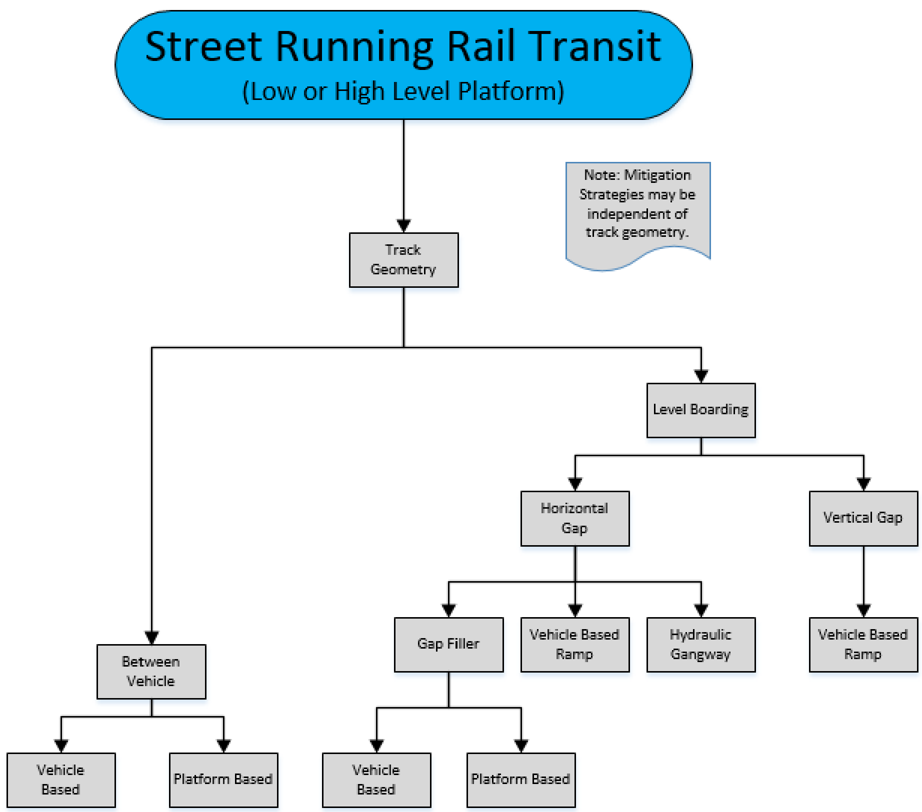

Figure 38: Street Running Rail Transit Mitigation Framework

The second significant difference between street running and heavy rail transit involves vehicle based ramps. Street running rail vehicles have self-deploying ramps that will deploy either automatically or at the request of a passenger. These vehicle based ramps can cover both a small horizontal or vertical gap. In general, most light rail systems do not have many issues with excessive horizontal gaps. However, some legacy systems still require passengers to take a step up to enter the vehicle. This step can be in excess of six inches. The most common mitigation strategy beyond the standard vehicle based ramps normally comes in the form of a platform based gap filler. As with the case of the heavy rail systems, these technologies come in many different forms.

COMMUTER RAIL TRANSIT MITIGATIONS

Figure 39 contains the mitigation flow chart for commuter rail transit. Commuter rail operations are unique with many systems operating on shared use corridors. The specific challenges of this have been discussed previously. While slightly out of the scope of the TCRP A-40 project, the research team felt it was important to include information on "near-level" boarding as well as true level boarding due to many systems in the United States having "near-level" boarding. Most of the mitigation strategies for each boarding case are consistent with the exception of one technique used in the "near-level" boarding case. In order to comply with ADA regulations commuter rail agencies must provide a means for level boarding for passengers with wheeled mobility devices. Rather than raising the entire platform, which could cause side clearance issues, the transit agency generally installs a mini-high platform. This platform generally is raised to be level with the vehicle floor and is slightly set back from the rest of the platform for side clearance. Access to the mini-high platform generally is accomplished by a ramp or a lift. When a passenger requires level boarding the conductor or station attendant will bring out a platform or vehicle based gangway or ramp to bridge the gap.

