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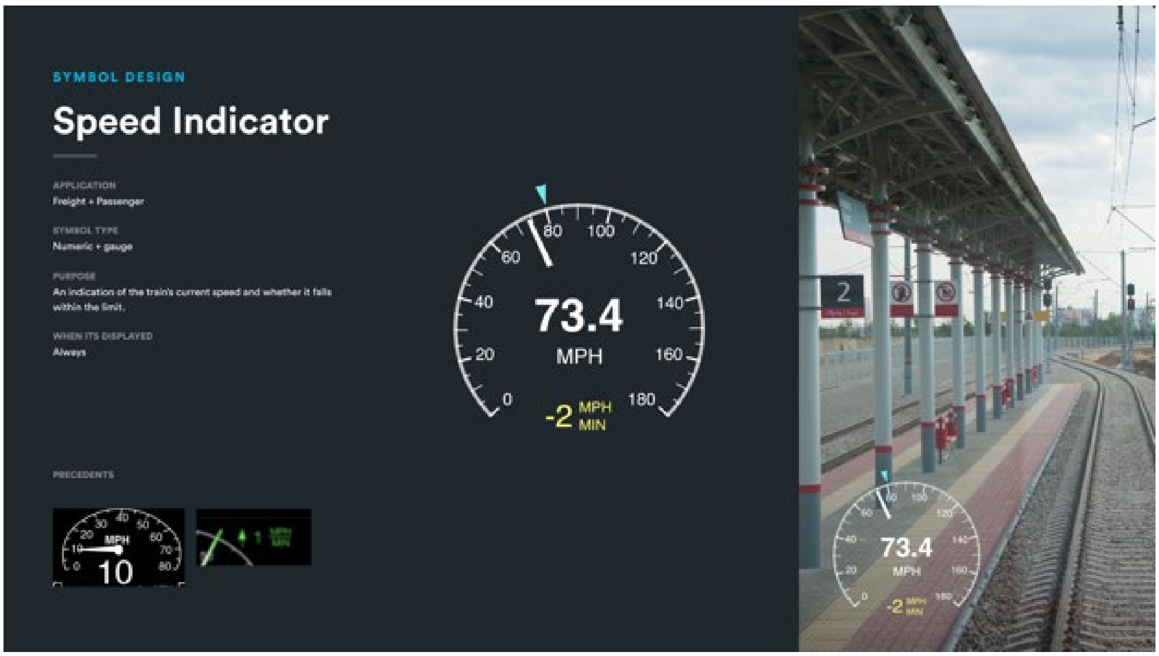
Washington, DC 20590

Development of Symbology for a Locomotive Head-Up Display (HUD)



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14. ABSTRACT
As part of a Federal Railroad Administration-funded Head-Up Display (HUD) research project that began in 2020, KEA Technologies Inc. developed a limited library of symbols for both freight and passenger operations, to be integrated in a prototype HUD developed separately by another team of researchers sponsored by FRA. The research team developed two surveys to collect feedback from stakeholders. Based on the feedback, the team made the suggested changes to the symbols and finalized the libraries. Three library subsets were created, one comprising all the symbols, a second comprising symbols only relevant to passenger operations, and a third comprising symbols only relevant to freight operations.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

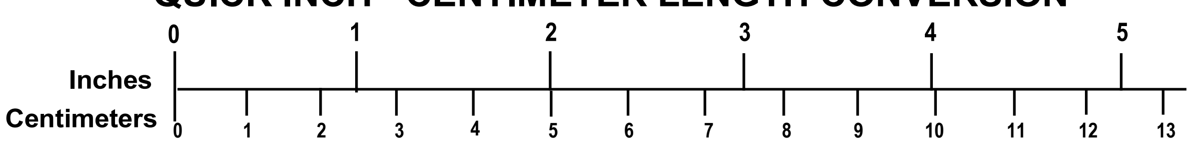
VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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Executive Summary

As part of a Federal Railroad Administration (FRA)-funded Head-Up Display (HUD) research project that began in 2020, KEA Technologies Inc. developed a limited library of symbols for both freight and passenger operations, to be integrated into a prototype HUD developed separately by another team of researchers sponsored by FRA. Historically, FRA has explored the feasibility and potential benefits of using HUD within locomotive cabins. In 2007, researchers conducted a user study of a prototype locomotive HUD and found that although no notable effects on performance were observed, engineers felt HUDs significantly reduced their workload (Thomas, Davies, Thorley, Gibson, & Davies, 2007). Evaluations conducted in other transportation fields have shown that using HUDs could significantly improve situational awareness, especially when visual conditions may be challenging (Stanton, Plant, Roberts, & Allison, 2019), and could decrease distraction levels (Doshi, Cheng, & Trivedi, 2009). It is important to understand how personnel will interpret and use the symbols which display critical operating information on a HUD, and to examine the effects of HUDs on human performance during operations in virtual and actual operating environments.

The team identified current symbols used across the rail industry by accessing user manuals and pictures of various displays including both passenger and freight main displays and additional displays such as Positive Train Control (PTC) and Trip Optimizer (TO). Researchers conducted a literature review to examine previous research efforts that developed symbology for HUD in rail and other transportation industries (e.g., the vehicle and automotive sectors) and spotlighted best practices for the design and development of symbology. The team then reviewed the HUD prototype to understand software and hardware specifications and limits. Once these technical requirements and literature review findings were compiled, the team worked with three experienced locomotive engineers to design and develop a first draft of the symbology library for both passenger and freight operations. Researchers categorized the symbols as most critical, medium critical, and non-critical to operations. Some of the symbols the team developed in this draft included several different design options for subject matter experts to review for clarity, efficacy, and urgency.

The research team developed two surveys to collect feedback from stakeholders. The first was a demographic survey that captured the individual's current and past professional experience, years in each position, and years in the rail industry. The team placed particular focus on understanding whether the individual was a current locomotive engineer or had ever worked as a locomotive engineer in the past, as these individuals would have operating experience and would be the primary HUD end user. The second survey included the library of proposed symbols and asked questions regarding the frequency of use, perceived meaning, criticality, and overall effectiveness of symbols. The team presented icons that had multiple options side-by-side, and the survey requested that subject matter experts report their preferences and the potential strengths and weaknesses of each example. The team also asked questions regarding each symbol's aesthetic properties, such as whether the colors, font, and size of the elements were appropriate. In total, the team received 28 survey responses. Five of the responses came from individuals with experience as freight engineers, 12 came from individuals with experience as passenger engineers, 7 came from engineers with experience in both freight and passenger, and the remaining 4 were from people involved in locomotive research and manufacturing.

Additionally, four of the previously mentioned locomotive engineers are currently in rail leadership and management positions.

The team made the suggested changes to the symbols based on stakeholder feedback collected in the surveys and finalized the libraries. Researchers created three library subsets, one comprising all the symbols, a second comprising symbols only relevant to passenger operations, and a third comprising symbols only relevant to freight operations. The libraries can be found in Appendix A: Final Symbology Libraries. The research team provided PNG images for each symbol with recommendations for use and symbol grouping to integrate with the prototype HUD. Future verification should be conducted to examine whether the symbols are clear and effective in a HUD environment.

1. Introduction

The Federal Railroad Administration (FRA) sponsored KEA Technologies Inc. to develop limited symbology libraries for both freight and passenger rail operations in conjunction with the development of a Head-Up Display (HUD) prototype developed under a separate project. The goal of this research was to not only understand how personnel will perceive the symbols and their integration into a HUD, but also to examine the effects of displaying the symbols during operations in virtual operating environments, as presented in FRA's Cab Technology Integration Laboratory (CTIL). This project began in September of 2020 and was completed in February 2022.

1.1 Background

In 2007, researchers conducted a user study of a prototype locomotive HUD and found that although there were no notable effects on performance, engineers thought that HUDs significantly reduced their workload (Thomas, Davies, Thorley, Gibson, & Davies, 2007). Evaluations conducted in other transportation fields have shown that using HUDs could significantly improve situational awareness, especially when visual conditions may otherwise be challenging (Stanton, Plant, Roberts, & Allison, 2019) and could decrease distraction levels (Doshi, Cheng, & Trivedi, 2009). If the rail industry adopts HUD technology, industry-wide universal libraries of symbology for manufacturers to use in HUD locomotive cab implementation for both passenger and freight operations would be of great benefit.

In 2017, FRA published research results from a study titled "A Preliminary Design for a Heads-Up Display for Rail Operations" (A. Liu & Jones, 2017). The project, sponsored by FRA and conducted by Dr. Liu of the Massachusetts Institute of Technology (MIT) Human Systems Lab (HSL), involved designing and examining the benefits of a locomotive HUD. Dr. Liu and his team found that HUDs would help locomotive engineers avoid accidents and improve their performance (A. Liu & Jones, 2017). Recommendations for future research included testing the prototype HUD in a simulated environment such as CTIL at Volpe National Transportation Systems Center located in Cambridge, MA.

Icons and symbols have been found to be more powerful than text and become even more impactful when accompanied by text (Carney, Campbell, & Mitchell, 1998). Several studies have been conducted to evaluate symbology and icons used across transportation industries. Green and Pew (1978) conducted an experiment to evaluate symbols found in automobiles and determined that symbols must be easily distinguishable from each other, specifically when their purpose or function is similar (e.g., headlights, fog lights, low beam and high beam, and parking lights) (Green & Pew, 1978). Some researchers have examined the effects of age on drivers as it relates to understanding symbology. Dewar, Kline, and Swanson (1994) found that younger drivers had a better understanding than older drivers on 39 percent of the symbols examined. Thus, the visual and structural properties of symbols are of great importance when designing new icons (Dewar et al., 1994). Easterby (1970) explored the structural elements of symbols and highlighted the most important characteristics: continuity, closure, symmetry, simplicity, and unity. These properties lead to increased recognition and understanding of symbols and icons by guiding an individual's eye to key features of importance (Easterby, 1970). Additionally, symbols that are designed to be realistic and resemble the actual objects tend to be more effective (Horton, 1994).

Thomas et al. (2007) conducted a user study of a prototype locomotive HUD in which five different formats were assessed for presentation of "conformal symbology." Researchers used two types of symbology, fixed and conformal (Thomas et al., 2007). Thomas et al. defined fixed symbology as symbols and alphanumeric characters, such as speed and engine status, that were in a fixed position on the display. In contrast, conformal symbology includes alphanumeric characters, symbols, and line segments that would be displayed as they align with "real" external features (e.g., artificial horizon, obstacle cue, etc.). The symbology used in this study were based on formats used in the aviation industry and currently used in locomotive cabs, such as a speed dial (Thomas et al., 2007). In addition to positive feedback about HUD, most participants responded positively to the conformal symbology and the cues used in the study. Future research should explore how to best use and manage conformal symbology while maintaining its impact on locomotive engineers.

In the prototype HUD design that Dr. Liu and his colleagues developed and tested, the proposed symbology included speed display, in-cab signals, moving elements to draw attention to external objects of interest, and a box that displayed messages for upcoming events. Given that this was a preliminary study, they used a simplified train simulator with HUD symbology projected onto a mirror in front of the computer display (Liu & Jones, 2017). Given the promising results from this study, the recommendation from FRA was to test the prototype HUD in a more realistic simulator with study participants. The purpose of this project was to continue the next phase of this work to develop and evaluate symbology integrated into a HUD prototype and understand the potential benefits and feasibility of using HUD in a locomotive cabin.

1.2 Objectives

The objective of this project was to create a subset of symbols for both freight and passenger rail operations to incorporate and test with a prototype HUD system. This effort identified the symbols currently used and which symbols are preferred across the rail industry. The team used design best practices and applications for symbology development using efforts from other transportation industries.

1.3 Overall Approach

Researchers used an experimental approach to design and test symbology for a rail domain locomotive HUD.

1.4 Scope

The project included the following tasks:

Task 1: Evaluation of Rail Industry Symbols. The team conducted an evaluation of current symbology used in the rail industry as well as other transportation fields, such as the aviation and automotive sectors, to determine the steps and best practices used in these industries to create a limited library of symbology. This evaluation also involved determining which symbols the rail industry may be able to adapt from other related transportation fields. This task was compiled into a literature review.

Task 2: Review of HUD Prototype Requirements. The team conducted a technical review of the current hardware and prototype HUD developed at MIT-HSL, as well as lessons learned from a preliminary study in a simplified simulated environment. This process established required specifications necessary to build the symbology library, such as space constraints, size restrictions, colors, number of elements displayed at a single time, ability to switch between elements, and other related characteristics.

Task 3: Design and Development of Symbology Library. Based on the findings from Task 1 and Task 2, KEA researchers built a limited symbology library both for passenger and freight rail operations. In conjunction with the library build, the KEA team verified whether a software component to integrate with the prototype HUD hardware was needed at this time. These builds were based on the specifications and requirements outlined by MIT-HSL as well as requirements from the rail industry.

Task 4: Rail Industry Evaluation of Symbology Library. Researchers collected subject matter expert feedback on the newly developed symbology libraries developed in Task 3 by conducting focus groups and key interviews with stakeholders from both freight and passenger rail operations. This feedback and consultation were used to determine preferred symbology within the industry and to make any necessary changes to the symbology libraries prior to moving onto subsequent tasks.

Task 5: Integration with HUD Prototype. The project team worked with MIT-HSL to ensure that the symbology libraries and the associated software can be seamlessly integrated into the HUD prototype.

1.5 Organization of the Report

Sections 2, 3, 4, and 5 of this report list details, findings, and activities of each work task mentioned in the Scope section above (Section 1.4) and their associated subtasks. Section 6 contains the research conclusions. Appendix A includes the symbol library for freight operations, the library for passenger operations, and the final combined library of all symbols.

2. Task 1 and 2: Literature Review of Symbology and HUD Guidelines in Transportation Fields

The concept of a HUD was first introduced in the 1950s and used exclusively in military aviation at the time. In the 1980s, HUD application branched into civil aviation, followed by automotive, naval, and industrial application in subsequent years (Ingman, 2005). HUD is designed to prevent human error by reducing workload and increasing situational awareness. A HUD was first introduced and tested in the aviation sector, which has been at the cutting edge of human processing research for over 50 years (Ingman, 2005). Therefore, there are several lessons to be learned from this industry in terms of HUD design and the design of the associated symbology implemented into the HUD. Likewise, HUD application has gained more popularity in the automotive industry in recent years and presents its own unique challenges in operating a vehicle on a roadway instead of in the sky. While research of HUD application in the rail industry is more limited, there have been recent studies that have helped identify considerations that the rail industry must make when designing and implementing HUD. These transportation sectors, along with their own unique research and literature on HUD application, will help determine steps and best practices used to create a comprehensive library of rail domain symbology for HUD implementation.

2.1 HUD and Symbology Studies in the Aviation Industry

Aircraft pilots are required to process a multitude of information as they operate, and their ability to react quickly and accurately to adapt to this information can mean life or death while in the sky. Thus, aviation has long been at the forefront in the study of human information processing (Ingman, 2005). The primary goal of a HUD in aviation is to increase the situational awareness of the pilot, especially in critical phases of flight such as takeoff and landing (Ingman, 2005). With all its associated cutting-edge technology, the aviation cockpit still relies on a human pilot to monitor these technologies and be prepared to adjust to unexpected circumstances (Ingman, 2005).

