HOUSTON METRORAIL HUMAN FACTORS SAFETY ANALYSIS

Prepared For:
The Kinder Institute

By:
Rice University
Human Factors Research Laboratory
Executive Summary

Concern over METRORail light rail vehicles collisions with cars, pedestrians, and motorists led the Kinder Institute to fund Rice Human Factors researchers to conduct a safety analysis of the rail lines. Researchers from Rice proposed that the METRORail system design may not abide by human factors principles, resulting in accidents similar to those seen in other safety critical systems. This safety assessment found that the METRORail system has several system wide human factors issues and several specific to particular sections of track. Possible safety enhancements are suggested for each issue.

The research team consisted of human factors researchers from Rice, who examined METRORail’s design, operations, and interactions with pedestrians, motorists, and cyclists using 11 human factors methods. Frequent road user behaviors were also observed and recorded. This study primarily took place from September to December 2019. Further work was interrupted due to the COVID-19 pandemic.

Previous safety analyses have been conducted by the Texas Transportation Institute (2004) and Transportation Safety and Security Solutions (2018). The former found that users are the cause of light rail collisions, a claim largely in opposition to human factors philosophy, while the latter recommended visual, audible, and physical barrier solutions to address accident rates. A most recent METRO safety enhancement, SmartSync, shows great promise in reducing collision rates.

Collision history shows that the most common type of collision is due to turns by motorists. This was identified as an issue in other light rail systems and was also identified as a major issue in the current safety analysis. Light rail lines in San Francisco, Los Angeles, and Portland have each had similar problems as the Houston METRORail. Portland, in particular, was successful at addressing the left turn issue through a comparison case study. An all red-traffic light phase allowing trains to pass before motorists could turn left proved to be the most effective safety enhancement.

The assessment found that several human factors issues exist in the system. Major issues include poor train visibility, inconsistent audible cues, crosswalk tempo, dynamic turn lanes, and both inadequate and excessive signage. There are additional system level and track specific issues identified in the report. Rice researchers recommended design enhancements that would help mitigate these human factors issues and create a safer and more user centric system. Future work would implement the recommended solutions and track accident rates over time.
1. Introduction

1.1 Challenge

In response to a history of fatal and injurious train collisions, the Houston METRORail has sought to make Houston’s light rail system safer. Past system analyses have found that the system is fundamentally safe and accidents are caused by the pedestrian or driver involved. However, these analyses did not address the root cause of the user error; why are users continually committing life endangering errors? Rice University Human Factors researchers proposed that the design and operation of the METRORail system does not meet empirically grounded human factors best practices. To assess this, Rice researchers analyzed the safety critical elements of the METRORail system using human factors and user-centered design methods to identify human factors violations and solutions. The contents of this report present the findings of this assessment and propose optimal design solutions that would reduce user error in METRORail's interactions with vehicles, pedestrians, and cyclists.

1.2 Scope

This work exclusively considered the interaction between pedestrians, motorists, and cyclists with system elements that contribute to overall safety. Specifically, this analysis focused on traffic lights, train signals, crosswalk signals, signage, pavement markings, intersection design, and visual and auditory cues. Ticketing machines and onboard train feedback were excluded from this study because they do not directly affect environmental safety.

The research team spent three months observing road user behaviors and surrounding transportation environment elements. Researchers did not directly consult pedestrians, motorists, or light rail vehicle operators. The findings of this report are largely based on observation by a team of human factors experts.

1.3 Report Contents

This report first presents an overview of past system analyses and recent safety solutions, as well as METRORail’s collision history to date. Following this is an account of the safety enhancements other light rails systems used to address their trend of collisions. The remaining sections of this report detail the methods used to analyze the system and the specific findings of the research team. Rice Human Factors researchers detailed human factors violations and causes and effective solutions that would create a safer road system.
2. Background

The Houston METRORail has an ongoing history of accidents. Within the first four weeks of public operation there were five train collisions with motor vehicles; several accidents also occurred in the testing phase prior to launch (Texas Transportation Institute, 2004). Fifteen years after METRORail’s implementation, it is one of the most injurious train systems in the country. A recent account of incidents reports 16 deaths and over 500 injuries (Oberg, 2018). Despite past efforts, this is still a prevalent safety concern. Previous efforts have focused on public awareness and system centric safety analyses, but they have been unable to eliminate the trend of car, pedestrian, and cyclist collisions.

METRORail employed the services of several consulting firms such as the Texas Transportation Institute (TTI) and Transportation Safety and Security Solutions (TSSS), Inc. to evaluate the system. TTI analyzed the system during its first year in operation in response to the accidents reported within the first few weeks. The majority of collisions during that time were with cars and TTI concluded that all the collisions examined were due to driver error—illegal turns, running red lights, etc. (Texas Transportation Institute, 2004). Their solutions included increased and clearer signage, increased use of pavement markings, and minor traffic signal modification. TSSS analyzed the system in 2018 and noted that METRORail is fundamentally safe and motorist error is the leading cause of accidents (Transportation Safety and Security Solutions, 2018). Their recommendations to reduce the frequency of collisions included visual and audible solutions that will better alert pedestrians and cyclists of an oncoming train, as well as passive alternatives like swing gates and pedestrian shoulder railings.

METRORail incidents have become a common occurrence and impedance for METRORail riders. The previous studies have focused on public awareness and alert solutions. Many of these have proven ineffective, including the “Stay in Your Lane” painting on trains and signage intended to focus pedestrians’ attention to the crosswalk system (Delaughter, 2018). However, one particularly effective system safety enhancement is SmartSync, which has only been implemented in Houston’s Central Business District. Smartsync is a traffic control program that places light rail vehicles and cars in parallel lanes in separate phases. For example, the train can only proceed when the cars have a red light. Therefore, cars making an illegal left turn during their phase would not collide with the train because the train has not moved. Smartsync has resulted in a 35 percent decrease in light rail vehicle collisions in Houston’s Central Business District since May 2018 (METRO, 2019). Smartsync has also lowered the wait times for pedestrians at intersections, which results in decreased crossing violations (METRO, 2019). Following the success of SmartSync, METRO has proposed
expanding its use and removing shared lanes and installing train only lanes; the combined efforts are projected to decrease the system collision rate by 30% (METRO, 2019).

2.1 METRORail Collisions

2.1.1 Information Gathered
METRORail Collision history from 2015 to 2019 was provided by the Records department of the Metropolitan Transit Authority. This information detailed the date, location, and collision type of the light rail incidents. However, full safety reports or police reports on the specific circumstances of the incidents were not available to the researchers. Any additional accident-related information was gathered from news sources when available. This limits the insights we can gain into the human factors causes of past train collisions.