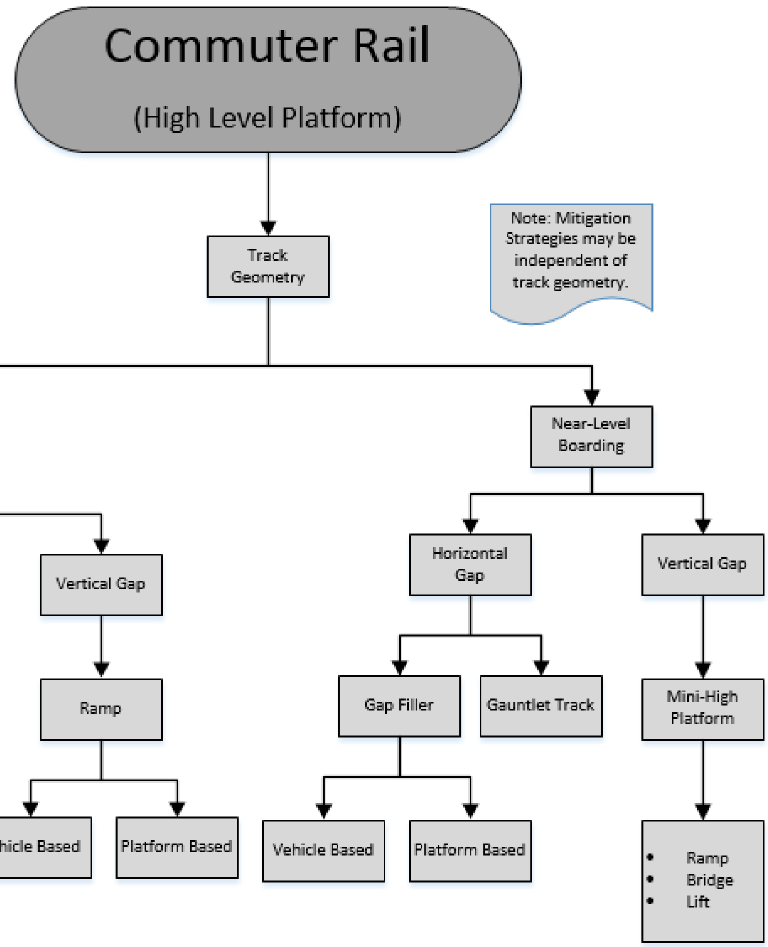

Figure 39: Commuter Rail Transit Mitigation Framework

When level boarding is present, the primary issues tend to relate to either a horizontal gap or vertical gap. When a vertical gap is present either a vehicle based or platform based ramp is used similar to the heavy rail system. For horizontal gaps there tends to be more options available. As previously discussed, commuter rail systems tend to operate on shared use corridors which often introduces a large horizontal gap for side clearance. There are various mitigation strategies that can be effective at reducing this gap. With gaps that are relatively small, six inches or less, vehicle or platform based gap fillers can be effective. However, for larger gaps it is likely that the gap fillers will be used as a supplement and not the primary mitigation. In some extreme cases, the horizontal gap could be more than a foot horizontally. For these platforms there are two technologies that could work well. Gauntlet tracks have begun to increase in popularity as have hydraulic gangways. Both of these mitigations can be effective on low volume lines or those that have temporal freight separation. Another potential solution is having a lower platform height that allows for a smaller side clearance.

OPERATIONAL MITIGATION STRATEGIES

As was previously discussed, operational mitigation strategies were separated from the technical factors due to the significant differences that were found between the different strategies (See Figure 40). Through the literature review, interviews with transit agencies, and site visits it was determined that the basis for operational safety stems from an effective and sustainable safety culture. This involves a significant safety program that is adopted by employees at every level. Below the level of safety culture the operations section was broken into two primary divisions; rail operations and public relations, education, marketing and outreach. On the rail operations side the primary mitigations came in the form of adjusting the number of personnel on the platform or adjusting door operations in specific curved stations. Increasing the number and improving the training of both train and station personnel has been shown to improve overall safety at platforms.