A HUD can help a pilot remain situationally aware by reducing “dwell time,” which is defined as the time the pilot takes to look at an instrument and extract information from it (Ingman, 2005). Research in aviation has found the minimum dwell time for the human mind to be 400-600 milliseconds (Ingman, 2005). Humans can either process information serially (i.e., one item at a time) or in parallel (i.e., taking in multiple channels of information at once) (Ingman, 2005). HUDs function based on the assumption that reducing the visual distance between information sources for the pilot minimizes eye movement and increases parallel processing, thus decreasing dwell time and allowing a pilot to process and respond to a greater volume of information more quickly (Ingman, 2005).

The information that is displayed on the HUD has long been refined by the aviation industry (Ingman, 2005). As this information is overlaid across the pilot’s field of vision, it is critically important to avoid “display clutter” (Ingman, 2005). Every symbol displayed on the HUD must serve a direct purpose in conveying critical information, with the cardinal rule in HUD design being “if in doubt, leave it out” (Ingman, 2005). It is also suggested in aviation HUD design that a pilot should have the option to “declutter” the display, with a minimum of at least two levels of reduced symbols available (Ingman, 2005). In abnormal altitude situations, when it is critical for the pilot to recover control, the HUD automatically declutters and displays only the necessary information for adjusting the aircraft back to a safe altitude (Ingman, 2005).

In 2009, the West Point Operations Research Center of Excellence published a study examining the hierarchy of information a pilot needs to process and new technologies including HUDs that could be used to convey this information most effectively (Deveans & Kewley, 2009). They evaluated whether these technologies had a significant impact on pilot situational awareness as well as if they reduced individual resource (i.e., visual, cognitive, auditory, fine motor, and speech) workload (Deveans & Kewley, 2009).

To evaluate the workload of various cockpit technology systems, researchers designed two scenarios designed to capture every task the pilot and co-pilot could undertake. The first scenario was a night air assault, in which the pilots were the second in a coordinated line of five aircrafts and came under fire from anti-aircraft weapons (Deveans & Kewley, 2009). The second scenario had pilots in a security convoy undergo minor aircraft malfunction and take ground rocket propelled grenade (RPG) fire. Both scenarios were developed with input from expert Blackhawk pilots with thousands of hours of experience (Deveans & Kewley, 2009).

An important part of the study design was a survey completed by 27 Blackhawk pilots ranking the hierarchy of information requirements for both the pilot and co-pilot for each of the scenarios (Deveans & Kewley, 2009). The survey included three parts, ranking the flight information in each part of the scenario from most to least important and ranking the perceived workload of each pilot resource (i.e., visual, cognitive, auditory, speech, and fine motor). The third section was a free response section where experts could indicate any information requirements not included in the scenarios and make suggestions for conveying the information (Deveans & Kewley, 2009).

There are several significant takeaways from this study for use in developing symbology for HUD applications. In all the scenarios run with all the various sample technologies used, visual and cognitive resources accounted for the two most considerable portions of the workload, with the cognitive load remaining consistently highest at around 50% of the workload (Deveans & Kewley, 2009). This finding suggests that the best approach to reducing overall workload is to reduce the required cognitive load by making symbols as intuitive as possible (Deveans & Kewley, 2009). Additionally, these findings highlight the importance of reducing the visual load by decluttering the visual field and placing important information where it is most easily understood and perceived (Deveans & Kewley, 2009).

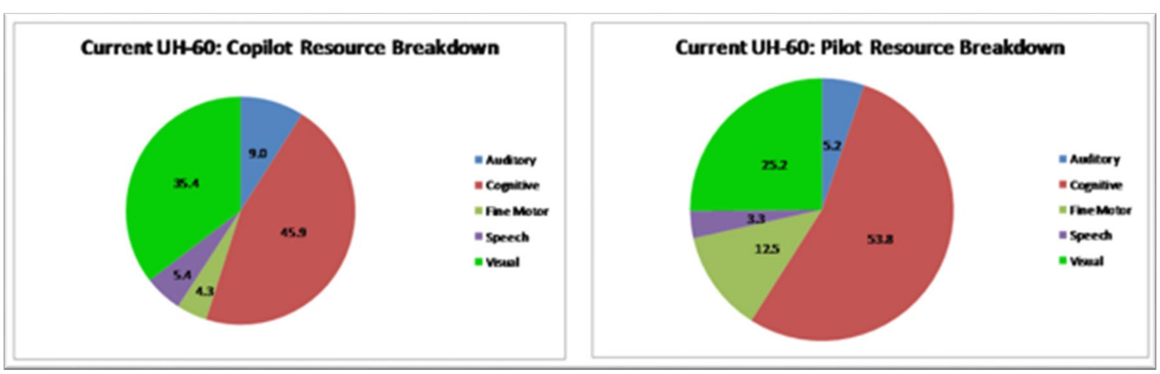


Figure 1: Attentional resource breakdown by pilot and co-pilot (Deveans & Kewley, 2009)

The study suggests several ways to optimize HUD symbology to be most effective. First, it suggests basing the layout of symbols on learned habit patterns (Deveans & Kewley, 2009). For example, if a pilot always checks cockpit flight instruments in a certain order, it might be best to layout the HUD symbology in the same orientation and appearance and as close to the physical gauges as possible while remaining in line of sight (Deveans & Kewley, 2009). The survey administered revealed that the flight parameters of interest for a certain time were airspeed, altitude, heading, and percent torque, checked in that order (Deveans & Kewley, 2009). Figure 2 shows the Primary Flight Display (PFD) used in current aircraft for daytime flying (left) and a HUD prototype for use in night-time flying (right). The arrows represent the eye movement of a pilot checking each of the factors listed above (Deveans & Kewley, 2009). Notably, the factors are arranged differently, and pilots who check the PFD during the day and then try to switch to the HUD at night might have a difficult time finding the critical information needed with a different orientation of gauges (Deveans & Kewley, 2009).

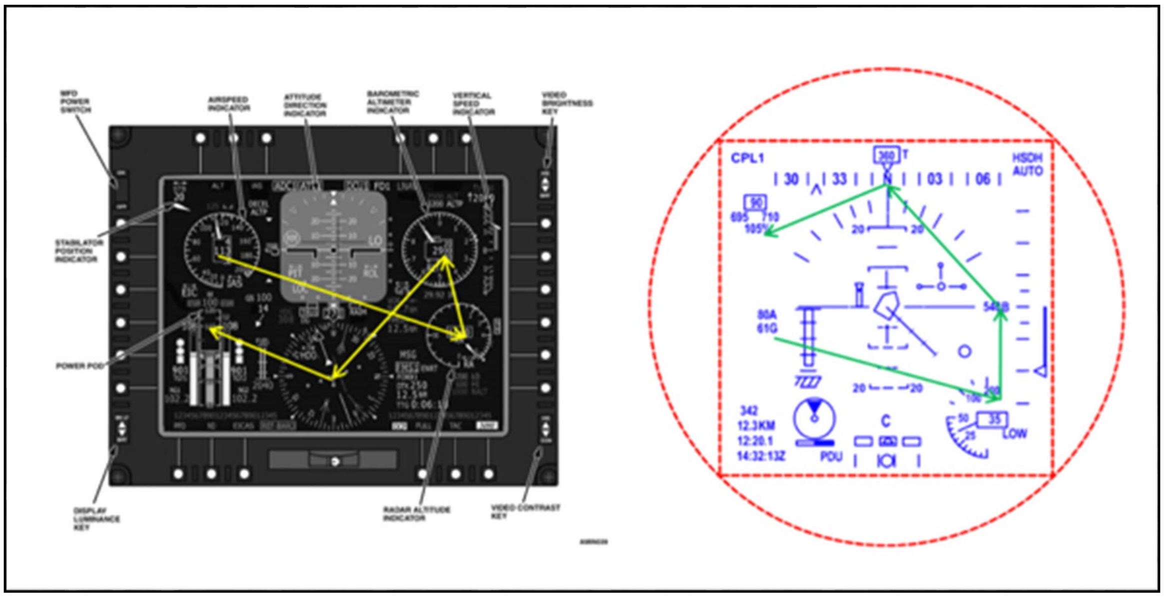


Figure 2: Diagram showing PFD used in current aircraft (left) and a HUD prototype (right) (Deveans & Kewley, 2009)

Lastly, this paper proposes a way to evaluate HUD designs, with a system called "Layout Appropriateness" developed by Dr. Andrew Sears in 1993. It allows designers to determine the best way to organize several "widgets" in a user interface based on task descriptions, cost, and frequency of use (Deveans & Kewley, 2009). It requires a set of symbols, the sequences of actions a user would perform, how frequently each sequence is performed, and a cost assigned to each action (i.e., time to process, or total head movement) (Deveans & Kewley, 2009). Using this system, different HUD designs can be compared quantitatively to determine the optimal layout.

A study conducted by the German Aerospace Center in 2016 proposed a new way of developing conformal symbols for a helmet mounted display (HMD) for helicopter pilots. HMDs and HUDs both often use conformal symbology over the natural background and have a lot of overlap in challenges and goals (Peinecke, Chignola, Schmid, & Friedl, 2016). This study aimed to develop non-intrusive symbols for pilots that informed them about obstacles to avoid without obscuring the field of vision needed to fly a helicopter (Peinecke et al., 2016).

The symbology library created in this study was made up of "glass domes" that are superimposed around the obstacle and include an icon at the top identifying the obstacle with a pictograph (Peinecke et al., 2016). This methodology left the actual obstacle in view of the pilot while allowing it to still be identified and avoided from a greater distance (Peinecke et al., 2016). Figure 3 shows a simulated view from the cockpit, with glass domes covering wind turbines and power lines, as indicated by the icons at the top of the symbol (Peinecke et al., 2016). In this display, not every turbine in the landscape is shown, only the ones within a determined distance to limit clutter. Clusters of obstacles in the distance appeared as one larger icon and split only when the pilot moved closer (Peinecke et al., 2016).

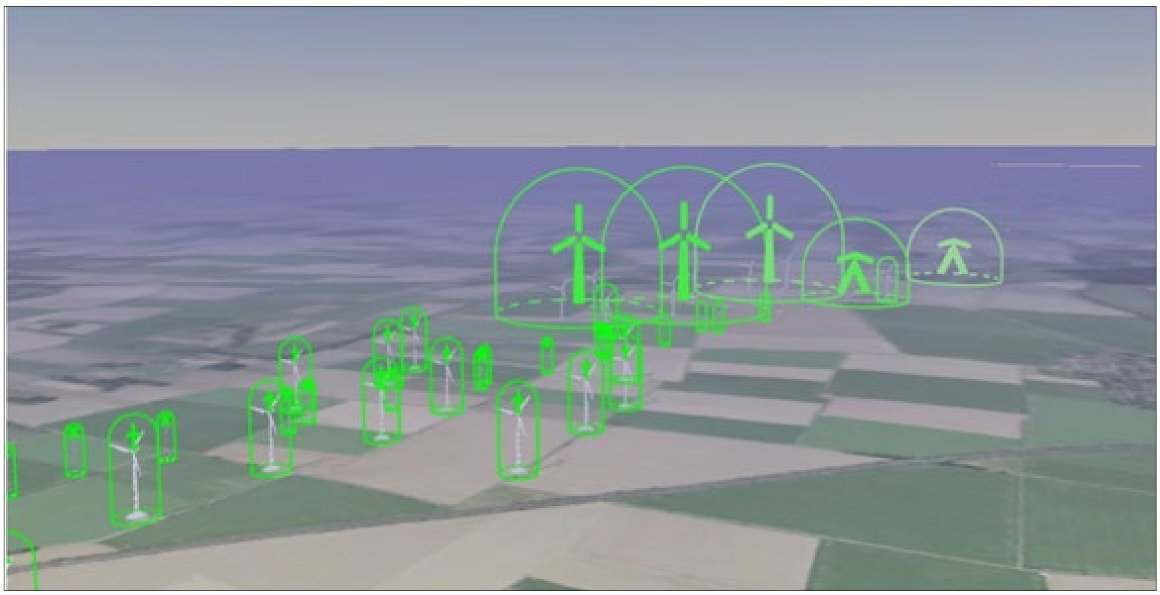


Figure 3: Helicopter pilot view overlaid with glass dome conformal symbols (Peinecke et al., 2016)

The symbols were tested using four pilots watching three different pre-programmed helicopter flights on an HMD, going over the various obstacles, and with varying weather (e.g., good or poor) affecting visibility. The scenarios included no symbology imposed, glass dome symbology imposed with early and late unclustering, and glass dome symbology imposed without any clustering (Peinecke et al., 2016). The study concluded that pilots preferred to have the glass dome symbols but noted that the clustering effect was somewhat disorienting. This was especially true when the clustering effect happened late, as the pilot was then close to the obstacle when it unclustered (Peinecke et al., 2016). The glass dome overlay was particularly helpful to the pilots in the adverse weather condition scenarios (Peinecke et al., 2016).

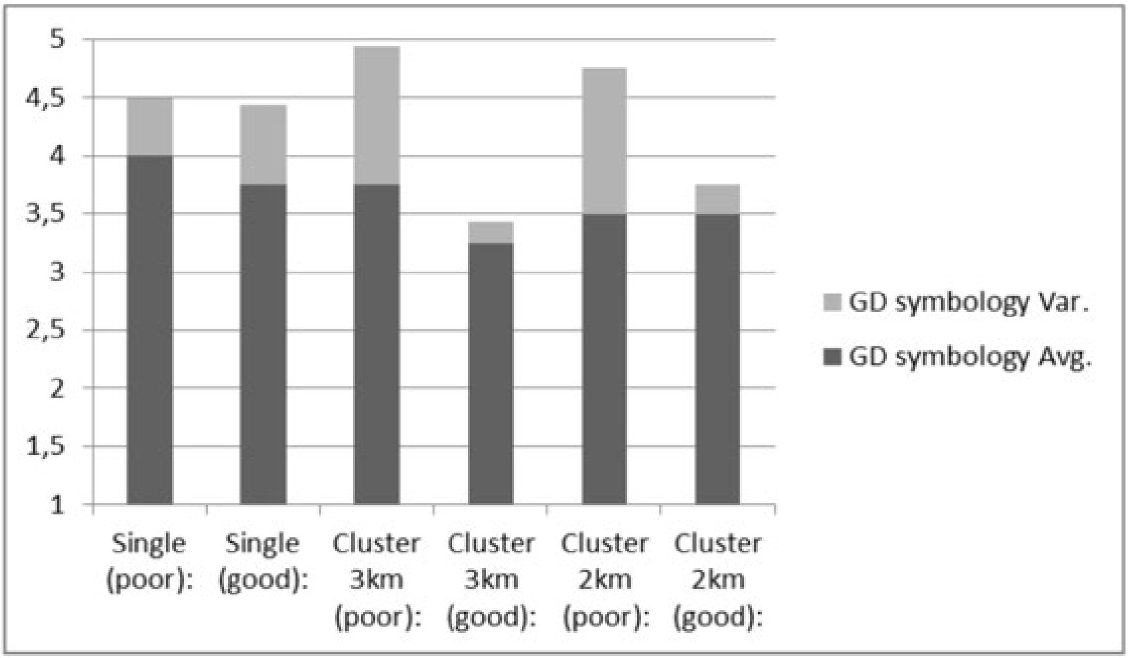


Figure 4: Summary of pilot's rating of the glass dome symbols (Peinecke et al., 2016)

A study published in the 2018 Asia Conference of Mechanical and Aerospace Engineering examined how color coding in a HUD affects information recognition in different environments (Ling, Bo, Bingzheng, Lingcun, Chengqi, & Yafeng, 2019). Many current HUDs use a monochrome green for all symbols (Ling et al., 2019). This color scheme has been proven effective in low-brightness conditions, but over the long-term or in conditions such as high-altitude clouds, the green is less effective (Ling et al., 2019). Pilots receive 90 percent of their information visually and color has been shown to be one of the most quickly processed cues in the visual system (Ling et al., 2019).