2.1.2 METRORail Collision History
Figure 1 presents the causes of system-wide collisions, as defined by METRO, in the past five years. There were a total of 459 reported collisions involving a METRORail light rail vehicle over this time period. Turns accounted for 41% of all collisions. Due to limited information, it is unclear whether these turns were illegal left turns or sanctioned turns. However, illegal left turns have previously been reported to be a major issue in the system and are suspected to be a significant part of this number. About 23% of collisions were due to motorists running red lights, while pedestrian and fouling collisions each accounted for 15% of collisions. The location and frequency of each collision are shown in Figure 2.
Figure 1
YY 2015-2019 System Wide Collisions

- Turns: 157
- Red Light: 73
- Rear-end: 13
- Fouling: 55
- Pedestrian: 56
- Cyclist: 10
Figure 2 highlights intersections with a high accident frequency along the METRORail tracks, most of which run along the red line. High incident stations in this context are defined as those with 8 or more collisions in the past five years. The following 11 intersections fit this criteria. As Metro returns to more normal operations following the pandemic, Metro may wish to focus further research efforts on these high-accident stations.
1. Fannin & Dryden – 28 collisions
2. Capitol and LaBranch – 18 collisions
3. Main and Pease – 15 collisions
4. Wheeler and UH Entrance #6 – 12 collisions
5. San Jacinto and Hermann Dr – 11 collisions
6. Main and Elgin – 10 collisions
7. Scott and IH-45 – 9 collisions
8. Main and St. Joseph – 9 collisions
9. Main and Alabama – 9 collisions
10. Scott and McGowen – 8 collisions
11. Fulton and Crosstimbers – collisions

2.2 Analysis of Similar Systems

An analysis of similar systems investigates how other systems similar to the system of interest have addressed comparable problems. This analysis looks at several metropolitan light rail systems across the U.S.

San Francisco
San Francisco's BART system is an above-grade, automated heavy commuter rail system that provides transportation between the San Francisco Bay Area counties. BART primarily features double tracks and does not loop. As the system is automated, on board operators have limited duties - alerting the system that the platform is clear for departure, trouble-shooting problems, and manually operating the trains when a system issue occurs (Winter et al, 2004). Despite the automation of the system, BART, like METRORail, has serious issues with collisions due to fouling. In response to the fatal injury of two transit workers on the track, BART installed trackside physical barriers and $2 million in safety barrier fencing to protect rail workers (CBS, 2018). Prior to this incident, employees working on the track were responsible for clearing the track in a timely fashion if a train was approaching. In the case of the two transit workers, the operator failed to announce the train’s arrival with the train horn, an issue also identified for METRORail. These safety measures separate the worker from the track and further reduce the likelihood of loss of life or injury. Moreover, the above-grade design differs from METRORail’s at grade system and reduces the potential for collisions with cars, bicyclists, and pedestrians.

Los Angeles
Los Angeles' Metro Rail system is an urban rail transportation system featuring both heavy and light rail lines. This analysis will only focus on its at grade light rail system. Los Angeles' Metro Rail system has had a large number of accidents due to motorists
circumventing light rail crossing gates. In response, four quadrant gates were implemented, preventing vehicles from each direction of traffic from crossing in front of an oncoming train. These gates also include exit gate arms to allow vehicles already on the tracks to exit. The exit gate arms come down after a few seconds delay, which blocks cars from driving around the gate arms. Four quadrants gates were found to provide the greatest safety benefits for the Los Angeles Metro Rail system (Railway Pro, 2017).

Portland
Portland’s MAX light rail system has over 90 stations and connects the six sections of Portland. The MAX presented an interesting study of motorist collisions at two light rail station intersections. One intersection has a sign prohibiting left turns, while a parallel intersection allows left turns only after an all red-traffic light phase, during which the train clears the intersection. Multiple collisions occurred at the intersection that prohibited left turns, while none occurred at the other intersection, because motorists often ignored the signage. The no left turn intersection was subsequently changed to mirror the design of the all-red phase intersection which reduced the collision rate. This is an example of how the system should support the goals of the user and the danger when it does not.

3. Methods
Twenty-three teams (23) were assembled to conduct field studies of the red, purple, and green lines of the Houston METRORail. Each team was responsible for at least two train stations and the area of track between them. The teams examined the intricacies and functioning of the whole system — the behavior of trains, cars, pedestrians, cyclists, in response to each other, signals, signage, and the built environment — and collected data on operational and user characteristics, incompatibilities between the system and user, and prominent errors. The following methods were performed along each section of track and were used to assess the safety critical elements of the system.

1. Heuristic assessment
2. Cognitive walkthrough
3. Pareto analysis
4. Operational analysis
5. Analysis of similar systems
6. Activity analysis
7. Critical incident study
8. Error analysis
9. Flow analysis
10. Function allocation
11. Task analysis

The following are analysis methods: operational analysis, pareto analysis, analysis of similar systems, activity analysis, critical incident study, and error analysis. Together they detail the workings of a system, determine priorities in the problem, inform on how others have addressed similar situations, highlight user actions, and uncover causes and severity of errors. These methods aid in understanding the nature of a problem and, subsequently, inform decisions on the future state of the system.

Flow analysis, function allocation, and task analysis are design guidance methods. Each uses knowledge about human capabilities and limitations to design a system to account for what humans are expected to do. Flow analysis portrays order of the functions people or systems perform, while function allocation considers whether humans, hardware, or software should be performing a given function. A task analysis details the tasks that people will perform and provides insight into potential errors or task incompatibility associated with task criticality, duration, and performance.

Heuristic assessment and cognitive walkthrough are usability methods that ensure a product or system fits the needs of the users. In the case of METRORail, these methods were used to determine if there were difficulties with using the system and how the user-system interaction could be improved.

Note that the observations of the system were conducted in the Fall of 2019, with analysis starting in the spring of 2020. Follow-up observations and analysis had to be put on hold as the pandemic struck and Metro sharply curtailed operations and passengers avoided public transportation for health and safety reasons. Even after the commencement of near normal operations, ridership, traffic/train/pedestrian counts and patterns were likely impacted post-pandemic.

4. User-System Incompatibilities

The following sections detail the findings of the research team. The research team identified human factors violations at the system level and along specific sections of track. Each human factors issue is accompanied by a description of its importance and/or cause and possible improvement actions. We start by describing problems that are common across the entire system, and then detail deficiencies at specific stations.
4.1 System-Wide

**Human factors violation 1**: The METRORail system is at grade.

*Importance*: At grade systems interact with pedestrians, motorists, and cyclists, which is an intricate interplay prone to error. This increases the likelihood of collisions compared to above grade or below ground systems.

*Possible actions:*

- Future track should be above grade or segregated from traffic entirely, to eliminate the collision potential with pedestrians, cars, or cyclists. Understanding that the at-grade decision was done for many important reasons, not the least of which is cost, systems where the trains are not at grade (e.g., Miami MetroMover, Figure 3) do not have these kinds of accidents since the trains do not interact with automobiles or cyclists at all. Pedestrians are safer as well, since they only have access to the trains at designated stations.