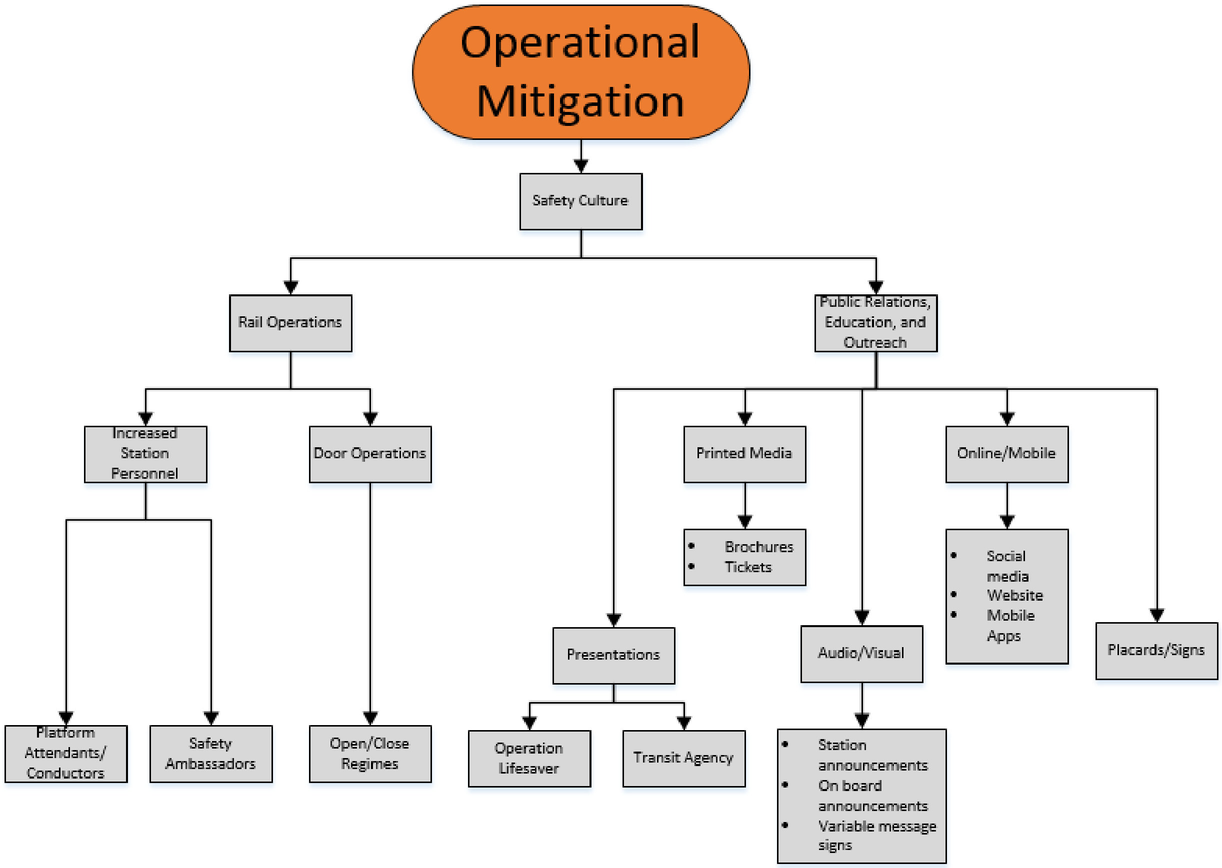

Figure 40: Operational Mitigation Framework

Operational mitigation can also include things such as public relations, education, marketing and outreach. The specific forms of each of these methods can vary significantly and have been discussed in detail in previous sections. However, the primary goal is to increase awareness and improve safety on rail transit systems. The platform-train-interface portion can either be the focus of these efforts or incorporated as part of a larger safety message. Through the literature review and interviews with key stakeholders it was concluded that public relations and outreach can be the most cost effective way to improve PTI safety.

7. Conclusion

Through an extensive literature review, interviews with stakeholders, incident data analysis, and site visits, conclusions that related to platform-train-interface safety could be drawn. The summary of the findings will be broken up into various sections that will reflect what sources they originate from.

It was determined early in the project that both the problems and potential solutions can vary significantly by rail transit mode. Thus a brief summary separated by mode were provided. Separated conclusions are used to give context to the source that each conclusion was made. However, it is important to summarize the overall conclusions from the project. Again, many of these conclusions should be separated by mode.

Heavy rail transit tends to see PTI related incidents for a variety of reasons. Some of the common reasons cited include high ridership, legacy stations, high platforms, diversity of vehicles operating on system, and maintenance issues. The specific issues a transit system faces can vary significantly throughout the system and even on the same rail line. The most common solutions used on heavy rail include public relations campaigns, platform edge extensions, extended door thresholds, and platform screen doors or gates (mostly outside the United States). The incident data the team received dealt exclusively with heavy rail and was discussed in in the data analysis section.

In general, street running rail transit (light rail and streetcar) do not often have problems with the physical gap between train and platform. This was determined primarily through interviews with stakeholders, the literature review, and site visits with transit agencies. However, street running rail transit tends to have issues with between car incidents when more than one married pair is coupled together. While there are currently various techniques that bring attention to the gap between vehicles, there has yet to be a technology developed designed to keep a passenger from falling into that gap that can be used with tight turning radius needed in a street running environment. Some of the passive solutions include chains, elastic straps, and plastic paddles between the vehicles. These between car incidents tend to be rare but often end in a fatality for the passenger involved.

Commuter rail has a unique set of issues concerning the gap between train and platform. This mostly has to do with both federal and state regulations that pertain to freight car clearance on shared corridors. However, commuter rail operations have been working to close the gap through various methods. Some of the common solutions include manually operated bridges, moving platforms, platform edge extenders, hydraulically operated gangways, passenger sidings, and gauntlet tracks. There are distinct advantages and disadvantages associated with each technology.

The data analysis performed for the project involved five heavy rail systems throughout the United States. Data from both street running and commuter rail systems were also sought but follow up interviews with transit operators regarding incident data the common response was that there were no incidents to report. The team was unable to locate commuter rail data from any agency. However data received from the New York site visits showed a dramatic reduction in incidents after many gap mitigations were deployed. In general, based on the data received it seems that PTI related incidents are not the most common incident occurring on U.S. heavy rail platforms. In fact in many cases PTI incidents make up less than ten percent of the total number of incidents. More common incidents include general slips and falls on the platform and falls on stairs and escalators. While not the most common, PTI related incident still do deserve attention. Based on the descriptions seen in the data analysis, many of the PTI related incidents did involve hospital visits. Reducing the number of PTI incidents will improve overall safety on the system.

Interviews with stakeholders have been some of the most valuable information received on the project. The transit agencies have provided useful insights into many significant safety issues that are seen on the systems. Initially, phone interviews were conducted with a variety of stakeholders. There was a predefined script that was designed to inform the research team of the concerns seen from different perspectives around the industry. Transit agencies that operated street running, heavy rail, and commuter rail were contacted and interviewed. Additionally, consultants that designed platforms, rail transit vehicle manufactures, and contractors that worked on platforms were interviewed to gain differing perspectives. Much of what was learned has already been summarized in the previous sections.

In the later stages of the project site visits were conducted at various rail transit operators in the United States. The aim of these visits were to bring together personnel from safety, operations, maintenance, liability, and engineering departments to better understand individual transit agency efforts to improve PTI safety. In addition, the site visits allowed the team to visit stations that employed effective mitigation strategies and stations that saw higher numbers of PTI related incidents.

While some of the key conclusions from the site visits has been discussed in previous sections, there was additional information obtained from these visits that was not recorded up until that point. Key conclusions and mitigation strategies were discussed from various site visits that took place in Los Angeles, San Diego, and Oceanside, California in the spring of 2015.

Los Angeles had an extensive system that operated both heavy rail and light rail. LA Metro focused a large amount of time and money into public relations campaigns that seems to be yielding positive results. Safety messages are conveyed through a variety of print and digital media that is virtually all available on their safety website. On the technical side, LA Metro has developed a platform based solution to draw attention to the between vehicle gap on all of their heavy rail and light rail stations. Furthermore they have utilized aluminum angles to extend the platform when the gap does not comply with ADA regulations. Lastly, horizontal tactile bars are placed on the platforms in at least one location signifying boarding locations for those with low vision.