This study included 20 students between 22 and 27 years of age with no color blindness (Ling et al., 2019). They reviewed 10 representative fighter environment pictures (e.g., desert scene, mountain scene) from which the primary color of the scene was identified and overlaid with a different HUD color (Ling et al., 2019). Their reaction time to various stimuli in these different color conditions was then recorded (Ling et al., 2019).

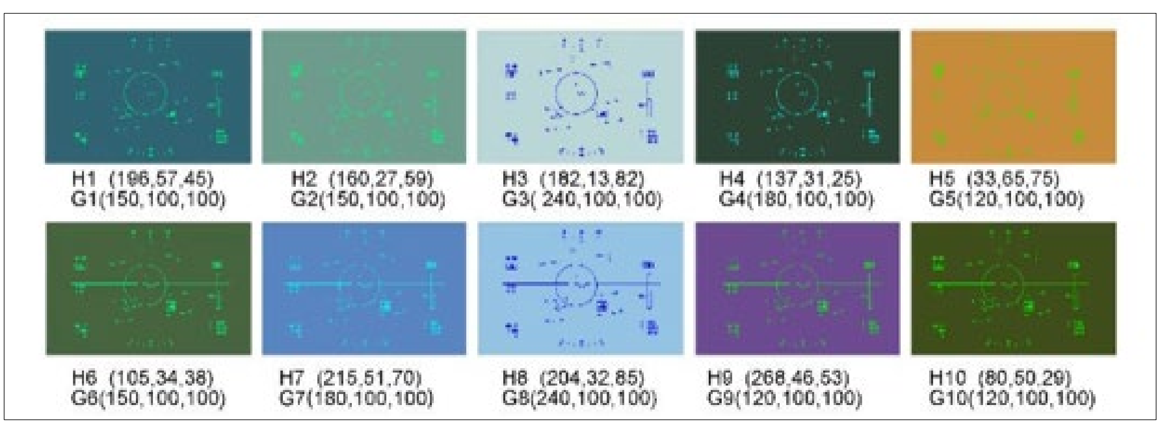


Figure 5: Summary of pilot's rating of the glass dome symbols (Peinecke et al., 2016)

The results show that there are significant differences in reaction time based on color, and that bi-color coding is more effective than monochrome coding (Ling et al., 2019). Any color scheme in a dark environment had an obvious advantage over those in a bright environment, as the dark environment had fewer interference from other stimuli (Ling et al., 2019). In addition, the study found that certain colors work best for certain environments. For example, in a mountain or plains landscape where the primary environment color is green and the brightness is low, a pink or red stands out best (Ling et al., 2019).

Table 1: Table of colors and their functions and responses (Ling et al., 2019)

Color	Display Function	Emotional Response	Physiological Response	Sense of Advance and Recede
Red	Warning, prohibition, activation, limit state	Excited, nervous	Sense of impending, visual fatigue; Stimulate nervous excitement, improve work efficiency	Advancing color
Orange	Prompt, caution, alarm	Excited, restless	Blood circulation increases; Relieve fatigue	Advancing color
Yellow	Abnormal/critical alarm, attention, status notification	Optimism, inspiration	Activate memory and active thinking	Advancing color
Green	Start up, normal operation, standard mode	Harmony, self-discipline, peace	Facilitates concentration of thought; Lower blood pressure	Normal Color
Blue	Sky background, notification	Calm, trust, fresh, profound	Lower blood pressure; Balance metabolism	Receding Color
Mauves	Less use, radioactive, corrosive	Mysterious and dreary	Depresses motor nerve, lymphatic and cardiac pulse system; hypnosis	Receding Color
Magenta	caution	Relaxing, soothing, gentle, romantic	Decreases adrenalin production; Promotes action and relaxes muscles; Stable mood	Advancing color
White	Scale and related figures	Stability, comfort and monotony	Keep blood pressure normal, keep actions simple and clear	Advancing color

The findings from this study suggest that color-coding information in a HUD will allow the most important or urgent details to stand out and allow for reduced scanning of the HUD and reduced error rates in visual information processing (Ling et al., 2019). Colors such as red, yellow, and green are perceived well over most environments, whereas colors like blue and purple should be avoided for signaling due to their poor visual acuity in comparison with most other colors (Ling et al., 2019). The color that was perceived best in 70 percent of the flight environments was yellow, with pink also doing well in many environments. This study demonstrates that the efficacy and perception of color in a HUD is highly dependent on the colors and lighting of the outside environment (Ling et al., 2019). *Testing HUD colors in the environments experienced by operators would be beneficial in selecting optimal color display*.

2.2 HUD and Symbology Studies in the Automotive Industry

Empirical studies and relevant literature have shown "that icons and symbols can provide a distinct advantage over text messages" (Carney et al., 1998). While HUD are somewhat new to the automotive industry, symbols to represent critical information while driving have been in place for decades and there are many studies evaluating the efficacy of these symbols. Green and Pew (1978) conducted an experiment with 50 university students to evaluate symbols for labeling automotive controls and displays. Experimental tasks included a familiarity task, an association task, a rating task, a paired-associative task, and a reaction time task. The familiarity task was meant to determine whether the participant had previous experience with the symbol. An association task was created to determine whether participants were able to pick out a symbol after reading a short paragraph describing its use. Additional tasks included a rating task, which involved subjects rating how adequately each symbol communicated its name or function, as well as a paired-associative task and reaction time task. The results were varied depending on the task, but the most significant finding was that several of the symbols were confused with each other, especially if they were similar in appearance or function (e.g., headlights, fog lights, low beam and high beam, and parking lights). *This research underlined the importance of symbols being easily distinguishable from each other, specifically when their purpose or function is similar* (Green & Pew, 1978).

Visual and structural properties of symbols are of great importance when designing new icons (Dewar et al., 1994). Carney et. al (1998) constructed a theoretical framework to be used as a analytic tool to help systematically and efficiently "evaluate symbols by identifying the semantic content of the message (or message set) that the symbol (or set of symbols) must convey" (Carney et al., 1998).

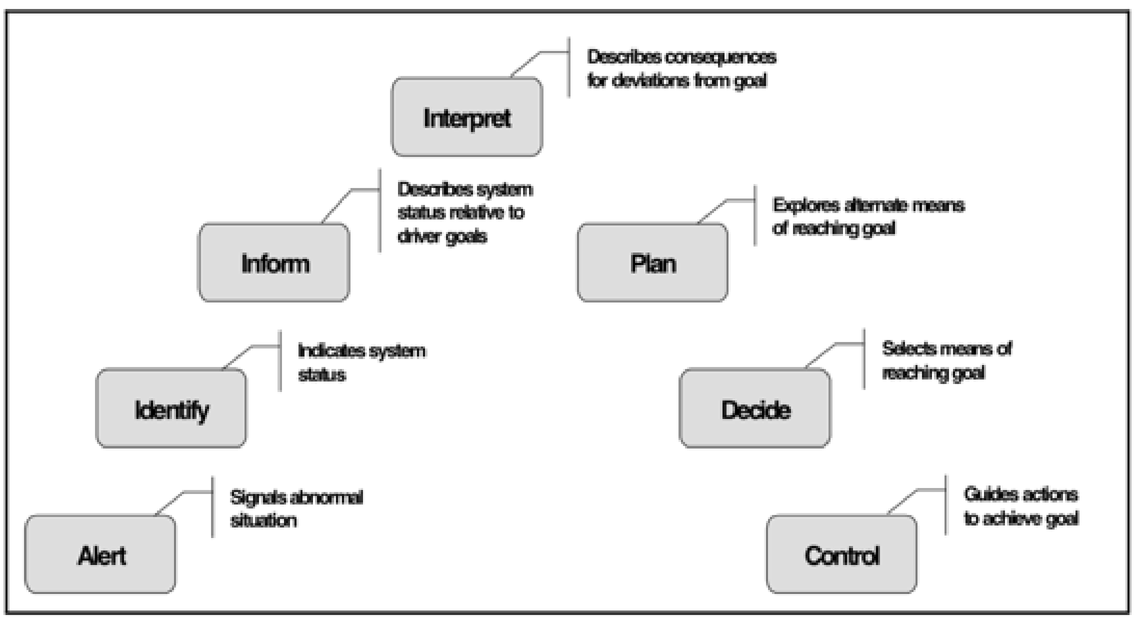


Figure 6: Conceptual framework of candidate symbology from Carney et al. (1998)

As with elements that appear in this structural framework, Easterby (1970) explored structural elements of symbols to evaluate how they affect understanding, learning, perception, and recognition. Easterby believed that structural properties of icons and symbols were extremely important factors as they give contextual cues from which individuals derive meaning. The most important characteristics of symbols that he highlighted were continuity, closure, symmetry, simplicity, and unity. These properties lead to increased recognition and understanding of symbols and icons by guiding an individual's eye to key features of importance (Easterby, 1970).

Additionally, symbols that are designed to be realistic and resemble the actual objects tend to be more effective (Horton, 1994). Horton suggested that presenting text labels with icons that are not obvious or presented for the first time may also make the symbols more effective.

In addition to these best design practices derived from empirical studies, there are several regulating bodies, including the National Highway and Safety Administration (NHTSA), that design and produce in-vehicle displays and standards. These standards are called Federal Motor Vehicle Safety Standards (FMVSS) and are accompanied by additional regulations published by the International Organization of Standards (ISO) and the Society of Automotive Engineers (SAE).

Aside from the specific design and figural elements of icons and symbols, studies have also begun to explore *how* to display these symbols within the automobile. As the number of systems being integrated into vehicles increases each year and fears of distracted driving increase, HUD has been offered as a viable solution to such problems (Tretten, Gärling, Nilsson, & Larsson, 2011). Studies have found that HUDs produce faster reaction times, earlier detection of road obstacles, and more time to scan a traffic or road scene among drivers (Liu, 2003). Within a vehicle, HUD can be described as a visual display that is within 15° of the driver's line of sight, or a virtual-image display within the driver's line of sight where images and symbols are located at some distance beyond the windshield (Tretten et al., 2011). Additionally, the SAE and several empirical studies have recommended that important warnings be located within 10 degrees of the driver's line of sight (Liu, 2003; Tretten et al., 2011).

Tretten et al. (2011) sought to understand drivers' perceptions of HUD and specifically HUD location within their own vehicle. Despite showing promising benefits, HUD is still rarely offered as a standard safety option to the average consumer, even as manufacturing of HUD has increased in recent years (Tretten et al., 2011). Thus, there is a gap in the HUD literature as it relates to automobiles, especially in terms of evaluating individuals' use of a HUD system longitudinally and for their personal preferences (Tretten et al., 2011). To address this gap in research, Tretten et al. (2011) conducted a study with forty participants and had them use their own vehicles to test different HUD locations using a portable HUD. Subsequently, researchers asked the subjects to rate the HUD using the Technology Acceptance Model (TAM). The TAM is a powerful analytical model used to determine whether users will accept a technology and help predict the likeliness they will use the technology in the future (Tretten et al., 2011).

The projected image from the portable HUD was white, with a font size of 1.3 cm by 2.8 cm, and the device's brightness could be manually and automatically manipulated (Tretten et al., 2011). Participants were told to adjust the luminance so that they could navigate traffic and see clearly. After the participants received instructions on how to use the portable HUD in their private automobiles, they were asked to test different locations for the HUD and to show researchers where they would prefer it to be placed (Tretten et al., 2011). The driving scenarios included using the HUD in rural, urban, and highway settings for at least 20 minutes in the daytime or nighttime. After participants finished a drive, the TAM questionnaire was administered, followed by an interview with open-ended questions regarding the participants' use of HUD and how they would prefer to use it in the future (Tretten et al., 2011).

Most of the subjects (57 percent) noted that they preferred to have the HUD image projected directly in front of them just below their line of sight (Tretten et al., 2011). Thirty percent of subjects preferred the location to be 5-6 degrees below their line of sight and 35 percent of subjects preferred it be located more than 10 degrees to the right or left of center. A significant result of this study was that 77 percent of subjects did not want the HUD to be located within their focal vision while driving, instead preferring for it to be set up right outside of their focal vision so they could quickly scan the landscape for information while driving (Tretten et al., 2011). Figure 7 shows the preferred HUD placements for subjects in this study.

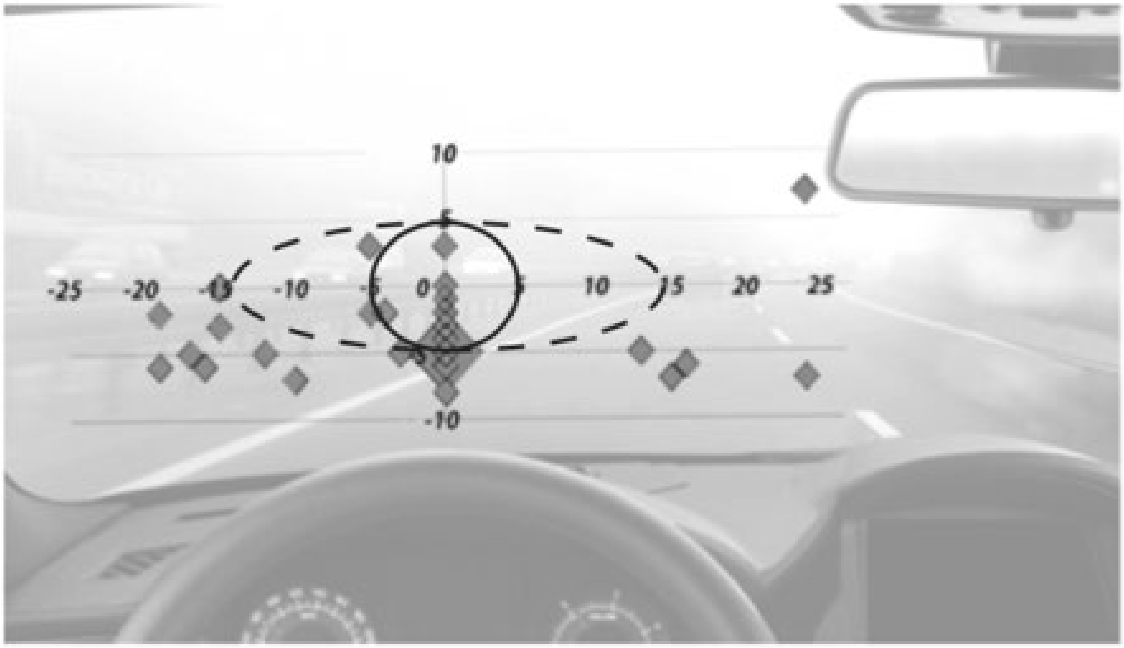


Figure 7: Results of preferred locations for HUD (Tretten et al., 2011)

The TAM results showed that participants liked the HUD and found it easy to use (Tretten et al., 2011). Participants also noted that they were more interested in using HUD in the future and elected to use the HUD over the Head-Down Display (HDD) in their car after they were familiar with the technology (Tretten et al., 2011). The findings of this study underscore the importance of conducting studies in real-world settings and allowing participants to not only give feedback to researchers, but also allowing them to adjust the technology to their personal preference (e.g., luminance, location placement, etc.) to understand consumer desires and needs.