**Figure 3:**
Example of the Miami Metromover system, which is not at-grade at many locations. Note how the pedestrians and traffic operate independently of the trains. Image courtesy of Phillip Pessar, Attribution 2.0 Generic (CC BY 2.0)
Human factors violation 2: The system has shared lanes between light rail vehicles and cars.

Importance: Shared lanes between cars and light rail vehicles increase the likelihood of collisions because the light rail vehicle is directly interacting with traffic. This is especially problematic for motorists who are new to the system and unable to predict the train’s movements. Dynamic lanes (where motorists are alternately allowed and disallowed into the lane) are especially confusing for motorists, and complex, confusing signage supporting these lanes exacerbates the situation. Additionally, this design has resulted in rear end collisions.

Possible actions:
- Future track should separate train and car lanes.
- Ensure shared lanes are clearly designated throughout the system, so motorists are not surprised, as shown below in Figure 4.

Figure 4
*Markings in the shared lane to alert the motorist*

Human factors violation 3: Some light rail vehicles are painted red (Figure 5), which is one of the most difficult colors for the human eye to detect, particularly at night.
Importance: Perception literature has identified that red is one of the least visible colors, especially in low light conditions. This poses a risk to pedestrians, motorists, and cyclists who must visually detect the trains in a busy environment.

Figure 5
Inappropriate use of a low visibility color on a train.

Possible actions:
- Trains should be painted a color that is better matched to the sensitivity of the human eye, like highlighter yellow-green, which is used on safety vests and fire trucks. An example of a highly visible color (e.g. 550nm) is shown in Figure 6. Research conducted with emergency vehicles has demonstrated that vehicles painted in high visibility colors are involved in significantly fewer accidents (Soloman and King, 1997).

Figure 6
Example of a train painted a highly visible color
Human factors violation 4: The light rail vehicle’s audible sounds are inconsistently used.

Importance and cause: METRORail trains have four audible signals, including a bell, horn, and low and high whistles. The bell and horn were observed to be sounded as the trains approached an intersection and arrived at or departed a station. However, this was highly inconsistent across the METRORail system and trains often did not engage an audible signal when approaching intersections or stations. Given this, pedestrians, motorists, and cyclists often do not receive audible feedback indicating an oncoming train. It also becomes difficult to anticipate when the train will start to move. This impedes users’ ability to take precautions. Sounding the bell or horn is currently a function of the light rail operator, which is problematic as it relies on their procedural memory. At some stations, crossing bell/horn sounds are played on the station’s speakers. This decoupling of the hazard (an approaching train) and the warning sound can be problematic, when the reliability of the signal is low (e.g., the warning sounds but there is no train).

Possible actions:

- Functionally reallocate the audible signals to an automatic system that sounds when the train is approaching an intersection and upon the train arriving at or departing a station.
- Have trains consistently sound their horns 15 seconds before arriving at the station or crossing

Human factors violation 5: Train station announcements are made well before the train arrives, but not as the train is arriving.

Importance: The station announcement that a train is arriving occurs about a minute before the train actually arrives and earlier in some cases. While this provides riders and pedestrians advanced notice, it does not give them more immediate notice to take final preparations. Additionally, those who arrive at the station area after the early announcement will be unaware of the approaching train. Without announcements closer to the actual arrival, riders may be standing too close to the platform edge and pedestrians might be crossing the rail tracks because they do not visually or audibly detect a train.
Possible actions:
- Play another train announcement at 30 seconds from the train’s anticipated arrival. This allows riders and pedestrians to be alert as the train is actually approaching the station.

Human factors violation 6: The LED train signs alerting motorists of an incoming train do not indicate the direction of the train, flash slowly, and give notice too close to the train’s arrival.

Importance: Without information on the direction of the train and advanced notice of its impending arrival, motorists do not have much time to respond accordingly. Motorists are prone to run red lights and would be discouraged from doing so if they were given direct messaging on the direction of the train and early notice to stop their vehicle. The LED train signal also does not flash at a speed that captures the attention, so motorists may not notice it.

Possible actions:
- Indicate the approaching direction of the train on the signals.
- Begin displaying the signal earlier to warn motorists and allow them time to cognitively acknowledge the messaging.
- Flash the LED signal faster to increase visual detection by the human eye.
- Indicate direction of the train using signs on the platforms and pavement markings

Human factors violation 7: Pedestrians rarely use the crosswalk buttons and expect the system to automatically engage.

Importance and cause: At certain intersections, pedestrians are automatically in the traffic cycle, primarily those intersections that do not have crosswalk buttons. However, there are still many intersections that require users to engage the crosswalk button for the system to place them in the crossing cycle. Pedestrians rarely use the crosswalk buttons because this is not wholly intuitive given that parts of the system are automatic. Additionally, crosswalk buttons are often inconveniently located due to the pole being positioned away from the crossing point or the button being oriented away from the user. Users need to be able to develop a strong conceptual model of how the system works, so they are not left to their own judgement of safety.
Possible actions:
- Maintain consistency throughout the system by having an automatic pedestrian crossing sequence at all intersections. Additionally, remove crosswalk buttons for consistency.

Human factors violation 8: Pedestrians cross the street regardless of crosswalk direction because of excessive wait times, particularly when there is no apparent danger.

Importance and cause: The crosswalk signals at several intersections require the user to wait several minutes whether there is danger or not. A common observed example is when the train is passing parallel to the crosswalk and cars are stopped, but pedestrian traffic is also directed to wait. Pedestrians are often in a rush and cross based on their own perception of safety because the system is misleading and there is no indication of how much longer they will have to wait.

Possible actions:
- Allow pedestrians to cross parallel to passing traffic, as long as other traffic is stopped.
- Implement a wait time countdown display on crosswalk signals to give pedestrians reasonable expectations. This is similar to the safe crossing countdown some crosswalk signals have.
- Implement SmartSync throughout the system, which has shown decreases in pedestrian wait time.

Human factors violation 9: Pedestrians jaywalk because of an inadequate number of crosswalks that align with their goals.

Importance: People are very goal oriented and will proceed in the fastest way possible to accomplish their goals. Crosswalks are often far away from each other, resulting in a lack of designated crossing paths for pedestrians who need to cross in between two crosswalks. This would require the pedestrian to walk to one of the crosswalks and then walk back to where they would actually like to go. Given this, pedestrians will forego the detour and cross over train tracks, often between fencing, to reach their destination. Current responses to this issue include signage like in Figure 7.
Possible actions:

- Install more crosswalks to reduce the distance between safe crossing paths and align with pedestrian crossing behaviors.

Figure 7
Signage Deterring Jaywalking

Human factors violation 10: Excessive signage across the light rail stations causes message overload.

Importance: At many intersections and stations there are several signs in addition to crosswalk and traffic signals. Excessive messaging, as shown in Figure 8, overwhelms users. Research has shown that when there are too many warnings, users will ignore them (Ramsay, 1989).

Possible actions:

- Reduce signage to the most important messaging at a particular station or intersection and avoid redundant signage.
Human factors violation 11: Signage throughout the system can be unclear, inadequate, or illegible.