San Diego MTS operates and maintains the San Diego Trolley system that operates in the metro area. Similar to LA Metro, the platforms use the horizontal tactile bars to signify boarding locations. MTS has developed a unique modified tactile warning strip that provides the vehicle deployed ramp a flat surface to rest on. This solution did require a FTA waiver, however it could potentially be applied to other systems in the United States to ensure there are not problems between the vehicle based ramps and truncated domes of the detectable warning. Additionally, MTS has overcome unique challenges associated with mixed operations on some of their light rail lines. Lastly, the staff at MTS stressed the importance of safety culture within a rail transit agency and how they have been successful borrowing many policies from the freight railroad industry.

The last site visit in the Southern California region was to the North County Transit District (NCTD). This transit agency operates both commuter and light rail in Oceanside, California. The commuter railroad does not attempt level boarding and thus the focus fell to the light rail. NCTD operates diesel multiple unit (DMU) light rail vehicles on a line that is shared with a local shortline freight railroad. The platforms must be set back to provide clearance to the freight cars and thus a large gap was introduced. To combat this gap, NCTD installed hydraulically operating metal gangways. At night when the freight service started the gangways can be lifted to provide the necessary clearances. Another technical solution developed by NCTD was installing fencing along the entire length of the platform, except the door locations. This makes it very difficult for a passenger to fall into the guideway whether a train is present or not.

Mitigation flowcharts were developed by the research team to provide greater clarification about potential mitigation strategies separated by mode. These flow charts allow stakeholders to quickly identify issues and potential mitigation strategies based on general requirements. The flowcharts were separated by modes in relation to the technical and engineering factors. However, operational mitigations were found to be largely independent of mode with minor exceptions.

Overall, the issues surrounding the platform-train-interface are often complicated and can vary significantly from system to system. While it is not the most common incident a transit agency tends to have at a station platform, these types of incidents can still cause serious injuries or even death to passengers. While the primary issues often differ by mode, there are some potential solutions that can benefit any rail transit agency regardless of mode. It was found through the literature review, stakeholder phone interviews, and site visits that public relations and education can often be the most economical solution to improve safety around the PTI.

Furthermore, a strong safety culture that promotes safe operations as the highest priority at the agency is also essential. The goal of the TCRP A-40 project is to develop a manual that transit agencies can use to improve the safety around the platform-train-interface. With both the operational and technical solutions discussed, there should be potential solutions for any rail transit agency regardless of size and budget.

8. References

REFERENCES

1. Braunstein, A. *New Jersey Transit Raritan Line*. *New York Subway*. 2012. Retrieved from http://www.nycsubway.org/wiki/New_Jersey_Transit_Raritan_Line. Accessed July 23, 2014.

2. Carpenter, S. *Passenger risk at the platform-train interface.* Rail Safety and Standards Board (RSSB), London, UK, 2011.

3. Chan, K. (2014). *Are Glass Sliding Platform Edge Doors Feasible for Skytrain Stations? Vacncity Buzz*. Retrieved from http://www.vancitybuzz.com/2014/04/glass-sliding-platform-screen-doors-feasible-skytrain-stations/. Accessed July 23, 2014.

4. *CTIA ' s Wireless Industry Annual Survey 2013*. CTIA- The Wireless Association. http://www. ctia.org /your-wireless-life/how-wireless-works/annual-wireless-industry-survey. Accessed August 15, 2014.

5. Daamen, W., Lee, Y., & Wiggenraad, P. Boarding and Alighting Experiments: Overview of Setup and Performance and Some Preliminary Results. *Transportation Research Record: Journal of the Transportation Research Board*, No. *2042,* Transportation Research Board of the National Academies, Washington, D.C., 2008, pp. 71-81.

6. Daniel, J. R., Rotter, N. G., & Nichnadowicz, V. F. *Customer Behavior Relative to Gap Between Platform and Train* (pp. 1–79). New Jersey Institue of Technology, Newark, NJ, 2009.

7. Davis, R., & Olson, L. *Streetcar Platform Design Approach.* HDR Technical Memorandum (pp. 1–8). 2014.

8. *Ensuring Rail Passenger Safety*. Honolulu Authority for Rapid Transit (HART). Retrieved from http://myemail.constantcontact.com/News-from-the-Honolulu-Rail-Transit-Project.html?soid=1102697428056&aid=Hx5Y3V3IrQE. Accessed July 25, 2014.

9. *Feasibility Study for Implementation of Platform Edge Door System*. British Columbia Transit. December 16, 1994.

10. *FRA Approach to Managing Gap Safety*. Federal Railroad Administration Office of Safety. 2007.

11. *Guidance Safeguards for Passengers Waiting on Platforms-Platform Screen Doors and Track Intrusion Detection System*, 1–2. Taipei Rapid Transit Corporation. http://english.trtc.com.tw/fp.asp?fpage=cp&xItem=1056659&ctNode=27510&mp=122032. Accessed July 22, 2014.

12. Horne, M. *Mind the Gap*. This is the Metadyne Website. http://www.metadyne.co.uk/mind_the_gap.htm. Accessed July 2, 104.