Table 2: Table of drivers' TAM results and perception before and after using HUD (Tretten et al., 2011)

Factor	Before (M)	After (M)	df	*t*	Sig
Behavioral Intentions	6.03	6.44	39	-4.229	.000
α	.603	.721			
Perceived Usefulness	5.13	5.30	39	-1.153	.256
α	.663	.692			
Perceived Ease of Use	6.08	6.43	39	-2.725	.010
α	.757	.607			

Liu (2003) investigated the effects on attention demand and driving performance when using HUD in vehicles. The four driving scenarios involved examining "attention-on-the-HUD" followed by "attention-on-the-road" under both low and high load road conditions. Participants were also asked to perform a few tasks during one of the four scenarios, including a detection task and speed limit sign response task (Liu, 2003). The HUD was arranged in the simulator at 6 to 12 degrees below the drivers' horizontal viewing line and the image of the HUD was projected 3.1 m in front of the driver. Additionally, the symbol font size was 10 by 10 cm^2 (~1.8 degrees) and the display resolution was 800 by 600 dpi (Liu, 2003).

Liu (2003) found that when the driving load was low, "attention-on-the-HUD" enabled the participants to respond quickly to the speed limit signs and there was less variance in movement (i.e., lateral acceleration, steering wheel angle). While focusing on the HUD, the response to speed limit signs was still more efficient during high load driving scenarios, but the changes in movement were more variable when the participants' attention was shifted to the road (Liu, 2003).

Table 3: Results of drivers under different load conditions and attention locations (Liu, 2003)

Driving loads	Performance measures	Attention on the road	Attention on the HUD	$F(1, 44)$	P value
Simple	Mean RT for speed limit sign detection (s)	3.3469	1.7126	33.669	0.0001
	Variance in lateral acceleration (ft/s^2)	6.3313	3.3841	15.801	0.0001
	Variance in steering wheel (degree)	3.1665	1.5349	21.918	0.0001
Complex	Mean RT for speed limit sign detection (s)	3.2389	1.7246	45.670	0.0001
	Acceleration variance (ft/s^2)	2.7923	3.3394	7.202	0.008

Overall, the HUD enabled drivers to respond more efficiently to unanticipated events (i.e., speed-limit detection and response tasks designed for the study) under both high and low load driving scenarios (Liu, 2003). However, researchers noted that the cognitive capture effect, which refers to the inefficient switching from HUD to primary tasks, was found as drivers' responses degraded to external targets as participants were processing the information displayed on the HUD. Liu (2003) noted that this effect may be produced by the "contrast/transparency and lower visual realism of non-conformal image displayed on the HUD and of the related scenes around the road" (Figure 8). Thus, designers of the HUD should be aware of the cognitive capture effect and take it into consideration when designing new elements. Additionally, visual realism in testing a HUD system should be an important experimental design consideration, as it has the potential to affect results.

(a)

(b)

Figure 8: Examples of manipulating drivers' attention locations: (a) attention-on-the-road, (b) attention-on-the-HUD (Liu, 2003)

In a study that looked at a novel active HUD for driver assistance, a unique prototype called the dynamic active display (DAD) was designed to present critical safety icons to the driver that minimize unnecessary visual clutter and distraction (Doshi et al., 2009). The DAD presents alerts to a driver only if necessary and while accounting for the state and pose of a driver, vehicle, and the environment. Researchers designed four distinct display protocols intended to assist a driver in following the speed limit on real roads to compare to a conventional dashboard display (Doshi et al., 2009). The four display protocols included:

1. No display – No DAD alert is given.
2. Warning – A triangular exclamation point warning sign appears and bounces as soon as the driver exceeds the speed limit.
3. Numbers – A textual alert constantly shows the driver's current speed and the road speed limit (e.g., 43/45). The text representing the driver's speed zooms in and out if the driver is above the speed limit.
4. Graphic – A graphical alert constantly shows a vertical status bar with the driver's speed and the speed limit clearly marked. The entire graphic bounces if the driver is above the speed limit.

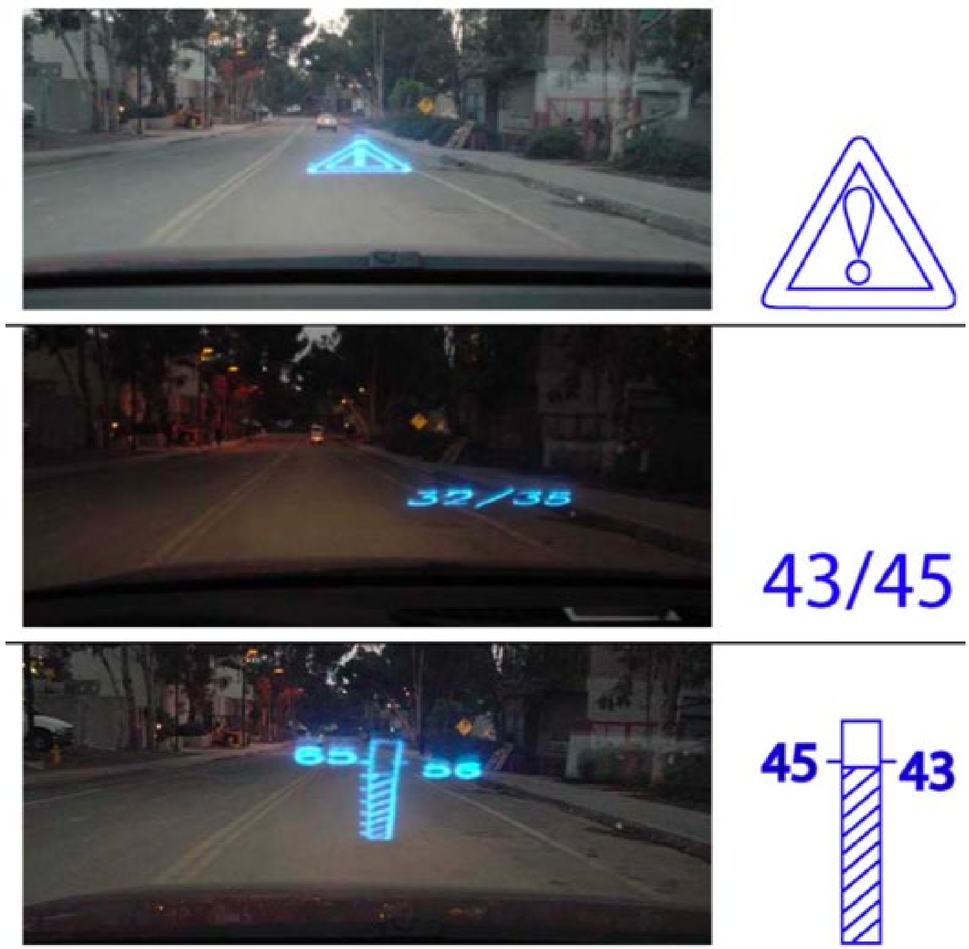


Figure 9: Three different display alerts used in the study (Doshi et al., 2009)

Participants were asked to pay specific attention to the speed limits and to follow them, but otherwise to drive as normally as possible (Doshi et al., 2009). Subjects drove a 20 minute course using each of the 4 display conditions. Researchers found that the caution symbol from the second condition resulted in a 2.24 second average time to slow down, which was the fastest reaction time (Doshi et al., 2009). After normalizing the times relative to the "no display" condition, on average the warning symbol resulted in a 38 percent drop in the time to slow down (Doshi et al., 2009). The other two display conditions which involved numbers and graphics were also effective, but not as effective as the warning symbol. Researchers suggested that this difference may be attributed to the fact that the information that the number and graphic symbols display take more time to process compared to a static display that is understood immediately (Doshi et al., 2009). These two conditions are also "active" signs being constantly displayed and thus less successfully captured the driver's attention when they were over the speed limit (Doshi et al., 2009).

Table 4: Drivers' average time to slow down with four different display conditions (Doshi et al., 2009)

Exp 1 - No Disp	5.09 sec
Exp 2 - Warning	2.85 sec
Exp 3 - Numbers	3.66 sec
Exp 4 - Graphic	3.28 sec

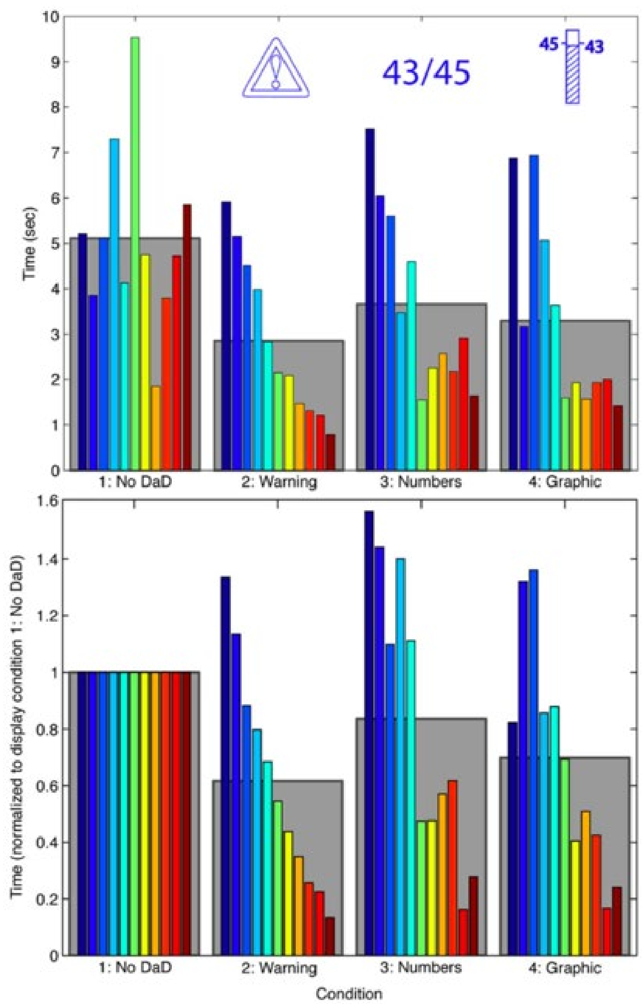


Figure 10: Time to slow down or the amount of time spent over the speed limit before slowing down with different alerts among 11 drivers in 4 different trials (Doshi et al., 2009)

Head pose data was also measured using a marker-based motion capture system (Doshi et al., 2009), and eye gaze was collected through a camera-based eye tracking system (Doshi et al., 2009). The head pose data showed that the warning symbol increased the time looking away from the road whereas the numerical symbol display decreased the time looking down by 63 percent overall (Doshi et al., 2009). Researchers found that while the warning symbol (condition 2) warned the driver that they were speeding by displaying the symbol, it did not display the driver's actual speed, which led them to look down at the speedometer (Doshi et al., 2009). This reasoning is confirmed by looking at the head pose data from display conditions 3 and 4, which both display the current speed to the driver, removing the need to look down at the speedometer. Under condition 3, which shows the driver's speed as well as the speed limit, the time spent looking forward through the windshield increased by 10 percent (Doshi et al., 2009).

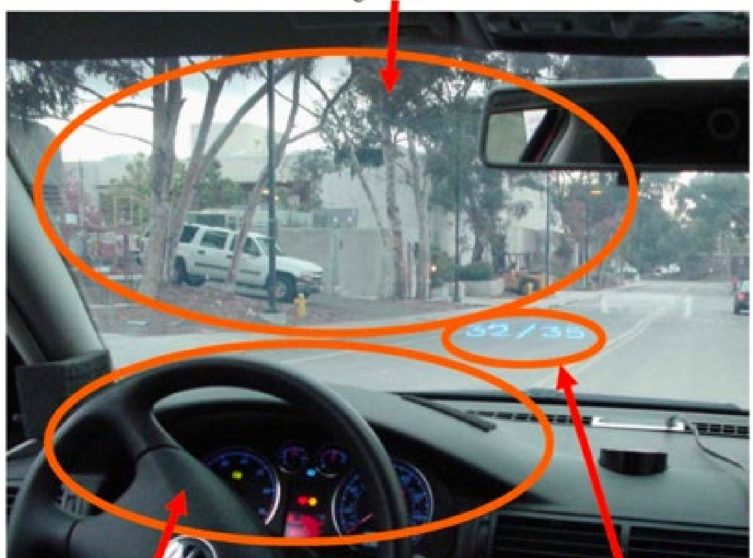


Figure 11: Results from head pose data (Doshi et al., 2009)

Table 5: Head pose data capturing time spent looking in each direction while above the speed limit averaged over all drivers (Doshi et al., 2009)

Alert Type:	1: [no alert]	2:	3: 43/45	4:
Ratio of time spent "looking **down**" with & without alert	1.00	3.40	0.37	0.31
Ratio of time spent "looking **at DAD**" with & without alert	1.00	6.80	1.37	5.50
Ratio of time spent "looking **forward**" with & without alert	1.00	0.95	1.10	1.03

The experimental study that Doshi et al. (2009) conducted underlines the importance of symbology design and display considerations. Some displays and symbols can increase distraction whereas others decrease distraction, underlining the importance of testing many different symbol designs and placement locations (Doshi et al., 2009). This study, along with the previous studies mentioned, all chose very limited symbols to display within the experimental HUDs, as attention and distractibility remain key areas of concern. The driver's speed was the element that was most prominently featured as either a static or dynamic symbol across all studies.

2.3 Head-Up Display and Symbology Studies in the Rail Industry

As mentioned, HUDs have proven successful within the automotive and aviation industries, as these technologies allow operators to access information without diverting their attention from the external world. An analysis on historical accidents and incidents determined that a suitable HUD within a locomotive cabin may help prevent up to 10 percent of incidents and 3 percent of accidents (Thomas et al., 2007). This was estimated to be an annual savings of about £2M for the UK rail network (Thomas et al., 2007). Table 6 demonstrates the findings from the analysis conducted on historical accident reports and the way in which HUD technology may address these issues.