*Importance:* The system features signage with messaging like “stop, look, and listen,” which does not indicate where to stop or what to look and listen for. This can be distracting and confusing for pedestrians. Signs with the same message but different designs also require the user to cognitively engage and recall their meaning. Additionally, signs are often oriented away from their intended audience or are illegible like in Figure 9.

*Possible actions:*
- Replace illegible signs and ensure all signs are upkept for readability.
- Consolidate signs with the same meaning into one design so users easily recognize its meaning.
Human factors violation 12: The traffic lights have a short delay between a red light in one direction and the green light or train signal for the perpendicular traffic.

Importance and cause: Motorists frequently run red lights throughout the system. They are often in a rush and will attempt to clear an intersection despite a yellow caution traffic signal soon to be a red light. The delay currently does not allow enough time for a car that ran a red light to clear the intersection before a train starts moving, increasing the potential for a collision.

Possible actions:
- Increase the delay between the red light in one direction and the subsequent traffic or train signal in the perpendicular direction.
- Install four quadrant gates that prevent cars from running a red light as a train is approaching.

Human factors violation 13: The system has left turn signage and dynamic lanes that confuse motorists.

Importance and cause: Several intersections consistently allow left turns from the far-left lane when it’s shared with the light rail vehicle. The middle lane is also a left turn lane, but turning is prohibited depending on the behavior of the train in the adjacent left lane.
(see Figure 10 from Cherk & Dittmar, 2019). There is simultaneous signage allowing left turns and a dynamic left turn sign that lights up periodically prohibiting turns, contradicting the original message and confusing drivers. Drivers also may not notice the dynamic no left turn light because it is not very salient. This causes drivers to turn in front of the train.

Possible actions:
- Remove dynamic turn lanes and only have turns from the far-left lane.
- In cases where the far-left turn lane is the dynamic lane, integrate turning direction into the traffic light.
- Implement SmartSync throughout the system to place trains and parallel cars in separate phases.
- Relocate the signal to be in an expected location for the driver, as shown in Figures 11 and 12.

Figure 10
Dynamic Left Turn Representation
Figure 11
Example of confusing and cluttered left turn signage

Figure 12
A proposed modification that puts the signal where the driver expects and remove sign clutter in the process
Human factors violation 14: Crosswalk design is not consistent throughout the system.

Importance: The red brick crosswalk design shown in Figure 13 is common throughout the parts of system, but it is not consistent with the standard crosswalk design seen in other parts of the system. Pedestrians may not recognize this as a crosswalk. The red brick also blends in with the pavement and light rail tracks, making them difficult to distinguish.

Possible actions:
- Use the standard crosswalk design throughout the system for consistency.

Figure 13
Crosswalk design that may not be readily identifiable as a crosswalk.
4.2 Specific Station Deficiencies

4.2A Melbourne to Northline Transit Center

Human factors violation 1: The crosswalk light directing pedestrians from the western side of Fulton street to the eastern side at the Fulton and Crosstimbers intersection is outside the pedestrians' visual field.

Importance and cause: Pedestrians do not have reliable feedback on whether it is safe to cross because the crosswalk light is angled away from the crosswalk.

Possible actions:
- Reorient the crosswalk light so it is visible for pedestrians heading west on Fulton street.

Human factors violation 2: Pedestrians climb through gaps in the pole barriers along the train tracks to cross over the tracks.

Importance: Critical incident analysis shows crossing in unmarked areas has proven fatal in two separate incidents. Pedestrians are at risk of being on the tracks while a LRV is approaching.

Possible actions:
- Install fencing along the middle of the track that extends the length of the track. This will prevent pedestrians from jaywalking across the train tracks.
- Use natural barriers like bushes along the street side of the pole barriers to impede and discourage access to the train tracks.

Human factors violation 3: Pedestrians climb over the fence bordering the tracks at Fulton and Crosstimbers instead of crossing the street at the crosswalk.

Importance and cause: Analyses showed that a significant percentage of pedestrians climb over the fence to cross the street as a faster route than crossing via the crosswalk. There are wide, grassy islands that run the length of the fence which are an affordance for this behavior (see figure 14).

Possible actions:
- Remove the islands along the length of the rail tracks to discourage the perceived safety and feasibility of crossing the street outside of designated crossing areas.
Human factors violation 4: The crosswalk at Northline Transit Center Bus Station does not accommodate the most common flow of pedestrian traffic (Figure 15).

Importance and cause: The system is not aligned with pedestrian behavior, as the activity analysis showed that pedestrians commonly cross outside of the crosswalk at an angle to directly reach the part of the sidewalk heading South. This can impact the bus drivers’ ability to predict pedestrian behavior and result in collisions.

Possible actions:
- Reposition the crosswalk to align better with pedestrians’ behavior and goals. The crosswalk should shift about five feet Southwest to account for this.
4.2B  Lindale Park to Cavalcade

**Human factors violation 1:** The areas of refuge at the North end of the Lindale rail station and the South side of the Cavalcade rail station are used for entering and exiting when they are strictly for emergency use only (see figure 16).

*Importance and cause:* A motor vehicle turning collision with the light rail occurred at this station in October 2017. The existing fencing and barriers – raised bumps, short railings – are not adequate to prevent pedestrians and cars from entering the track area. Crossing at this area requires pedestrians to proceed over the train tracks and into the open road. Additionally, the signage directing pedestrians to exit at the other end of the station is written in small black text on a white background; this is not prominent.

Possible actions:
- Increase the saliency of the signage by using bold and larger text and changing the sign color to lime green, which is highly visible.
- Install gating with a door for access to discourage pedestrian use of the area.
- At the Cavalcade station, add solid gating along the street side of the rail tracks to prevent pedestrian exit.
Human factors violation 2: The midpoint entrance at the Lindale station only allows pedestrians to exit West, so pedestrians heading East often cross over the tracks and through the gating (Figure 17).

Importance and cause: In the absence of a provided safe exit, pedestrians will proceed in the fastest way possible to reach their destinations. The system does not support the goals of users wishing to go East. Additionally, the pole barriers have gaps pedestrians can fit through.

Possible actions:
- Install a midpoint exit for pedestrians who wish to exit to the East side of the rail station.
- Change the current pole style barrier to a solid metal barrier to prevent unwanted crossing through the gaps in the pole barriers.
4.2C  Moody Park to Fulton/North Central

Human factors violation 1: A limited number of crosswalks and lengthy distances between crosswalks results in increased jaywalking.

Importance and cause: The Fulton station has one crosswalk servicing both the northbound and the southbound station. This crosswalk is between the two stations, however there is no designated crosswalk at the opposite end of either station. Similarly, the Moody Park station does not have clearly demarcated crossing paths at the north end of the station. The system is not providing an adequate number of safe crossing mechanisms at this station, which increases jaywalking as users may be unaware of where the safe crossing zone is. Of note, a fatal pedestrian train collision occurred at the Fulton/North Central station as the pedestrian tried to cross over the rail tracks.