13. Hulse, J. *Intrusion Detection and Prevention Technologies available to Rail Transit*. 2014. Delcan Corportation, Kingston, Ontario, Canada. Presented at the 2013 APTA Rail Conference.

14. Hunter-Zaworski, K. *Workshop and Web Conference Report on "Improving Rail Transit Safety at Platform/Train, Platform/Guideway, and Platform/Roadway Interfaces".* 2014.

15. Kenny, R. *Addressing the Gap: LIRR President's Testimony.* February 8, 2007. Long Island Rail Road (LIRR). http://web.mta.info/lirr/safety/GapHearing.pdf. Accessed August 10, 2014.

16. Kirse, K. *TriMet's WES Commuter Rail Use of Gauntlet Track For Level Boarding*. Tri-County Metropolitan Transportation District of Oregon. http://www.apta.com/mc/rail/previous/2010/Presentations/TriMet-WES-Commuter-Rail.pdf. Accessed July 22, 2014.

17. *Modern Streetcar Vehicle Guideline.* American Public Transportation Association (APTA). APTA Standards Development Program. Washington, D.C., 2013.

18. *Passenger risk at the platform-train interface.* Rail Safety and Standards Board (RSSB), London, UK, 2011.

19. Reiss, S., Lozano, R., Cannell, M., Puglisi, D., & Mitchell, L. *Successful Implementation of Station Platforms Between Car Barriers*. Transportation Research Board of the National Academies, Washington, D.C., 2014, pp. 2-8.

20. Rose, P. *Between-car Barriers Enhance Safety on Muni Metro*. San Francisco Municipal Transportation Agency. http://www.sfmta.com/ko/news/press-releases/between-car-barriers-enhance-safety-muni-metro. Accessed July 24, 2014.

21. Santoso, D. S., & Mahadthal, S. *How Safe is the Rail Platform? A Study of Bangkok Mass Transit System (BTS*). Eastern Asia Society for Transportation Studies. Retrieved from http://easts.info/on-line/proceedings/vol9/PDF/P233.pdf. Accessed July 20, 2014.

22. Schutte, J., Dimter, T., & Scholz, S. A New Video Based Guideway Intrusion Detection System for Public Transportation Infrastructures. *International Union of Railways*. 2006.

23. Schwebel, D. C., Stavrinos, D., Byington, K. W., Davis, T., O'Neal, E. E., & de Jong, D. (2012). Distraction and pedestrian safety: how talking on the phone, texting, and listening to music impact crossing the street. *Accident; Analysis and Prevention*, *45*, 266–71. doi:10.1016/j.aap.2011.07.011

24. Smiler, S. *Easy Access. City Transport*. City Transport. Retrieved from http://www.citytransport.info/Access.htm#Train. Accessed July 8, 2014.

25. Stavrinos, D., Byington, K. W., & Schwebel, D. C. (2011). Distracted walking: cell phones increase injury risk for college pedestrians. *Journal of Safety Research*, *42*(2), 101–7. doi:10.1016/j.jsr.2011.01.004

26. Yamada, S., Terabe, S.. & Kasai, M. Safety Performance Measures for Railway Stations. In *TRB 93rd Annual Meeting Compendium of Papers*, No. 14-1868, Transportation Research Board of the National Academies, Washington, D.C., 2014.

27. McNeil Management Services, "Independent Review: Skytrain Service Disruptions on July 17 and July 21, 2014". Last accessed November 21, 2014 http://www.translink.ca/~/media/documents/about_translink/media/2014/tra_1795_independent_review_booklet_final.ashx

28. Botha, J., Neighbor, M., & Kaur, S. "An Approach for Actions to Prevent Suicides on Commuter and Metro Rail Systems in the United States." Report 12-33. Mineta Transportation Institute at San Jose State University. 2014.

29. McElveen, Levern. "Defining and Measuring a Transit Safety Culture." 2014.

30. Devadoss, R., Amad, S., & Raman, D. "Platform-train interface for rail passengers – technology review." Cooperative Research Centre for Rail Innovation. Brisbane, Australia, 2012.

31. Klein, Jonathan. "ADA Requirements for Rail Operators." Federal Transit Administration. 2010. http://www.apta.com/mc/rail/previous/2010/ Presentations/ADA-Requirments-Impacting-Rail-System-Construction-and-operations.pdf.

32. "Service in an Integrated Setting to Passengers at Intercity, Commuter, and High-Speed Rail Station Platforms Constructed or Altered After February 1, 2012." Part (f). CFR 49, Part 37, Subpart C, 37.42, (f). U.S. Government Publishing Office. February 26, 2015. Accessed March 3, 2015.

33. “ADA & Level Boarding – Consolidated Questions and Answers.” Office of the Secretary of Transportation, General Counsel, U.S. Department of Transportation. Washington D.C., 2012. http://www.ecfr.gov/cgi-bin/text-idx?SID=efa53a498236ca04a85f69a40135675c&node=sp49.1.37.c&rgn=div6. Accessed 3 March, 2015.

34. “Side Clearances.” Oregon Department of Transportation Rail Division. Division 310. http://arcweb.sos.state.or.us/pages/rules/oars_700/oar_741/741_310.html. Accessed 3 March, 2015.

35. “Regulations Governing Clearances on Railroads and Street Railroads with Reference to Side and Overhead Structures, Parallel Tracks, Crossings of Public Roads, Highways and Streets.” California Public Utilities Commission, 1948. http://docs.cpuc.ca.gov/PUBLISHED/GENERAL_ORDER/59571.htm. Accessed 3 March, 2015.