Table 6: Description of HUD functionality defined to help prevent future accidents and incidents (Thomas et al., 2007)

HUD Functionality	Description
Head-up instruments	A common theme to the incidents and accidents is a general loss of situational awareness during the train driving task, especially of current vehicle speed. It is considered that the head-up presentation of instruments and information that is currently only available heads-down may help improve situational awareness and workload, thereby contributing positively to safety.
Previous aspect information	The AWS 'sunflower' display is usually intended as a reminder that signals have been passed showing a caution aspect[2]; however, as it is not directly in the line of sight, it may be inadvertently overlooked. Placing an AWS 'repeater' closer to the direct line of sight, may have benefits and a number of incidents report drivers who have 'forgotten' that they are driving against adverse signals. As technology evolves (and especially initiatives connected with ERTMS and ETCS) additional technical capability will become available well beyond the current AWS system, and this capability may best be exploited using a HUD.
Night vision capability	Poor visibility at night may be a contributing factor in a number of incidents. The ability of HUDs to provide night vision may have the potential to assist in these circumstances.
Line speed indication	Inappropriate train speed may result from a number of factors, including poor situational awareness, missing critical visual cues and poor judgement in braking.
Conformal cue for signals	Many incidents, including a significant number of Category A SPADs, occur because drivers miss signals, often believing that a specific signal displaying a caution aspect does not apply to their train, or inadvertently 'reading across' to adjacent signals. A cue, presented on the HUD, indicating directly which signal applies to the current running line (perhaps by drawing a box around the signal head on the HUD as shown in Figure 6) may have the potential to significantly reduce the probability of such incidents.
DRA information	The DRA is a device in the driving cab that enables the driver to set a reminder that the signal ahead is at danger. When set, the DRA prevents the driver being able to take power. However, if the driver fails to set the DRA when required this may increase the probability of starting against a red signal. Information could be presented on the HUD to remind the driver to set the DRA.
System State	The status of the signalling system regarding train movement to determine whether or not the line could be occupied. Advanced warning on a HUD could warn the driver to adopt defensive driving techniques.

Thomas et al. (2007) noted that there are two major benefits of HUD: “firstly, the time saving and benefits to situational awareness that arise from the presentation of information in the line of sight; secondly, the HUD allows presentation of information not easily accomplished by any other means.” Within train cabins, locomotive engineers must survey the track while also responding to in-cab signaling systems, which require the engineer to look away from the track and down at the HDD console (Thomas et al., 2007). Studies conducted in the aviation sector that measure the gaze direction of pilots without a HUD have demonstrated that on average less than 20 percent of their time is spent looking outside the flight deck to the external world (Thomas et al., 2007). Table 7 outlines the time taken to redirect visual attention from forward-view of the external world to console instruments that require the operator to look down.

Table 7: Contributions to the “time budget” in an instrument scan (Thomas et al., 2007)

Redirection of Visual Attention Component	Guide time taken
Saccadic Eye Movements	0.3 s per fixation
Convergence	0.25 s
Accommodation	0.25 s (90 ms per dioptre)
Adaptation	0.5 – 10 s
Mental Attention	< 1 s
TOTAL	**> 2 s**

Studies that use eye tracking technology to investigate the eye movements and gaze patterns of train drivers support these findings. In a study conducted in a simulator, researchers categorized point of gaze to the following elements: sky, signs, cab, moving objects, track ahead, off track, and signals (Groeger, Bradshaw, Everatt, Merat, & Field, 2002). Results showed that train operators spent most of their time looking either within the locomotive cabin, at signs, at the track ahead, or at signals. A much smaller amount of time comparatively was spent looking at moving objects, the sky, or off-track (surrounding landscape) (Groeger et al., 2002).

In a follow-up study to Groeger et al. (2002), researchers used eye tracking technology to study the visual behavior of 86 train drivers (Luke, Brook-Carter, Parkes, Grimes, & Mills, 2006). Examples of the data collected included duration and frequency of glances made toward different characteristics of the visual scene (Luke et al., 2006). The study found that train drivers spent most of their time attending to a small area of the external visual scene, outlined in yellow in Figure 12 below (Luke et al., 2006).

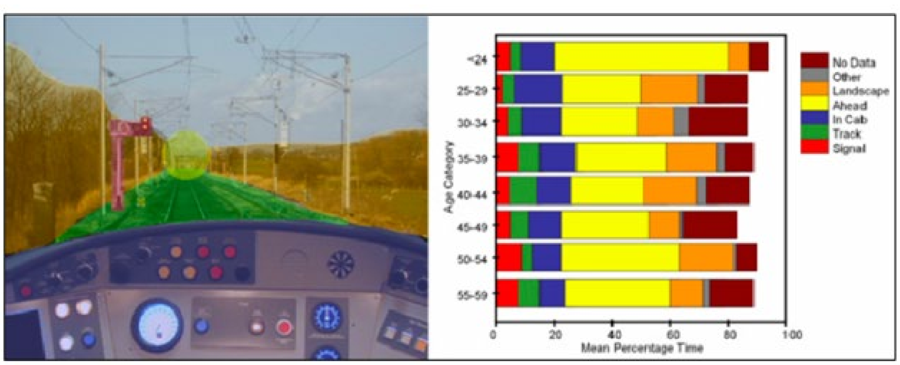


Figure 12: Point of gaze analysis during train driving (Luke et al., 2006)

Thomas et al. (2007) suggest that this area should be the focus when designing a HUD and its associated symbology. HUD installation would also remove the time spent viewing in-cab signals (blue categories) and could effectively be combined with the yellow area, which is the location drivers focused on for most of the time (Thomas et al., 2007).

Thomas et al. (2007) outlined the two fundamental forms that informational content is displayed on HUDs: symbology and imagery. Symbology is defined as instrument information that is displayed as alphanumeric characters and other symbols and typically mimics the information in the way that it is traditionally displayed on the instruments and console (Thomas et al., 2007). Symbology can then be split into subclasses of fixed and conformal symbology. Thomas et al. (2007) defined fixed symbology as symbols and alphanumeric characters, such as speed and engine status, that are in a fixed position on the display. In contrast, conformal symbology include alphanumeric characters, symbols and line segments that would be displayed as they align with “real” external features (e.g., artificial horizon, obstacle cue, etc.). The second class of displayed information is imagery and is typically conformal (Thomas et al., 2007). Imagery is either pictorial or image information and can either be sourced synthetically or from a sensor (camera or thermal imager) (Thomas et al., 2007).

Table 8: Classes of information that can be displayed on a HUD (Thomas et al., 2007)

Class of Information	Subclass	Content	Examples
Symbology	Fixed	Alphanumeric characters, symbols, line segments. Fixed position on display	Speed information, engine status, navigation/time data, warnings.
	Conformal	Alphanumeric characters, symbols, line segments. Aligned with real world features	Artificial horizon, obstacle cue, wire frame synthetic terrain view.
Imagery	(Conformal)	Scene image, possibly synthetic image “enhanced and synthetic vision”	Low-light TV, thermal image, synthetic terrain view.

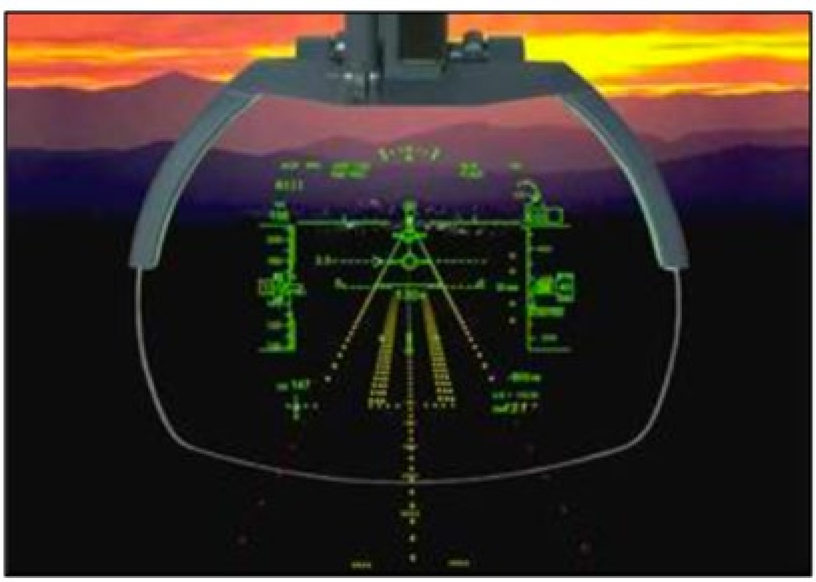


Figure 13: Example of fixed versus conformal symbology display (Thomas et al., 2007)

The major HUD components include a display, a combiner, and a light source. Figure 14 shows an illustration of how these HUD components are typically arranged. Several technologies may be used to display the HUD including Liquid crystal displays (LCD), digital micro mirror device (DMD) reflective displays, organic light-emitting diode (OLED) displays, electroluminescent (EL) displays, and vacuum fluorescent emissive displays (VFD) (Thomas et al., 2007). Combiner technology also must be considered, particularly if it is going to be flat or curved (and thus part of the lens system) (Thomas et al., 2007). Additionally, if the HUD is going to display information in color, the combiner must reflect either all visible wavelengths, or at least those which hold the color information from the display (Thomas et al., 2007). Figure 15 shows the effects of a spectrally selective combiner versus a neutral combiner on ambient and display illumination.

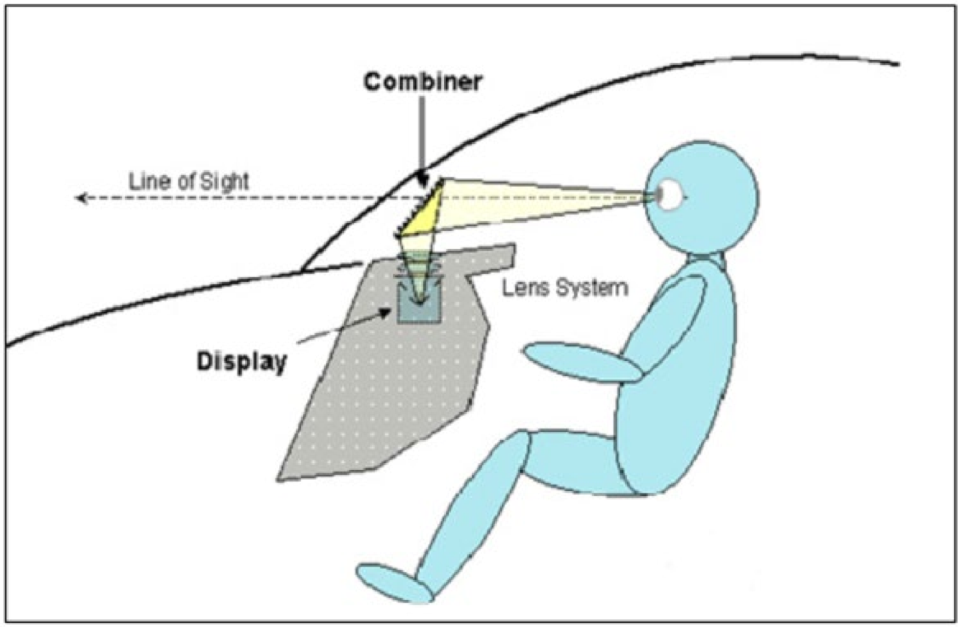


Figure 14: Schematic of essential HUD components (Thomas et al., 2007)

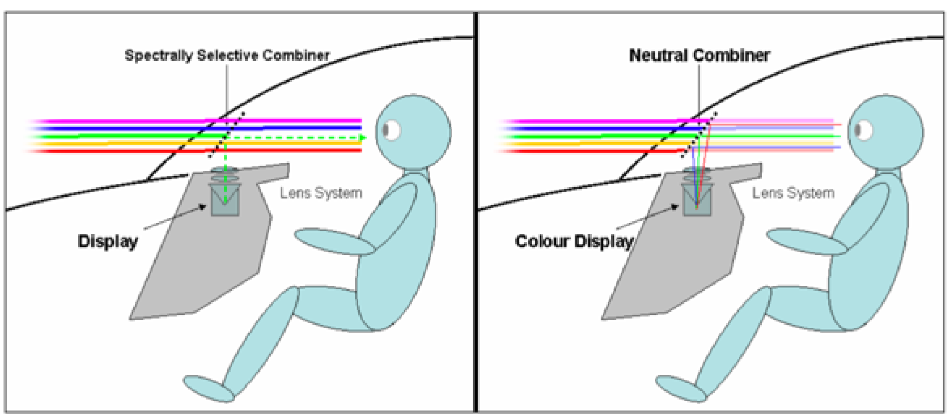


Figure 15: Schematic comparing spectrally selective combiner versus neutral combiner (Thomas et al., 2007)

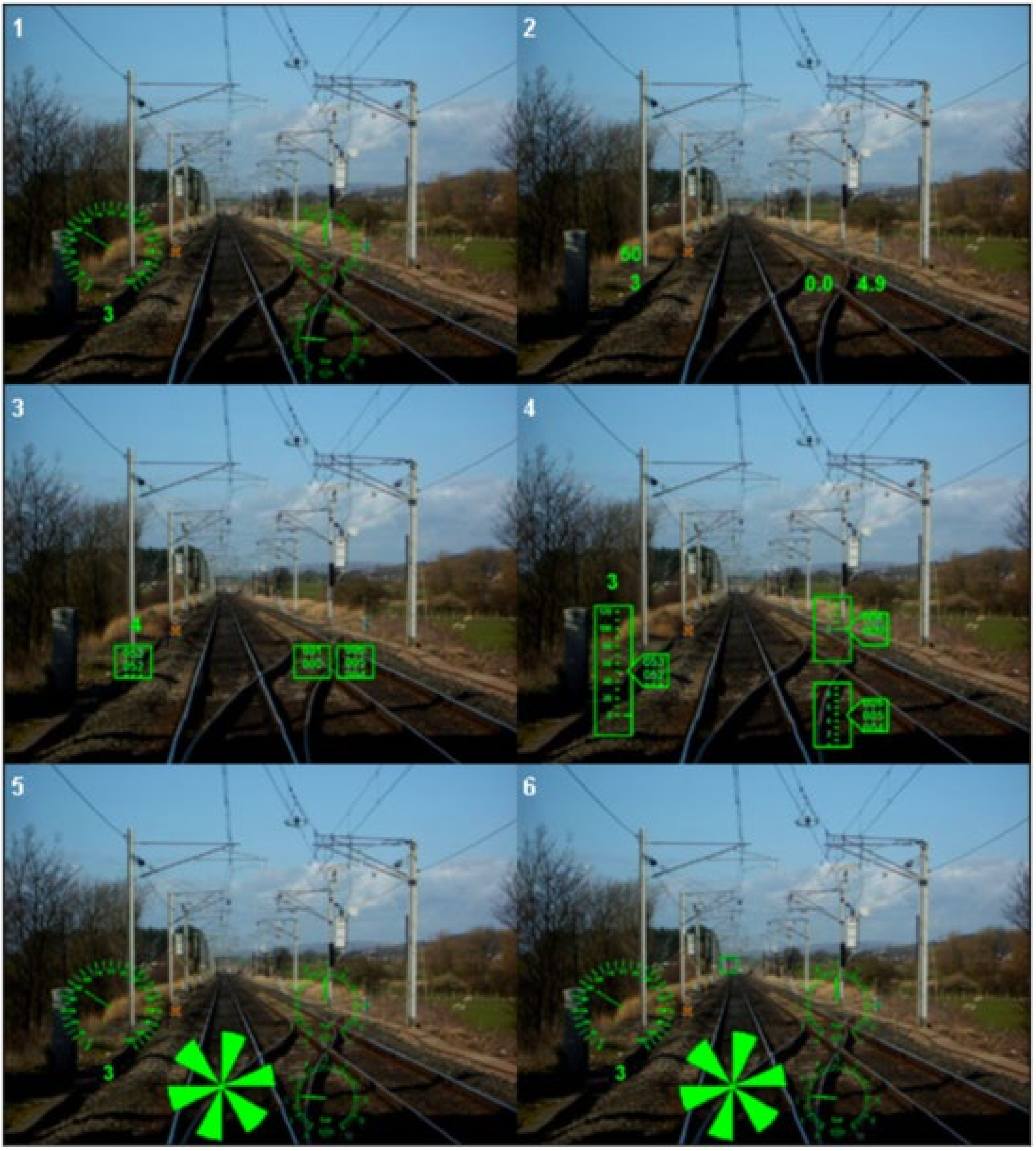
Thomas et al. (2007) conducted a user study of a prototype locomotive HUD in which five different formats were assessed for presentation of "conformal symbology." The Rail Research