Possible actions:
- Add clearly demarcated crosswalks to accommodate pedestrian crossing needs at both ends of the stations to decrease the distance between safe crossing locations and the stations.
Human factors violation 2: There is a gap between the fenced pole barriers that provides open access to the rail tracks. Pedestrians may interpret this as a safe crossing point because it is open to them (Figure 18).

Importance and cause: The gates are intended to prevent pedestrians and cars from accessing the rail tracks. This gap does not convey this intent and presents itself as a viable access point for crossing. Pedestrians naturally look for the most efficient route to their crossing goals and the gap will encourage jaywalking across the rail tracks.

Possible actions:
- Ensure all fencing and barriers are continuous in their coverage along the rail tracks with no gaps.
- Replace pole barriers with solid metal barriers to eliminate gaps.

Figure 18
Gap Between Pole Barriers at Beggs and Fulton Street

4.2D Quitman/Near Northside to Burnett Transit Center/Casa de Amigos

Human factors violation 1: The platform edge at both stations is painted white, which is not a common warning color, nor is it very noticeable.

Importance: It is important to use highly visible colors and ones that conform to a user’s mental model of danger when conveying the need for precaution to users. The color alone does not deter users from standing close to the train.
Possible actions:

- Change platform edge color to yellow, which will increase visibility of the edge and is commonly associated with warning.
- Paint warning words such as “Stand Clear” on the colored platform edge (see Figure 19).

**Figure 19**

*Example platform marking*

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**Human factors violation 2:** At the Burnett Transit Center, the white platform edge is not aligned with the yellow and black warning line. The yellow and black warning line is much closer to the track, which sends conflicting safe distances to riders (Figure 20).
Importance: Pedestrians are given a mix of conflicting sensory messages because of the misalignment. The white edge is likely intended for the pedestrian, but the yellow and black borders are more noticeable and fit the user’s mental model of a warning.

Possible actions:
- Provide a common yellow and black warning color scheme to clearly convey the risk of danger along the track.

Figure 20
Platform Edge and Warning Line Misalignment at Burnett Transit Center

Human factors violation 3: The raised cement along the rail tracks can be easily accessed by pedestrians.

Importance and cause: There are currently no barriers blocking access to the raised cement edge running along the tracks (see Figure 21). This is a potential hazard that pedestrians could walk along in dangerous proximity to the light rail. Additionally, it could be misinterpreted as another potential waiting area.

Possible actions:
- Prevent access to the cement edge through fencing or other barriers.
Indicate with signage that the waiting area for the light rail ends at the yellow and black barrier cut off.

**Figure 21**
*Open Access to Raised Cement Rail Edge at Burnett Transit Center*

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**Human factors violation 4**: Passengers can exit the platforms at the Quitman/Northside station from the wrong side or location, resulting in crossing the rail tracks or entering open road.

*Importance and cause*: Figure 22 presents an open waiting or crossing area that does not restrict access to the rail tracks or open road; any barriers stop at this area. Pedestrians can exit or enter over the rail tracks and are encouraged by the presentation of the space, which is a serious hazard. Similarly, Figure 23 presents an area of refuge with crossing access to the rail tracks and open road. As noted, the text to exit at the other end of the station is small and does not draw attention in stimulating environments.

**Possible actions**:
- Install signs when passengers deboard directing them to the correct exit direction.
- Increase the saliency of the “exit other end of station” sign by using bold and larger text.
Human factors violation 5: Pedestrians on the crosswalk wait for the train to pass in close proximity to the rail tracks.

*Importance and cause:* Despite crosswalk light direction pedestrians can expedite crossing by waiting on the crosswalk for the train to pass as in Figure 24. Pedestrians
are often in a hurry and there are no barriers preventing them from being dangerously close to the train. This is particularly hazardous at this station where a pedestrian can unintentionally wind up between two passing light rails.

Possible actions:
- Install an automated boom barrier that prevents pedestrians from entering the crosswalk while a light rail is passing or approaching.

**Figure 24**
*Pedestrian Crossing Close to Rail Tracks at Quitman/Near Northside*

4.2E  **UH-Downtown to Preston**

**Human factors violation 1:** When turning cars drive onto the tracks instead of correctly into their turning lane.

*Importance and cause:* The signage telling motorists not to drive on the tracks is small and does not stand out in the general environment. It is also difficult to interpret while driving (Figure 25).

Possible actions:
- Implement more defined turning lane demarcation that proceeds throughout the turn to direct motorists.
- Consider using “Do Not Enter” signs which would deter motorists from turning directly onto the rail tracks.
Human factors violation 2: A significant number of pedestrians consistently jaywalk at the Preston stations due to four connecting crosswalks.

Importance and cause: The majority of accidents near these stations have involved pedestrians. Pedestrians who would like to safely walk from the northbound station to the southbound station, or vice versa, proceed directly across the middle of the road which is not a safe crossing path. Additionally, this path results in diagonal crossing outside of the crosswalks (Figure 26).

Possible actions:
- Install a crosswalk signal between the northbound and southbound Preston stations that is in time with the crosswalks parallel to it.
Human factors violation 3: The Northbound train at Main Street and Rothwell street is obscured by the bridge.

*Importance and cause:* There is heavy motorist and pedestrian traffic at this intersection and not being able to readily see the train approach is hazardous. The train only becomes completely visible once it is in or near the intersection, which does not allow for needed reaction time.

Possible actions:
- Reduce the general train operating speed and require a slower speed when approaching an intersection to allow for pedestrian and motorist reaction times.

Human factors violation 4: Pedestrians at the UH Downtown station will walk along the rails tracks instead of immediately crossing the street at a crosswalk.

*Importance and cause:* There are no barriers or signage to deter pedestrians from walking down the train tracks. Additionally, this pedestrian behavior can be seen between two sets of rail tracks.

Possible actions:
- Add barriers between sets of rail tracks to prevent pedestrians from walking down the tracks or viewing that route as a viable option.
4.2F  Main Street Square to Bell Station

**Human factors violation 1:** A majority of pedestrians at these stations completely disregard crosswalk direction.

*Importance and cause:* Pedestrians at the intersections of the Main Street Square station and Bell station display a lack of trust in the traffic system and rely on their own judgement to determine crossing safety. Crosswalk signals do not consistently align with the actual crossing safety, so pedestrians proceed on their own judgement.

Possible actions:
- Provide a countdown on the crosswalk signal that indicates how long pedestrians will have to wait to cross the street.
- Post jaywalking fine signage to deter pedestrians from doing so.

4.2G  Downtown Transit Center to McGowen

**Human factors violation 1:** Warning signs are obstructed by poles and trees.

*Importance and cause:* Warning signs are not easily visible by pedestrians and motorists throughout the system, which inhibits error prevention and communicating information.

Possible actions:
- Situate warning signs so they are easily visible and not blocked.