36. “A.A.R. Equipment Diagrams for Interchange Service.” The Great Northern Empire – Then and Now, 2003. http://www.greatnorthernempire.net/index2.htm? GNE_AAREquipmentDiagrams.htm. Accessed 2 March, 2015.

37. “BiLevel Coaches.” *Regional Trains- Bombardier Transportation. http://www.bombardier.com/en/transportation/products-services/rail-vehicles/commuter-and-regional-trains/double-deck-coaches.html*. Accessed 2 March, 2015.

38. "49 CFR, Subtitle A, Part 37, Subpart C, 37.42 (f)." ECFR — Code of Federal Regulations. Government Publishing Office, n.d. http://www.ecfr.gov/cgi-bin/text-idx?SID=efa53a498236ca04a85f69a40135675c&node=sp49.1.37.c&rgn=div6. Accessed 25 January, 2015.

39. "ADA & Level Boarding - Consolidated Questions and Answers." ADA & Level Boarding. Federal Transit Administration, n.d. Web. 10 Jan. 2015.

40. Standard S-2028-91, “Equipment Diagram for Limited Interchange Service, Plate C”; Manual of Standards and Recommended Practices, Section C, Part I (latest revision); Association of American Railroads.

41. Standard S-2026-91, “Equipment Diagram for Unrestricted Interchange Service, Plate B”; Manual of Standards and Recommended Practices, Section C, Part I (latest revision); Association of American Railroads.

42. "Division 310 (Side Clearances)." Oregon Secretary of State Archives Division. Department of Transportation, Rail Division, n.d. Web. 15 Jan. 2015.

43. "Regulations Governing Clearances on Railroads and Street Railroads With Reference To Side and Overhead Structures, Parallel Tracks, Crossings of Public Roads, Highways and Streets." Public Utilities Commission of the State of California, n.d. Web. 18 Jan. 2015.

44. "LA Metro Site Visit Interview." Personal interview. 18 Mar. 2015.

45. "Public Hearing Regarding Equivalent Facilitation for Modification of Detectable-Warning Tactile Strip To Accommodate Bridge Plate on Low-Floor Vehicles (Wayne Terry and John Haggerty SANDAG)." (n.d.): 55-57. Metropolitan Transit System. 14 July 2011. Web. 10 Jan. 2015.

46. "San Diego MTS Site Visit Interview." Personal interview. 20 Mar. 2015.

47. "NCTD Site Visit Interview." Personal interview. 21 Mar. 2015.

9. Appendix

JOINT RAIL CONFERENCE 2015 MANUSCIPT

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TCRP A-40 Manual to Improve Rail Transit Safety at Platform/Train Interfaces: Summary of Platform-Train Interface Incidents.

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ABSTRACT

The overall goal of the project is to develop a manual for the Transit Cooperative Research Program (TCRP) that will allow practitioners to improve safety at rail public transportation platform/train and platform/guideway interfaces. Specific objectives include expanding upon previous safety studies and providing recommendations for mitigation strategies. Key factors that affect safety in relation to the platform-vehicle interface (PTI) have been identified through data collection. For the purpose of this study PTI refers to incidents related to the interface between the train and platform also known as gap incidents. Factors were analyzed to determine appropriate measures that would allow transit agencies to both prevent and minimize consequences of these incidents.

This paper focuses primarily on platform vehicle interface incident data that were collected from four large transit operators in the United States.

INTRODUCTION

NEED AND JUSTIFICATION

Many transit agencies and researchers recognize that PTI incidents are an important safety concern. Incidents that involve the gap between the platform and train are not necessarily only dependent on the gap size. This is supported by a literature review that suggests that there may be other contributing factors that impact boarding and alighting safety. Various studies from around the world have considered aspects of gap safety in relation to different rail transit modes. Many of these documents were reviewed to ensure that the project effectively addresses issues concerning the platform-train-interface. This paper is based on one part of the research that is currently being undertaken as part of the Transit Cooperative Research Program (TCRP) A-40 project. The objective of the research project is to develop a manual for practitioners to improve safety at rail public transportation platform/train and platform/guideway interfaces. The research reported in this paper focuses on the incidents that resulted in injuries and fatalities and were reported by some of the larger US transit agencies. Mitigation of the incidents will impact the overall safety of system operations by reducing dwell time and system delays, and also reducing both the number and severity of platform train interface incidents.

NOMENCLATURE

PTI Platform Train Interface

PSD Platform Screen Door

NTD National Transit Database

TCRP Transit Cooperative Research Program

DISCUSSION

Data Collection from Stakeholder Transit Agencies

Data collection from the stakeholder transit agencies has been ongoing since May 2014. This activity has taken many forms including telephone calls, face-to-face meetings, informal site visits, web surveys, and interviews. A number of safety officers at several larges transit agencies have provided incident data sets and participated in follow up phone interviews. In addition to contacting transit agencies, the research team examined the National Transit Database (NTD) and the Federal Railroad Administration Safety reports for incident data. These databases contain aggregate data on injuries and fatalities but do not include detailed information related to the vehicle platform interface incidents.

Incident Data

Safety officers at several of the larger US transit agencies were contacted for incident data. This data is very sensitive and it took weeks to months to obtain. Incident data was obtained from twelve transit agencies however only four provided data that was useful for analysis. In compliance with TCRP privacy guidelines the transit agencies will be referred to as transit systems A, B, C, and D. The data collected from these agencies only concerns heavy rail transit. Many of the light rail operators did not have any platform–vehicle incident data to report and no PTI data was received from commuter operators.