Simulator at BAE Systems in the United Kingdom was used, which mimicked a generic modern locomotive cabin and was based on Virgin trains and Alstom ‘Pendolino’ Class 390 trains (Thomas et al., 2007). Sixteen subjects participated in the study and were given both verbal and written instructions for the HUD system and then familiarized themselves with the simulator by conducting test runs with and without the HUD (Thomas et al., 2007).

The trials were based on the analysis of historical data on accidents and incidents and focused on providing information in the line of the driver’s sight, such as speed information, AWS information, and providing conformal cues to indicate signal locations (Thomas et al., 2007). The following trial formats were sequentially run:

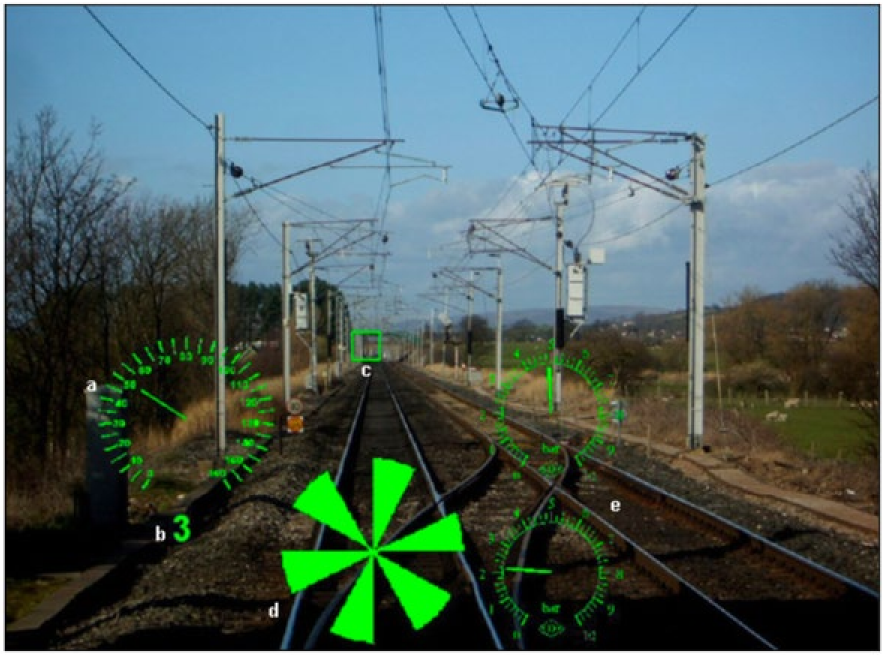
1. Potential of the HUD for presentation of speed information: five different formats assessed
2. Potential of the HUD for presentation of last signal aspect information: three different formats assessed
3. Potential of the HUD for presentation of brake information: five different formats assessed
4. Potential of the HUD for presentation of conformal symbology (indicating signal locations): five different formats assessed
5. Implications of a HUD for speed keeping and workload: comparison of driving with and without the HUD
6. Structured discussion

Subjects were asked to drive the same route twice during the fifth trial section, once while using the HUD and once without (Thomas et al., 2007). Participants were also required to give an assessment of mental workload every 30 seconds during the speed keeping tasks. During the sixth trial section, subjects were asked to discuss potential uses for the HUD and to note any issues they may have encountered. The symbology used in this study were based on formats used in the aviation industry and currently used in locomotive cabs, such as a speed dial (Thomas et al., 2007). In addition to speed information, other key elements that were displayed for the simulator trials were brake and Automatic Warning System (AWS) information. Figure 16 and Figure 17 show examples of the different symbology displays used during the simulator trials.



Detail: (1) speed and brake information presented as conventional dials on the HUD; (2) speed and brake information presented as pure digital readouts; (3) speed and brake information presented as scrolling digits; (4) speed and brake information presented as tape indicators (two variants were used, both visually similar); (5) same as no. 1 but with repeater of AWS sunflower; (6) same as no. 5 but with addition of conformal box to indicate signal (left center).

Figure 16: Different symbology displays used during the simulator trials (Thomas et al., 2007)



Detail: (a) speed dial (indicating 50 mph); (b) power brake setting (indicating power setting of 3); (c) conformal cue indicating position of next signal; (d) repeater of the AWS sunflower; (e) a head-up repeater of the twin brake pressure gauges. (Note that photographs of images through HUDs are technically difficult, therefore, this is a simulated version of the symbology used in these trials.)

Figure 17: Enlargement of a single example of symbology display in simulation trials (Thomas et al., 2007)

One of the key findings of the study was that the HUD led to a dramatically reduced workload for most drivers (Figure 18) (Thomas et al., 2007). This finding was statistically significant, with a mean workload score of about 2 when using the HUD on the 1 to 5 scoring scale shown in Figure 19. These relative units translated to a reduction of .38 workload points when using the HUD, with a 20 to 40 percent decrease in reported workload (Thomas et al., 2007). Curiously, although there was a drop in workload, driver performance did not change (Thomas et al., 2007).

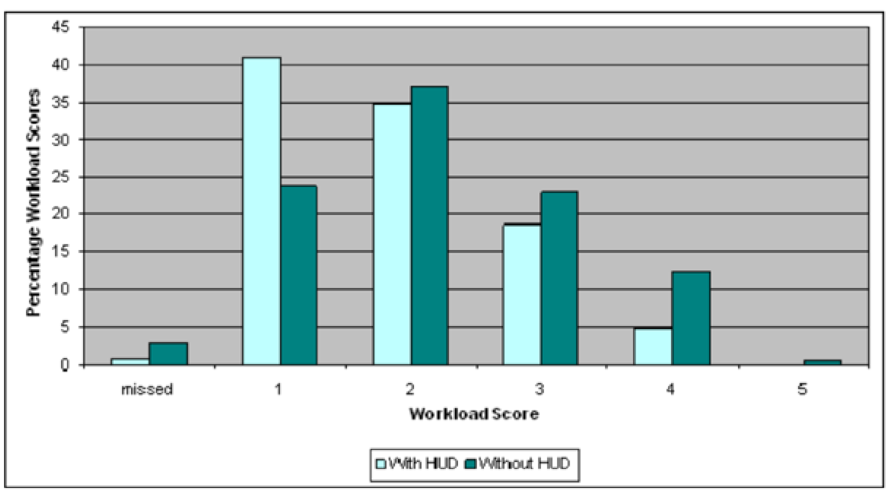


Figure 18: Percentage workload score across all participants driving with and without HUD (Thomas et al., 2007)

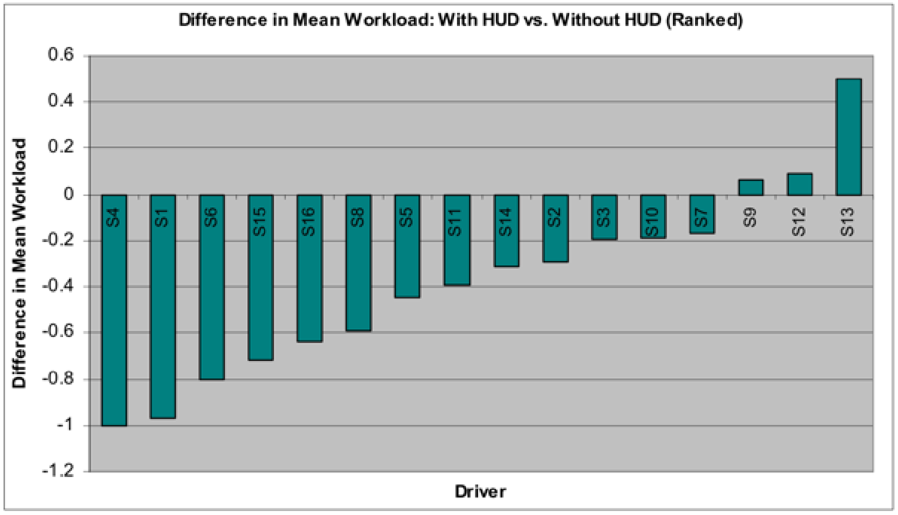


Figure 19: Difference in mean workload during driving task across all participants driving with and without HUD (Thomas et al., 2007)

In addition to reducing their workload, most participants responded positively to the conformal symbology and the cues used in the study (Thomas et al., 2007). Many participants noted that conformal cues could be used to highlight other features in the external world such as level crossings, temporary speed restrictions, emergency speed restrictions, permanent speed restrictions, advance warning boards, stop boards, the limit of shunt, worksite marker boards, car stop markers, and to attract attention to where signals and signs should be in cases where they are obscured or compromised (e.g., foliage, vandalization, etc.) (Thomas et al., 2007). Train drivers gave positive feedback on the HUD during the open discussion task and specifically noted its potential for cueing the position of signals, which was determined to be particularly helpful to reducing the likelihood of Signals Passed at Danger (SPADs), which pose a significant safety concern (Thomas et al., 2007).

In conjunction with the Locomotives and Human Factors team at Bombardier Transportation (BT) in Germany, Rohit Agarwal conducted a user study workshop with three train drivers from Green Cargo to understand the requirements and needs of operators for his master's thesis. In the first task of the workshop, drivers were asked to navigate a mock route in a train simulator. Researchers found that the total amount of time that the driver's eyes were down was 51 percent (Agarwal, 2018). This finding is in line with previous studies (Doshi et al., 2009; Thomas et al., 2007), including those from the automotive and aviation sectors, which found that operators spend a significant time looking down at the control console and thus move their eyes away from the external field.

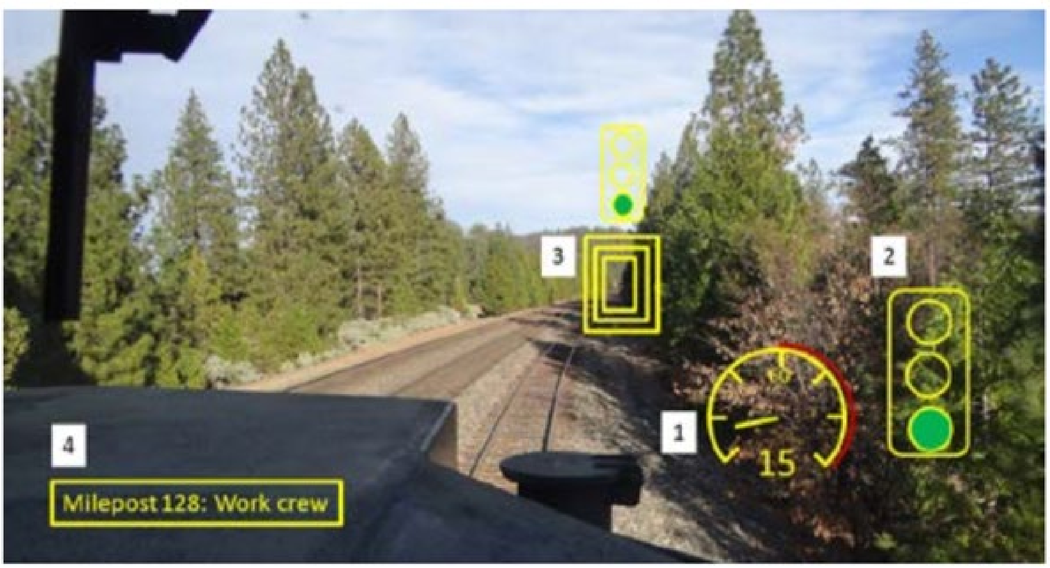
In the next task, interviews were conducted with drivers asking about the needs and requirements of their ideal HUD (Agarwal, 2018). Drivers noted that they wanted only the most crucial information to be shown to ensure that the display was not crowded. They also emphasized that information should be presented continuously with options to hide screens and customize the display to the operator's preference. It was also noted that the display's brightness and contrast need to be quickly adjustable, especially when entering and exiting low light areas such as tunnels (Agarwal, 2018). Each driver identified five major features that should be required in the display as well as three optional features, as shown in Table 9.

Table 9: The required and optional features of the HUD display (Agarwal, 2018)

Required:	Optional:
Target distance indicator	Operating Mode
Speed indicator (bow indication, digital indication and speed restriction)	Planning Area
Braking Curve	Gradient
Supervision Level	

Drivers were also asked to sketch their preferred HUD in terms of positioning and display elements. The major findings from the sketches were: the HUD should be displayed at the lowest part of the windscreen and should be centered; the HUD shouldn't interfere with wayside signals or instructions; and the HUD should be below the horizon and in the middle (Agarwal, 2018). This confirms previous findings that the HUD should be just below the line of sight of the operator and should not distract or interfere with other important signals. It was also determined that the size of the symbols should be large so that drivers can easily see the information and not need to focus to understand what it is indicating (Agarwal, 2018). In terms of colors, the recommendation was to use the same colors used by the carrier's current display, in this case the ERTMS DMI, as they have been well researched and implemented throughout all trains (Agarwal, 2018).

The prototype HUD design developed and tested by MIT-HSL was based on a set of information requirements developed by Voelbel (2014) that is based on passenger rail operations (Voelbel, 2014). Using a hybrid Cognitive Task Analysis on in-cab operations, these information requirements were developed and used as a basis for descriptions of a locomotive engineer's critical tasks and decision processes (Voelbel, 2014). The proposed symbology that Liu and Jones (2017) included were speed display, in-cab signals, moving elements to draw attention to external objects of interest, and a box that displayed messages for upcoming events (Figure 20).