**Human factors violation 2:** Pedestrians illegally cross between Southbound and Northbound stations.

*Importance and cause:* Pedestrians often confuse which direction they would like to travel and have to rush to the other station. This is in part due to unclear signage regarding the direction a train will travel. The road design also does not indicate that the area between northbound and southbound stations is not a crossing area; the brick blends with the red brick of the actual crosswalk (see Figure 27). As a result, pedestrians perceive it as a crossing area and use it frequently.

Possible actions:
- Install barriers to indicate that crossing between the stations is prohibited.
Use yellow and black warning colors across the bricked area between stations to indicate that it is not a crossing zone.

**Figure 27**
*Pedestrian Crossing Lane Clearly Not Marked at McGowen St. & Joseph St.*

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4.2H **Ensemble/HCC to Wheeler Transit Center**

**Human factors violation 1:** Signage surrounding the intersection of Main Street and Elgin Street is occluded.

*Importance and cause:* Trees almost completely obstruct the visibility of railroad crossing warnings and “no left turn” and “no right turn on red” signs. Eastbound, large pillars of a skywalk block these signs as well.

Possible actions:
- Re-position signs so they are fully visible by the intended audience.

**Human factors violation 2:** Main Street and Elgin Street do not allow left turns, but users make left turns anyways.

*Importance and cause:* To accomplish their goal of making a left turn on a particular street, drivers would have to make three successive right turns. Motorists are very goal
oriented and will weigh the inconvenience of completing the sequence of rights over the risk of making an illegal left over train tracks.

Possible actions:
  ● Allow left turns and install safety measures like a red turn-arrow light and automated signals that a train is approaching.

4.21 Museum District to Hermann Park/Rice U

Human factors violation 1: Motorists stop their cars in the path of boom barriers or get caught between the barriers; there is no error recovery for this.

*Importance and cause:* Drivers often attempt to clear the boom barriers as they lower and misjudge their speed and proximity to the barrier. This places cars in close contact with approaching light rail vehicles, increasing the likelihood of a collision.

Possible actions:
  ● Add exit arms to allow cars to clear the intersection.
  ● Add markings on the ground to provide a concrete visual of where the boom barrier will lower.
  ● Install a train approaching signs to ensure motorists are aware of the impending danger.

Human factors violation 2: “Train approaching” signs are only present for cars traveling in the same direction as the light rail. Cars traveling perpendicular to the train have no indicators alerting them of the train’s approach.

*Importance and cause:* A review of critical incidents along this section of track highlights several red light collisions at several intersections along Fannin Street and San Jacinto Street. The drivers ran red lights perpendicular to the train and may not have been aware of the approaching train given that there are no train indicators in their direction.

Possible actions:
  ● Install automated flashing “train approaching” signs parallel and perpendicular to the light rail’s path to alert drivers in both directions.

Human factors violation 3: Lengthy sections of track along Fannin Street and San Jacinto Street are very close to the sidewalk endangering pedestrians.
Importance and cause: There were 13 fouling collisions along this section of track, which can likely be attributed to how close the light rail tracks are to the sidewalk (see Figure 28). There are no physical barriers separating pedestrians from the train and the track path closely resembles the road in color; therefore, it is not readily distinguished. Additionally, there are no warning signs of the train approaching so a pedestrian would have to rely on their perception in a very stimulated environment.

Possible actions:
- Install fencing along the curb to prevent pedestrians from standing too close to the light rail tracks.
- Color the curb with yellow and black stripes to provide a visual warning.

Figure 28
Location of Two Fouling Incidents at San Jacinto and Wichita

Human factors violation 4: The light rail tracks switch from the left side of the road to the right side at San Jacinto Street and Hermann Drive (Figure 29).

Importance and cause: Interfaces should be predictable and the light rail crossing a lane of traffic is not typical, nor is the movement likely to be anticipated. This is especially true for drivers or pedestrians who have not navigated the area before. They likely will not know to switch lanes, anticipate the train suddenly sharing the lane, or to watch for the train while crossing the street. The intersection of San Jacinto Street and Hermann Drive is also the site of four fouling collisions.
Possible actions:
- Make the rail tracks more prominent by using yellow and black coloring along the path the train crosses lanes.

**Figure 29**
*Light Rail Tracks Crossing Lanes at San Jacinto Street and Hermann Drive*

**Human factors violation 5:** The crossing path at the Wheeler Station (see Figure 30) does not conform to the pedestrians’ mental model of a crosswalk.

*Importance and cause:* There are no crosswalk markings on the ground, which typically indicate that precaution should be taken while crossing. Additionally, there is no immediate system feedback that it is safe to cross the rail tracks. This could contribute to the six pedestrian collisions at the Wheeler Station.

Possible actions:
- Install warnings like flashing lights that are in time with the arrival and departure of the light rail trains.
- Install small boom barriers when the light rail is arriving and departing.
**Human factors violation 6:** When crossing at Fannin and Blodgett to reach the Wheeler station, pedestrians do not have an immediate designated path to the station.

*Importance and cause:* There is an overgrown path that appears to take pedestrians to the Wheeler Station, but this is not clearly indicated or advertised as an intended safe path. Additionally, there are several signs indicating that pedestrians are not supposed to walk in a particular direction, but one of them seems to deter pedestrians from the grassy path. In this case, pedestrians may still try to cross over the train tracks to reach the Wheeler station. The fence blocking pedestrians from the tracks does not run the length of the sidewalk either (Figure 31).

Possible actions:
- Elongate the fencing to the edge of the street to completely block direct access to the rail tracks from the sidewalk.
- Use signage that displays the pedestrian on the rail tracks to directly communicate not to walk/cross over the rails tracks to pedestrians.
4.2J  Memorial Hermann Hospital/Houston Zoo to Dryden/TMC

Human factors violation 1: Signage relevant to pedestrians differs across this section of track and is inadequately sized and placed at times.

Importance and cause: Signage should promote recognition, rather than recall to limit the cognitive effort required to understand the intended message. Additionally, signs should be easily readable and placed to deter a particular action. Figure 32 presents a poorly designed sign with small text that is not well placed; the sign currently lowers the wiring of the fence making it easier to go over the fencing. Figure 33, shows a sign saying “Do not enter left turn lane on x” which is not easily read due to the size of text. The red LED ‘x’ can confuse drivers because it was placed over the middle lane, but is referencing the far-left lane shared with the light rail.

Possible actions:
- Standardize signs of the same meaning across stations to allow users to easily recognize them and their meaning.
- Ensure signs are visible, adequately placed, and readable with large font.
Figure 32
Sign at Memorial Hermann/Zoo Station

Figure 33
Signage at Dryden/TMC Station
**Human factors violation 2:** The intersection at Fannin Street and Dryden Street features several signs for drivers that are unclear and confusing when presented together.