In general the platform incident data from the transit agencies did not have enough incidents to conduct a detailed statistical analysis, however it was possible to see trends in the data that was provided. In addition, follow-up phone interviews were also conducted for clarification of incident data items.

Data Analysis and Assessment

It is also important to frame the analysis in context. The following table is derived from data from the National Transit Database and aims to draw attention to the scale of the transit systems discussed. It is inappropriate to compare these systems by total number of incidents as there is a significant difference in ridership and train revenue miles.

Table 22: Yearly Ridership of the Four Stakeholder Systems

2013	Vehicle and Passenger Revenue Miles	Train Revenue Miles
Transit System A	344,975,317	37,908,349
Transit System B	69,046,006	11,569,883
Transit System C	75,884,600	11,971,325
Transit System D	7,884,786	1,955,280

Identifying factors which correlate between incidents and interface characteristics

Discussions with the transit agencies and the analysis of data indicated that the analysis needed to be separated by mode: street level transit such as light rail transit and streetcars, heavy urban rail, and commuter rail that often operate on shared track. As previously stated, this study focuses only on heavy urban rail transit due to availability of data. The incident data analysis from four large transit agencies is summarized in the following sections.

Transit Agency A

Transit system A provided the most complete dataset, covering incidents occurring between January 2013 and December 2013. It should be noted that Transit system A provided incident data for only PTI related incidents and not other platform related incidents. In addition to the raw data, an interview with the safety officers during the summer of 2014 was also conducted to clarify some of the data and answer additional questions.

System A Data Summary (January 2013 – December 2013)

- Majority of incidents occurred during boarding (68%), as opposed to alighting (32%).

Table 23 Number of Incidents Boarding versus Alighting

Entering vs. Exiting		
# of Incidents	120	
Boarding	82	68%
Alighting	38	32%
Total		100%

- Majority of incidents involved female passengers (61%). It was discussed during the follow up interview that female passengers may be more likely to report an incident than a male passenger.

Table 24 Number of Incidents Male versus Female

Male vs. Female		
# of Incidents	127	
Male	49	39%
Female	78	61%
Total		100%

- More gap injuries were recorded on tangent or straight track as opposed to curved or curve transitions. It should be noted that there are many more tangent platforms than curved, thus proportionally the curved/transition platform incidents may be more common relative to total number of platforms.

Table 25 Number of Incidents Tangent versus Curved Track

Tangent vs. Curve Track		
# of Incidents	97	
Tangent	63	65%
Curve/Trans	34	35%

- Track Division #1 had 76% of the incidents and Track Division #2 saw the remaining 24%. Discussion with transit system A staff members clarified that vehicles used in Division #1 are smaller and are 105.5 inches wide while the vehicles on Division #2 are larger with a width of 120 inches. As a result, Division #1 vehicles often see larger horizontal gaps than Division #2 vehicles.

Table 26 Number of Incidents by Track Division

Track Division (#1 or#2)		
# of Incidents	127	
Division #1	96	76%
Division #2	31	24%
Total		100%

- The majority of injuries fell into the “Adult” age category. It should be noted that it is reasonable to conclude that the majority of passengers using the system are in the “adult” age category. Data was not provided on the general age demographic profile of the system A passengers. Age categories were predefined by transit system A and were reported for incidents in which age was known.

Table 27 Number of Incidents by Passenger Age Grouping

Age of Injured Passenger		
# of Incidents	60	
Child	15	25%
Adult	40	67%
Elderly	5	8%
Total		100%

- Injuries divided up equally between peak and non-peak times. However, it appears that the PM peak sees a slightly higher number of incidents as compared to the AM peak.

Table 28 Number of Incidents by Time of Day

Injury Time of Day		
# of Incidents	159	

AM Peak	35	22%
PM Peak	44	28%
Off Peak	80	50%
Total		100%

- There is slight increase in gap incidents during summer months (July, August, and September) but overall gap injuries appear to be consistent throughout the year.

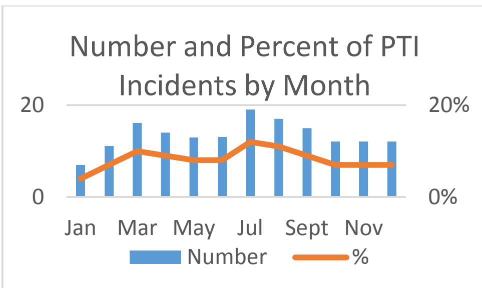

Figure 43: Number of PTI Incidents by Month

Other Data Notes

For incidents in which it was recorded, it appears that the right and left leg are equally likely to be involved in a gap incident. Only one wheelchair and one stroller incident were recorded in the transit system A data. In general, it was stated by many passengers involved with PTI incidents that overcrowding or pushing were instrumental in causing the event. During the interview with transit system A staff there was discussion about whether some of the incidents occurred when passengers stepped out of the vehicle temporarily to provide more room for alighting or boarding passengers. It was noted that 68% of the incidents occur during boarding and a question to be researched further is whether this is due to passengers rushing to board before the door closes.