Symbology includes: (1) a speed display, (2) in-cab signals, (3) a moving dynamic element highlighting external objects of interest, and (4) a message box for upcoming events.

Figure 20: Prototype HUD design (Liu & Jones, 2017)

Given that this was a preliminary study, researchers used a simplified train simulator with HUD symbology projected onto a mirror in front of the computer display (Liu & Jones, 2017). The prototype HUD replicated the design of the in-cab speedometer, with its own digital and simulated analog speed displays (Liu & Jones, 2017). Thomas et al. (2007) found that train drivers slightly preferred the analog speed dial. The red arc tracing the analog speed display represents the current speed limit, which allows the operator to see whether their speed falls within the appropriate limit. The signal symbol on the bottom right shows the signal aspect for the current track segment and serves as an external cue to memory (Liu & Jones, 2017).

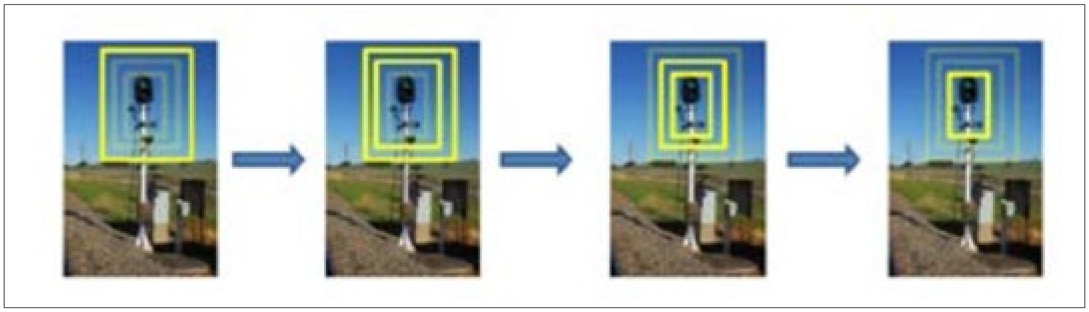


Figure 21: Dynamic graphical overlay symbology (Liu & Jones, 2017)

Using conformal symbology and implied motion, this dynamic graphic overlay captures and directs the driver's attention to the location of items such as a work crew or an upcoming signal (Liu & Jones, 2017). The overlay changes in size as features become closer. If the item is a signal, it may be represented on the display as shown in Figure 20 (Liu & Jones, 2017). The message box displays information such as messages directly from the dispatcher, track warrants, and reminders of other operational conditions (Liu & Jones, 2017). Given the promising results from this study, the recommendation from FRA was to test the prototype HUD in a more realistic simulator with participants.

2.4 Key Design Takeaways

Campbell, Richman, Carney, and Lee (2004) compiled a volume of guidelines for developing in-vehicle display icons. The importance of having a defined process for icon development is outlined in the chart below (Figure 22). Their recommended process involves checking to see if a symbol currently exists for the information being conveyed, and if not, advises an evaluation process for new ideas to ensure they are properly interpreted (Campbell et al., 2004).

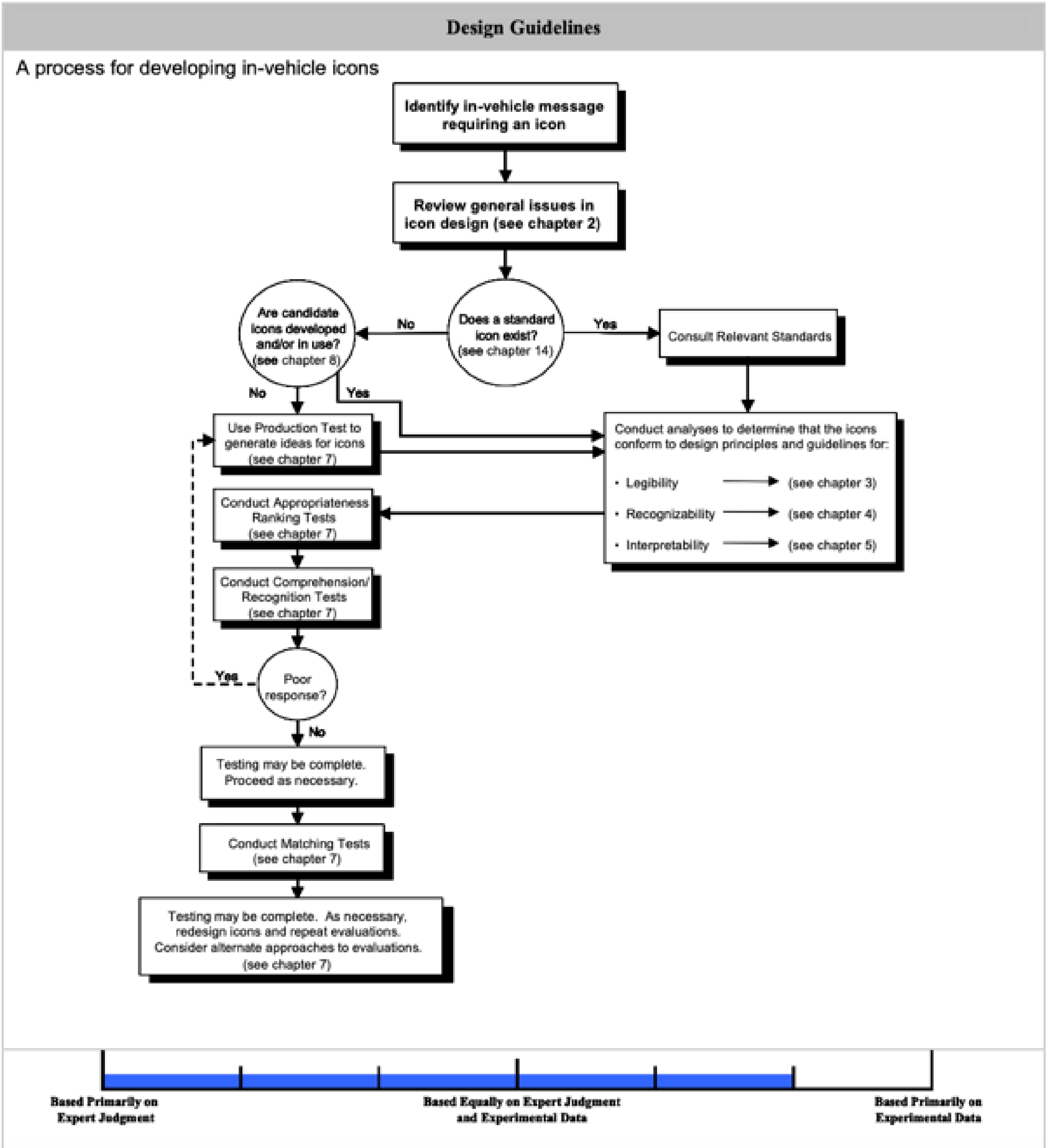


Figure 22: General development process for in-vehicle icons (Campbell et al., 2004)

Some of the guidelines given in Campbell et al. (2004) are not applicable to HUD icon design due to the nature of a HUD (e.g., deciding the background for the symbol). However, many of their recommendations are universal enough to provide guidance for symbology design in any field. Detailed in Easterby's guidelines for symbology in 1970, some of the most important characteristics of symbols highlighted were continuity, closure, symmetry, simplicity, and unity. These properties lead to increased recognition and understanding of symbols and icons by guiding an individual's eye to key features of importance.

Figure 23 shows three important categories in evaluating the efficacy of a symbol (Campbell et al., 2004). The first two categories deal with the construction of the symbol (e.g., the color, brightness, size, orientation, etc.). The third category factors in the general knowledge of the population for which the symbols are being designed. For example, a red octagon to many people indicates STOP, but someone completely unfamiliar with modern roads might not have the same interpretation (Campbell et al., 2004).

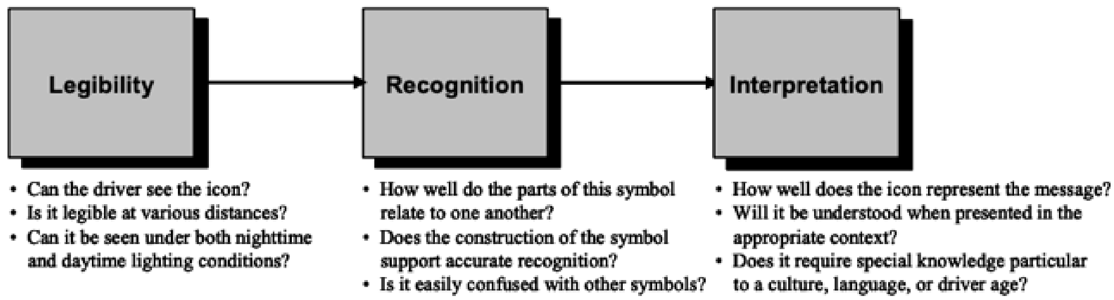


Figure 23: Sequence of icon comprehension and use (Campbell et al., 2004)

The recommendations from all sectors of symbology development researched in this review are compiled below. Recommendations are grouped based on the following aspects of symbol design: color, text, detail and realism, layout, size, and adjustability.

Guidelines for Using Color

Color can be a useful tool in designing a symbol due to its quick visual processing time (Ling et al., 2019). Certain colors also have almost universal implication, such as green for go, yellow for caution, and red for stop/warning (Ling et al., 2019). However, in HUD designs the background the symbol must appear against is constantly changing. Thus, the color's effectiveness must be considered against the array of different landscapes and be effective in each. Ling et al. (2019) suggests that the color of symbols should be evaluated as they appear against their environment, and potentially have different modes to be best seen in different environments (e.g., a rainy dusk versus a bright snow scape).

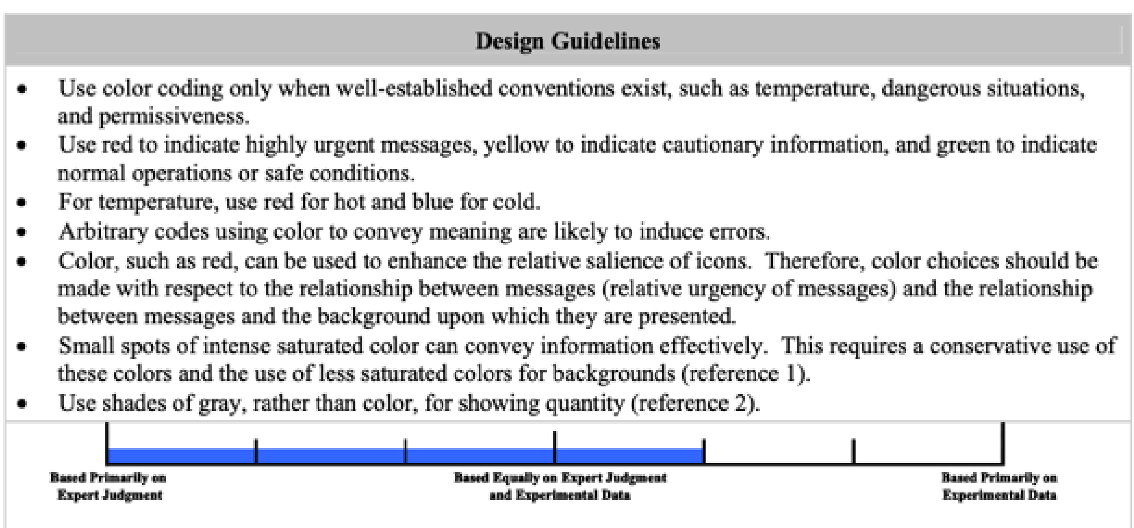


Figure 24: Schematic examples of the use of color (Campbell et al., 2004)

This is consistent with the Tretten et al. (2011) study of HUD in automobiles which underscores the importance of conducting HUD studies in real-world settings. Some colors test well against many landscapes (e.g., red, yellow, and green), while some colors should be avoided due to their poor visual acuity (e.g., blue or purple) (Campbell et al., 2004; Ling et al., 2019). Color can also have an impact on the urgency of a message. For example, red and orange are most typically used for high urgency and should be limited in use to preserve their effect (Campbell et al., 2004). Additionally, the current colors used in rail operations to convey certain symbols should be considered and if possible kept consistent (Agarwal, 2018).

Guidelines for Using Text

Text labels have been shown to be useful when accompanying an unfamiliar icon (Campbell et al., 2004; Horton, 1994). Figure 25 shows some of the technical guidelines used in creating text within symbols, most importantly keeping the number of words low and choosing simple and easy to read fonts. The usefulness of the text included in a symbol must be balanced with the extra space that it uses and its limiting effect on the universality of the icon (i.e., limiting its comprehension to one specific language) (Campbell et al., 2004). Adding some text to an otherwise hard to interpret or vague symbol may increase the time it takes to process but decrease the amount of time a driver is looking away from the road.

Design Guidelines

- Text labels should be brief, no more than 2-3 words.
- The type should be at least 0.27 degrees of visual angle (16 arcmin.); 0.40 degrees (24 arcmin.), maximum.
- Use a clear and simple sans serif typeface such as Helvetica. Avoid using boldface, italics, underlining, or differences of color to emphasize words.
- The space between lines should be at least 1/30 the line length.
- Use both uppercase and lowercase letters rather than all of one or the other.
- Character width-to-height ratios should be 0.6:1 - 1:1 (width:height).
- Wider characters should be used as criticality increases.
- If text must be compressed, compress the space between characters rather than the characters (1).
- Use initial capital letters for multiword labels not incorporated in the symbol.

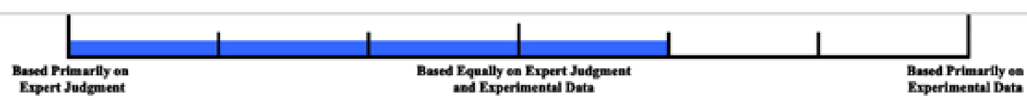


Figure 25: Schematic examples of text labels (Campbell et al., 2004)

In a 2009 study by Doshi et al., drivers' head movement and reaction time were tracked as they drove an automobile with a HUD. When a driver was presented with a symbol warning them that they were speeding, the driver had the fastest return to under the speed limit (Doshi et al., 2009). However, when shown a numerical display of their speed instead, the time spent looking down at the dashboard decreased by 63 percent. Therefore, a warning symbol successfully brought their speed down but caused the driver to then spend time checking the speedometer and looking away from the road (Doshi et al., 2009).

Guidelines for Detail and Realism

Only the details that contribute to the meaning of the symbol should be included, while details that distract from the true goals of recognition and comprehension should be omitted (Campbell et al., 2004). A significant detail refers to a symbol element that would reduce icon recognition and comprehension if removed. Campbell et al. (2004) suggest using a grid of 20 by 20 when constructing a symbol and omitting any details smaller than 1 unit of the grid, which can help avoid clutter. Figure 26 shows the levels of realism a symbol can be styled in, as well as when each might best be used (Campbell et al., 2004). For HUD design, highly realistic or detailed symbols are not ideal due to the complexity of the background against which they will be displayed.