*Importance and cause:* The Fannin Street and Dryden Street intersection has 28 reported collisions on record, most of which were due to left turns. Figure 34 (Figure from Arango, 2019) presents a confusing and conflicting message to drivers at first glance. The left yellow square is a sign reading “left turn on ← only” intended for drivers in the far-left lane shared with the rail tracks, while the image in the yellow square on the right is telling drivers in the through lane not to turn left over the rail tracks. Drivers in the through lane may not understand that the signage allowing left turns is not intended for them while under the time and traffic pressures of driving. Additionally, Figure 35 presents how darker conditions affect the visibility of the signs. Figure 36 presents a confused driver at this left turn and dangerous behavior of waiting on the tracks.

Possible actions:
- Make the far-left lane a train only lane and allow left turns after an all-red phase allowing the train to pass.

**Figure 34**
*Intersection of Fannin Street and Dryden Street*
Human factors violation 3: Misalignment of crosswalks and sidewalks ramps poses a risk to wheelchair users.

Importance and cause: Wheelchair users will have to navigate outside of the straight path designated by the crosswalk markings to reach the ramp, shown in Figure 37.
(Figure from Arango, 2019). Navigating to the ramp may be a risk for wheelchair users since this would require them to leave the crosswalk.

Possible actions:
- Ensure there are sidewalk ramps directly at the end of each crosswalk as the system should accommodate all users.

Figure 37
Sidewalk Ramp Misaligned with Crosswalk at the Dryden/TMC Station

4.2K TMC Transit Center

Human factors violation 1: Vehicles become trapped between the crossing gate and the light rail, at times resulting in near collisions (Figure 38).

Importance and cause: The light rail crossing gate will lower as the train passes through, however this gate is far away from the rail tracks. A poorly timed light or a driver rushing through the light could result in the driver passing through the gate and becoming stuck as the train passes. The onus is then on the driver to notice the train in their periphery and stop the vehicle before a collision.
Possible actions:
- Move the light rail crossing gate closer to the rail tracks to limit the distance a driver would need to cover to safely pass the train should they quickly go under the descending crossing arm. This also puts the driver in a position to have greater visibility of the approaching train as they assess safety.
- In addition, include exit arms that lower after a delay to allow cars to clear the intersection.

Figure 38
Light Rail Crossing Gate far from Light Rail Tracks at Fannin and Braeswood Intersection

4.2L Smith Lands to Fannin South

Human factors violation 1: The Smith Lands station features crosswalk signals that only change if a pedestrian presses the button.

Importance and cause: The Smith Lands station is used heavily by employees of the Texas Medical Center, resulting in high pedestrian traffic. Pedestrians at this station consistently cross illegally given that the system does not regularly include their crossing in the traffic cycle. There is no indication that pedestrians have to press the crosswalk button, which is also inconveniently placed facing a barrier (see Figure 39).

Possible actions:
- Remove the need for pedestrians to engage the crosswalk button by making pedestrian crossing part of the traffic cycle. Also remove crosswalk buttons after automating the crossing cycle.
● If crosswalk buttons remain, orient all crosswalk buttons to be easily accessible by pedestrians; in this case, facing toward the street.

**Figure 39**
*Parking Lot Crosswalk Signal at Smith Lands Station*

**Human factors violation 2:** Large vehicles, like commuter buses, cannot make a U-turn from the left turn lane and use the middle through lane instead.

*Importance and cause:* There is limited space for large vehicles to complete what is a wide U-turn from the left lane, so they complete the turn from the middle lane. This is problematic given the left turn signal only senses cars in the left most lane. As such, buses are forced to turn left on red at times. Thus, bus and truck drivers are forced to rely on their own judgement to turn safely and avoid an accident.

Possible actions:
- Turn the middle lane into a second turning lane that still allows through traffic. The left turn signal would then detect larger vehicles in this lane as well.

**Human factors violation 3:** During events at NRG Stadium, there is a special route that allows the southbound train to arrive at the station traveling North. This causes pedestrian confusion and unsafe crossing over the rail tracks.
Importance and cause: When the Southbound train arrives via this route, it boards and deboards passengers on the special platform side of the track (Figure 40). Pedestrians are typically waiting on the opposite side of the track and will cross the rail tracks in front of the train to board from the special platform. This causes confusion and a rush of pedestrians unsafely crossing the rail tracks.

Possible actions:
- The Southbound light rail should open the doors on both sides of the track to eliminate the need for pedestrians to cross the tracks.
- Include the direction of the train in its display and provide a system announcement indicating which direction the train is traveling.

Figure 40
Special Event Platform at NRG Stadium

Human factors violation 4: At the intersection of Fannin Street and I-610, support pillars create a blind spot for train operators.

Importance and cause: Three light rail collisions with pedestrians have occurred at this intersection. A lack of visibility for the train operator is likely to have contributed to these incidents. If the train operator cannot see the pedestrians, and vice versa, collisions are more likely. In two of the incidents the pedestrians were unable to rely on sound, as one was hearing impaired and the other is reported to have been wearing headphones.
Possible actions:
  ● Install a camera to provide a real time feedback of the area, so train operators can see despite the blind spot.

**4.2M Theater District to Convention District**

**Human factors violation 1**: Vehicles frequently run red lights at high speeds.

*Importance and cause*: Drivers will see a yellow light and accelerate to clear the light before it turns red. However, drivers often misjudge the timing and wind up running a red light. This poses a hazard to cross traffic, including cars, pedestrians, and light rail vehicles. These other road users are following the system status and will not be expecting the car that ran the red light.

Possible actions:
  ● Increase the delay between the red light and the traffic lights in the cross traffic to allow a buffer for vehicles to safely clear the red light they run.
  ● Boom barriers along the rail tracks would also alert drivers to impending danger and prevent them from accelerating into an oncoming train’s path.

**Human factors violation 2**: The dynamic left turn at the intersection of Capitol Street and Smith Street can cause drivers to turn left in front of an oncoming light rail vehicle.

*Importance and cause*: Figure 41 presents the two left turn lanes motorists will encounter when traveling westbound on Capitol Street approaching Smith Street. The primary issue is that the middle lane is advertised as a through lane and a left turn lane, but left turns are sometimes restricted. When the light rail is approaching the intersection in the far left lane, a no left turn signal is turned on for drivers in the middle lane. Drivers may not see the alert and still attempt to turn left, given that the lane typically allows this behavior, causing a collision.

Possible actions:
  ● Remove dynamic left turn lanes over light rail tracks and require vehicles to turn left from the far left lane.
Human factors violation 1: At the Coffee Plant/Second Ward Station pedestrians exit at the area of refuge, which is prohibited and results in illegal light rail crossing.