Transit system B

Transit system B also provided an extensive dataset that included incident data from November 2013 through early October 2014. The dataset for transit system B included all incidents on rail transit platforms in contrast to transit system A which only provided data on PTI incidents. A summary of the various incident types can be seen in table 8. Transit system B reported that PTI incidents accounted for about 8 percent of the total platform related incidents. Of the 852 incidents reported, 73 involved the PTI. Furthermore, from the written descriptions of the incidents it appears that people are more likely to trip over the gap between the train and platform as opposed to falling in the gap. However it should be noted that transit system B did report a number of passengers falling into and getting stuck in the gap.

Upon further analysis, it appears that PTI related incidents are more common at the elevated stations on the system as opposed to the at grade or underground platforms. Specific reasoning for this is unknown and further research should be conducted to identify factors that may cause this. Additionally, the majority of the incidents occur during the middle of the day (9:00AM to 4:00 PM) followed closely by the PM Peak period that was designated as trips between 4:00 PM and 7:00 PM. Both men and women were equally as likely to be injured due to a PTI incident. However, it should be noted that nearly 25 percent of the incidents did not specify a gender.

Table 29 Transit System B Incident Types

Incident Type	Incidents by Type	% of Total
Closed in Door (1)	31	4%
Slipped and Fell (2)	275	33%
Gap/PTI (3)	73	8%
Intoxication (4)	32	4%
Injured by Escalator/Stairs (5)	352	41%
Attempted or Successful Suicide (6)	2	0%
Involved Wheelchair (7)	7	1%
Struck by Train (8)	0	0%
Fell into Guideway/Right-of-Way (9)	79	9%
Total	**852**	**100%**

The most common injuries seen by transit system B were slips or falls on the platform not related to boarding or alighting and injuries sustained on an escalator or staircase. Another unique trend seen in transit system B were the number of passengers who fell into the guideway. It was the third most common incident that occurred within the relevant dataset. Despite the high number of guideway intrusions, there appeared to be no passengers struck by a train and none were listed as successful or attempted suicide.

In transit systems B and C, there were people that complained about getting caught in the vehicle doors while boarding or alighting, however this was reported in only 4 percent of the incidents with transit system B. While door incidents are not always related to gap incidents, they are often linked. Written descriptions of passenger incidents commonly stated that being struck by doors or avoiding closing doors were a reason for tripping or falling into the gap.

Transit System C

The number and type of platform related incidents for transit system C can be seen in Table 9. The data used for this analysis was a subset of incident data provided by transit system C ranging from incidents that occurred as far back as 2010 and as recent as 2014. Gap and/or PTI incidents only account for 5 percent of the total number of platform related incidents.

Table 30 Transit System C Recorded Incident Data by Type

Incident Type	Number of Incidents	% of Total Incidents
Closed in Door	19	20%
Slipped and Fell	14	14%
Gap/PTI Incident	5	5%
Intoxication	4	4%
Injured by Escalator	52	54%
Attempted or Successful Suicide	3	3%

Total	97	100%

In addition to gap related incidents, 20 percent of the incidents occurred when passengers were struck or caught during the door closing phase. This type of incident was also commonly seen in other data that were received from transit systems. Of the reported PTI type incidents at transit system C, only one involved a passenger getting stuck between the platform and train. The remaining injuries involved tripping or falling while boarding or alighting the train.

Transit System D

Table 10 includes data received from Transit Agency D that involved platform related incidents from August 2013 to August 2014. This incident data tended to be slightly more specific than the data from transit system C but still contained fewer details than information received from transit systems A and B. Transit system D did not report many PTI injuries, but the incidents still had an impact on the overall safety of the system. Many of these incidents involved passengers falling or slipping when boarding or alighting as opposed to falling into the gap. In fact, only one passenger physically got caught between the train and platform.

Table 31 Transit System D Transit Recorded Incident Data by Type

Incident Type	**Number of Incidents**	**% of Total Incidents**
Closed in Door	9	4%
Slipped and Fell	58	24%
Gap/PTI Incident	9	4%
Intoxication	4	2%
Injured by Escalator	159	65%
Attempted or Successful Suicide	0	0%
Involved Wheelchair	3	1%
Struck by Train	2	1%
Total	**244**	**100%**

CONCLUSION

There are certain trends that can be seen in the transit agency's incident reports. Transit system A had many "gap" related incidents which may be attributed to gap geometry and high ridership. Based on the data studied, it can be concluded that PTI type incidents are not a frequent type of platform related safety incident, however they still can have a significant impact on overall system safety. Additional analysis of the data suggests that heavy rail transit tends to be most vulnerable to PTI type platform incidents. Street operating rail transit modes such as light rail and streetcar, experience very few if any reportable PTI incidents. While not the focus of this analysis, commuter rail tends to experience fewer PTI related incidents as compared to heavy rail transit, but often more than street operating modes.

Within the PTI incidents, the most common injury involved tripping or falling while boarding or alighting from the train. It appears that tripping over the gap is far more common than physically falling into and becoming stuck in the gap. Conclusions about which gender is more commonly involved in PTI incidents can be difficult to make. The data received from transit system A seems to suggest females more commonly are involved. However, data received from the remaining agencies appear to be balanced between the genders. Passengers getting struck by and caught in vehicle doors is also a frequently reported incident that should be investigated further. As previously mentioned, it is possible that door closing regimes may impact the frequency and severity of PTI incidents. Future investigation is needed to determine the impact on PTI safety of ambient lighting in the vehicle vestibule and at the edge of the platform.

While beyond the scope of the current project, it appears that incidents related to slips, falls, on platforms, escalators and stairs tend to be far more common than (PTI) type incidents.

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