Importance and cause: The signage directing pedestrians to exit at the other end of the station is written in small black text on a white background, which does not stand out as shown in Figure 42 (Figure from Zhou & Cole, 2019). Additionally, there is a missing section of curb at the area of refuge with a crosswalk on the other side of the rail tracks shown in Figure 43 (Figure from Zhou & Cole, 2019). This presents itself as an exit to pedestrians, which contradicts the message on the signs. Lastly, the station features only one “exit” sign pointing in the direction of the correct exit. Pedestrians may not see the sign unless they are directly in front of it. It is also above the average person’s visual field.
Possible actions:

- Install signs when passengers deboard directing them to the correct exit direction.
- Increase the saliency of the “exit other end of station” sign by using bold and larger text and changing the sign color to yellow, which is more visible.

**Figure 42**
*Area of Refuge at Coffee Plant/Second Ward Station*

**Figure 43**
*Area of Refuge Crossing Gap at Coffee Plant/Second Ward Station*
Human factors violation 2: Pedestrians cross over the light rail tracks to reach the parking lot across the street from the Eado/Stadium Station.

Importance and cause: The nearest crosswalk is roughly 300 feet from the station, which is an inconvenience to pedestrians. Given this, pedestrians have created a path through a section of dismantled fencing along the track displayed in Figure 44 (Figure from Zhou & Cole, 2019). This leads pedestrians to cross the light rail tracks from the station, potentially endangering them, to expedite their goal of reaching the parking lot.

Possible actions:
- Install more crosswalks to accommodate high traffic pedestrian paths.
- Fix fencing to deter pedestrians from crossing through the fence in large numbers. Additionally, fencing without gaps would be more effective in deterring pedestrians from circumventing the fence.

Figure 44
Dismantled Fencing at Eado/Stadium Station

4.2O Lockwood/Eastwood to Altic/Howard Hughes

Human factors violation 1: At the Lockwood/Eastwood pedestrians exit at the area of refuge, which is prohibited and results in illegal light rail crossing.
Importance and cause: The signage directing pedestrians to exit at the other end of the station is written in small black text on a white background, which is not attention grabbing. Fencing deterring pedestrians from crossing over the light rail tracks also stops at the start of the refuge area. This could be interpreted as a crossing area.

Possible actions:
- Install signs when passengers deboard directing them to the correct exit direction.
- Increase the saliency of the “exit other end of station” sign by using bold and larger text and changing the sign color to lime green, which is highly visible.

4.2P Cesar Chavez/67th St. to Magnolia Park Transit Center

Human factors violation 1: Users do not know which way to exit the Cesar Chavez station.

Importance and cause: There is only one designated exit at the Cesar Chavez station, but pedestrians consistently exit from the wrong side of the platform. The signage is unclear and limited once riders exit the train and many proceed to the wheelchair refuge area instead of to the correct exit. Pedestrians are then exposed to oncoming traffic.

Possible actions:
- Revise the sign to indicate that there is only one exit.
- Consider implementing announcements that indicate which direction to exit.

Human factors violation 2: Users enter and exit the Magnolia Park station by crossing Harrisburg Boulevard at a narrow median where they must cross over rail tracks.

Importance and cause: It is not very clear that users should not enter and exit the station at the tail ends. Crossing over the rail tracks to do so puts the pedestrians at risk of collision.

Possible actions:
- Add pedestrian gates to prevent crossing at this point.
4.2Q  Macgregor Park/Martin Luther King Jr. to Palm Center Transit Center

**Human factors violation 1:** Pedestrians at Palm Center station walk along the rail tracks or cross through chained-pole barriers because the station only has one exit.

*Importance:* There is only one exit South of the station. Pedestrians who wish to go North would have to exit South of the station, cross the street, and then walk back to their intended destination. This adds significant time to their commute, so pedestrians create paths along the tracks and through pole barriers that better align with their goals. These actions put them at risk of being hit by the train. Additionally, there is only one sign instructing users to exit south of the stop. It is placed north of the stop after the user has already started down the path.

Possible actions:
- Provide more immediate signage to deter users from beginning to exit North of the station.
- Install crosswalks that accommodate pedestrians that would like to go North.

4.2R  TSU/UH Athletics District to UH South/University Oaks

**Human factors violation 1:** Pedestrians confuse red warning markers near UH South/University Oaks station as a designated crossing path (Figure 45).

*Importance and cause:* Red crosswalks are prevalent in the system, so users may be equating red with crossing areas. In this particular case, this path is not a crosswalk and places pedestrians dangerously over the light rail tracks.

Possible actions:
- Remove the red warning markers if they are not necessary.
Figure 45
Red Warning Markers near UH South/University Oaks Station

**Human factors violation 2:** The “Stop, look, listen” banners at the stations blend in with the environment and are not highly visible.

*Importance and cause:* Figure 46 presents one of the “Stop, look, listen” banners displayed at the stations. The red coloring is one of the least visible colors to the human eye and blends in with the red crossing area. Additionally, this banner will be especially difficult to detect in the dark. Users are likely not receiving the message as intended.

Possible actions:
- Do not use predominantly red banners to communicate with system users.
- Use yellow signs with black text and clearly indicate what users are supposed to look and listen for.
4.2S Leeland/Third Ward to Elgin/Third Ward

There were no human factors violations along this section of track that have not been previously described in the system wide issues.

5. Conclusions

This report is a comprehensive review of the safety critical human factors issues of the METRORail system. Human factors methods were carried out to evaluate the system, identify the problems contributing to accidents, and suggest solutions to mitigate the problems. In total, eleven methods were used including design, analysis, and usability methods. The suggestions contained in this report reflect the human factors judgment of the research team.

A review of collision data over the past five years highlighted the turn, pedestrian, and red light issues in the system. Turns alone account for roughly 40% of accidents, while together the three causes account for almost 75% of collisions. Further, collision data also highlighted intersections that have a high frequency of light rail related accidents.

A review of light rail systems in other metropolitan cities indicated that several had problems similar to the Houston METRORail system. Safety enhancements in these
cities suggest fencing and barriers to prevent fouling, four quadrant gates to preclude red light collisions, and an all-red phase prior to left turns. Each city reported success in decreasing their collision frequency with their respective safety implementations.

This assessment identified system wide and track section specific human factors violations and opportunities for improvement. These issues generally fall in the category of visibility of the trains, audible cues, traffic light timing, left turns, inconsistent crosswalk systems, pedestrian behaviors and expectations, and the built environment. Recommended safety improvements described in this report would mitigate the human factors issues that are contributing to METRORail accidents. Because of the at-grade design of the system, these kinds of accidents cannot be completely eliminated. Future track extensions should consider not-at-grade systems, or systems that are more completely segregated from traffic and pedestrians.

Metro has spent a good portion of their effort trying to change the behavior of their users and those who interact with the system (e.g, Stop, Look and Listen campaign, Stop/Think trains, campaigns to educate users and drivers on train operations (Delaughter, 2018)). The user centered design solutions described in this report are intended to fit the system to the user, rather than the other way around. Human factors research has shown that insufficient system design that ignores the fundamental concepts of human perception and cognition will ultimately result in accidents. The proposed solutions are intended to account for actual user behavior, and mitigating those behaviors through system design. Subsequent steps including implementing an optimal design and assessing the accident rate over time.
References