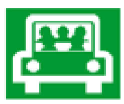
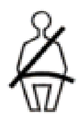
Example	Level of Realism	Design Style	When to Use
	Simplified drawing	Simplified drawing with distinct interior details	For presenting complex symbols with small significant parts, especially when objects have similar profiles (e.g., mechanical or electrical devices)
	Caricature	Exaggeration of crucial details	For presenting symbols that have a small, crucial feature or for simplifying complex details
	Outline	Outline with only prominent details	For presenting small symbols that represent a familiar object with a distinct profile
	Silhouette	Shape filled with solid color contrasting with background	For presenting symbols that are too thin to show in outline format and for symbols that have a very distinct profile and do not require detail for recognition

Figure 26: Five levels of realism (Campbell et al., 2004)

Guidelines for Layout

It is important to note that recommended layouts vary depending on the application (e.g., auto, rail, aviation, etc.). HUD for automotive application can be described as a visual display that is within 15 degrees of the driver's line of sight or a virtual-image display within the driver's line of sight where images and symbols are located at some distance beyond the windshield (Tretten et al., 2011). The main purpose of a HUD is to display information to a user over their normal field of vision, so that they can take in information from the HUD without taking their eyes from the landscape behind it. This should reduce the time spent looking away from their surroundings and improve situational awareness. Every symbol displayed on the HUD must serve a direct purpose in conveying critical information, with the cardinal rule in HUD design being "if in doubt, leave it out" (Ingman, 2005).

The SAE and several empirical studies have recommended that important warnings be located within 10 degrees of the driver's line of sight (Liu, 2003; Tretten et al., 2011). In a study of HUD in automobiles, most of the subjects (57 percent) noted that they preferred to have the HUD image projected directly in front of them just below their line of sight (Tretten et al., 2011). A significant result of this study was that most subjects (77 percent) did not want the HUD to be located within their focal vision while driving, instead preferring for it to be set up right outside of their focal vision so they could quickly scan the landscape for information while driving (Tretten et al., 2011).

Similarly, train drivers spend most of their time attending to a small area of the external visual scene. The area is located directly in front of them on the train tracks (Luke et al., 2006).

Agrawal (2008) concluded that the HUD should be displayed at the lowest part of the windscreen and should be centered, it shouldn't interfere with wayside signals or instructions, and it should be below the horizon and in the middle. This confirms previous findings that the HUD should be just below the operator's line of sight and should not distract or interfere with other important signals. See Table 9 above for the required and optional features of the HUD display from Agarwal (2018).

The "Layout Appropriateness" equation was developed by Dr. Andrew Sears in 1993. It allows designers to determine the best way to organize several "widgets" in a user interface based on task descriptions, cost, and frequency of use (Deveans & Kewley, 2009). It requires a set of symbols, the sequences of actions a user would perform, how frequently each sequence is performed, and a cost assigned to each action (i.e., time to process, or total head movement) (Deveans & Kewley, 2009). In the most appropriate layout, the symbols that are checked in sequence would be next to each other on the display.

In deciding layout, it is also important to decide whether to make some symbols conformal. In addition to reducing their workload, most participants in the Thomas et al. (2007) study responded positively to the conformal symbology and the cues used in the study. Many participants noted that conformal cues could be used to highlight other features in the external world such as level crossings, temporary speed restrictions, emergency speed restrictions, permanent speed restrictions, advance warning boards, stop boards, the limit of shunt, worksite marker boards, car stop markers, and to attract attention to where signals and signs should be in cases where they are obscured or compromised (e.g., foliage, vandalization, etc.) (Thomas et al., 2007).

Guidelines for Size

The main condition for size is that symbols should be large enough that drivers can easily see the information without needing to focus to understand what it represents (Agarwal, 2018). The size of symbols presented in a HUD is based on the viewpoint of the user. The maximum visual angle suggested (85 arcminutes) is aimed at ensuring conspicuity, while the minimum visual angle (41 arcminutes) simply ensures legibility based on the assumption that the symbol will not be placed outside a 15 degree angular displacement from the central line of the normal direction of user's vision (Campbell et al., 2004). The minimum size of graphical symbols is 1/100th their viewing distance, which corresponds to 0.57 degrees visual angle (Campbell et al., 2004).

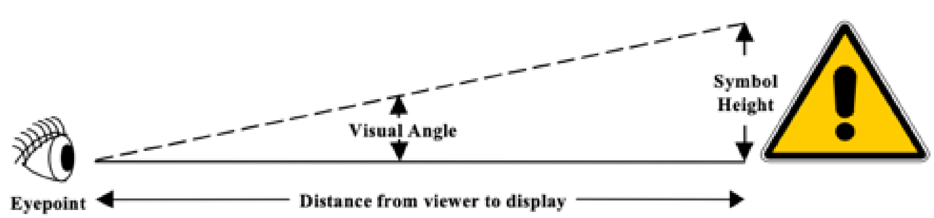


Figure 3-3. Relationship Between Viewing Distance, Symbol Height, and Visual Angle

Figure 27: Relationship between viewing distance, symbol height, and visual angle (Campbell et al., 2004)

Guidelines for Adjustability

Across all transportation fields researched, a consistent finding in HUD design was the importance of adjustability (Agarwal, 2018; Ingman, 2005; Tretten et al., 2011). One of the major categories that users indicated should be customizable was the number of symbols shown on the screen, or "clutter." While maximizing the number of symbols on the screen could serve to provide the user all necessary information at once, it also can distract from or obscure the visual landscape behind the display. Users testing HUD design in aviation, automobile, and rail all state their preference for various "levels" of clutter, and the option to remove all HUD symbols quickly in high-stress situations (Agarwal, 2018; Ingman, 2005; Tretten et al., 2011).

Another important factor to consider is the color and brightness of symbols. Due to the changing environment over which a HUD must display, the brightness and color should also be adjustable. While testing a HUD for rail, users stated that display brightness and contrast needs to be quickly adjustable, especially when entering and exiting low light areas such as tunnels (Agarwal, 2018). Findings of the Tretten et al. (2011) study underscore the importance of conducting HUD research in real-world settings and allowing participants to not only give feedback to researchers, but also allowing them to adjust the technology to their personal preference (e.g., luminance, location placement, etc.).

2.5 Lessons Learned with the Introduction of Technology

FRA is interested in exploring the implementation of HUD technology into locomotive cabs. This literature review explored fields in which HUD technology has been further developed and researched, such as the aviation and automotive sectors. The major findings from these industries show that HUD reduced the time that the operator spent looking down or away from the external world (out of the window), improved situational awareness, improved performance, and reduced workload (Ingman, 2005; Liu & Jones, 2017; Liu, 2003). This review also includes the research done thus far in the rail industry and could aid in putting together guidelines for developing HUD symbology. A visual tracking study of locomotive engineers showed that two areas engineers spent the most time viewing were directly ahead and down at the dashboard (Luke et al., 2006). If those areas could be combined with implementation of a HUD, an engineer could absorb information from the dashboard and the outside world simultaneously without having to look away from the track (Luke et al., 2006). Consistent with both aviation and automotive studies, HUD implementation in rail studies led to a significantly reduced workload for most drivers (Thomas et al., 2007).

This document also provides specific symbology design considerations, especially in HUD application. Campbell et al. (2004) recommend a defined process for symbol development, which involves evaluation of proposed symbols for legibility, interpretability, and recognition. Within symbol design, color, text, detail and realism, layout, size, and adjustability must be considered. Easterby (1970) stressed the importance of structural properties of icons and symbols as they give contextual cues from which individuals derive meaning as well as increase recognition and understanding of the symbol. However, implementing best design practices is more complicated when the end application is a HUD. For example, color is useful in symbol design due to its quick visual processing time (Ling et al., 2019), but in HUD, the background is constantly changing and thus color needs to be considered in relation to various landscapes. Additionally, while highly realistic symbols are typically more effective for the end user, for HUD design, highly realistic or detailed symbols are not ideal due to the complexity of the background they will be displayed against (Horton, 1994). Layout and adjustability are also important design considerations due to the necessity of a clutter-free screen so situational awareness of the outside world is never compromised. Creating customizable layers of symbols so the user can decide the level of clutter on their screen or have the option to remove HUD symbology is also important, especially for locomotive areas in which there is a quick change in landscape contrast, such as tunnels or low-light areas (Agarwal, 2018; Ingman, 2005; Tretten et al., 2011).

2.6 Current Symbols Used in Rail and Commonalities Between Systems

Very few pieces of information in the current rail display are indicated with icon symbology. Instead, most of the controls are represented by text buttons. However, examining the common elements included on the main operating screens of various rail operation programs may highlight what information is most vital in developing symbology for HUD application. The speedometer is the most obvious and consistently shown symbol across several display options. Thomas et al. (2007) found that train drivers slightly preferred an analog speed dial, with the numerical speed also included.

Common features between displays are important because not only do they convey the information an engineer checks most, they also draw the operator’s attention from the surrounding landscape. Further research is needed to obtain direct feedback from engineers regarding which features of the various displays they look at the most. With these features integrated into the HUD, engineers will be able to check the information they need to safely operate, while reducing the time they take their eyes away from the external world. All research collected in this literature review suggests that a HUD application in rail would significantly reduce workload and improve situational awareness among engineers. This would be potentially beneficial to preventing future incidents and accidents.

3. Task 3: Design and Development of Symbology Library

3.1 Background

For a locomotive HUD to be effective, a library of symbols must be created that are quickly recognizable to current locomotive engineers and clearly visible in the environment of a HUD. The team built a preliminary library of symbols for passenger and freight rail and addressed the software requirements for integration into HUD. Libraries include the most pertinent symbols for HUD application for both freight and passenger operations. Some of the symbols developed have several different design options for subject matter experts to review for clarity, efficacy, and urgency.

Based on the findings from the literature review and conversations with locomotive engineers, the team developed designs for the most relevant icons for HUD application in both passenger and freight rail operations. These lists include symbols that are featured on main displays across rail carriers and symbols that have been used in previous HUD studies in rail and other transportation industries, such as the aviation and automotive fields.

Preliminary conversations with two passenger engineers and one freight engineer helped the team understand what elements and symbols engineers spend the most time looking at on their HDD while operating the trains. In addition to describing which controls and symbols they found most important, the engineers were also asked about symbols they wish they had or that they would want on a HUD. These include symbols that do not currently exist in rail or are limited in their current representation. Engineers also noted symbols or controls that were necessary and potentially unique to freight or passenger operations and ranked the resulting list of symbols from most critical to least critical in the context of a HUD. The team worked with design partners and used this information regarding best design practices in a HUD setting to guide the creation of drafts of each symbol.

3.2 Freight and Passenger Symbol Lists Ranked

Based on feedback from the three locomotive engineers consulted, Table 10 and Table 11 show the proposed passenger and freight symbols for HUD application ranked in order of criticality. Numbers highlighted as green indicate most critical, yellow indicates somewhat critical, and red indicates least critical. These categorizations may determine which symbols are always necessary to show on the HUD and which might only need to appear as necessary or as preferred by the engineer in subsequent operations or tasks.

Table 10: Passenger symbols ranked by importance

Ranking	Symbols	Source
1	Speed (MPH)	Passenger manual, Lit. Review Findings: Previous HUD Studies
2	Upcoming speed restriction	Lit. Review Findings: Previous HUD Studies
3	Milepost/Current Train Location	Lit. Review Findings: Previous HUD Studies
4	Cab Signal	Engineer suggestion, Lit. Review Findings: Previous HUD Studies
5	Time of day	Engineer suggestion

Ranking	Symbols	Source
6	Upcoming Stations and Next Stop	Lit. Review Findings: Previous HUD Studies, Engineer suggestion
7	ER	Passenger manual
8	BP	Passenger manual
9	Accelerometer	Passenger manual, Engineer suggestion
10	Headlight/Ditch Light Indicator	Engineer suggestion, Lit. Review Findings: Previous HUD Studies
11	Throttle	Freight manual
12	Effort Klb.	Passenger manual
13	Delay in Block	Engineer suggestion
14	Fault Message/Error Message	Passenger manual, Engineer suggestion, Lit. Review Findings: Previous HUD Studies
15	Stop	Lit. Review Findings: Previous HUD Studies
16	Curve	Engineer suggestion
17	Bell	Engineer suggestion, Lit. Review Findings: Previous HUD Studies
18	Main Reservoir	Passenger manual
19	Condition Brakes	Engineer suggestion, Lit. Review Findings: Previous HUD Studies
20	Radio Communication Notification	Lit. Review Findings: Previous HUD Studies
21	Quiet Zone	Engineer suggestion, Lit. Review Findings: Previous HUD Studies
22	Weather	Engineer suggestion

Table 11: Freight symbols ranked by importance

Ranking	Symbols	Source
1	Speed (MPH)	Freight manual, Lit. Review Findings: Previous HUD Studies
2	Accelerometer	Freight manual, Lit. Review Findings: Previous HUD Studies,
3	Upcoming speed restriction	Lit. Review Findings: Previous HUD Studies, Trip Optimizer, PTC
4	Milepost/Current Train Location	Lit. Review Findings: Previous HUD Studies, PTC, Trip Optimizer
5	Cab Signal	Engineer suggestion, Lit. Review Findings: Previous HUD Studies
6	Distance Counter	Freight manual
7	ER	Freight manual, Trip Optimizer
8	BP	Freight manual, Lit. Review Findings: Previous HUD Studies, Trip Optimizer

Ranking	Symbols	Source
9	Throttle	Freight manual, Lit. Review Findings: Previous HUD Studies, Trip Optimizer
10	Effort Klb.	Freight manual
11	Grade	Trip Optimizer, PTC
12	Curve	Engineer suggestion
13	Headlight/Ditch Light Indicator	Engineer suggestion
14	Stop	Lit. Review Findings: Previous HUD Studies
15	Rear	Freight manual
16	Flow	Freight manual
17	Main	Freight manual
18	Radio Communication Notification	Lit. Review Findings: Previous HUD Studies
19	Stopping Distance	PTC, Freight manual
20	Fault Message/Error Message	Engineer suggestion
21	Quiet Zone	Engineer suggestion
22	Weather	Engineer suggestion

3.3 Symbols Created

The research team worked with design partners to create drafts of each symbol. The team provided summaries of each symbol's context and intended purpose, as well as any current representations already used in the locomotive industry. Several symbols, including a condition brake warning for icy weather, quiet zone, headlight/ditch light indicator, curve, time of day, current weather conditions, and grade either had no or limited current symbol representations in the HDDs on locomotives and thus are original and unique designs. Some symbols have multiple aesthetic options in preparation for the next project task, which focused on collecting feedback from subject matter experts within the locomotive industry on their preferences and interpretation of the symbols. The symbol drafts are included in Figure 28 to Figure 53 below:

Figure 28: Draft of Current Train Location/Signals

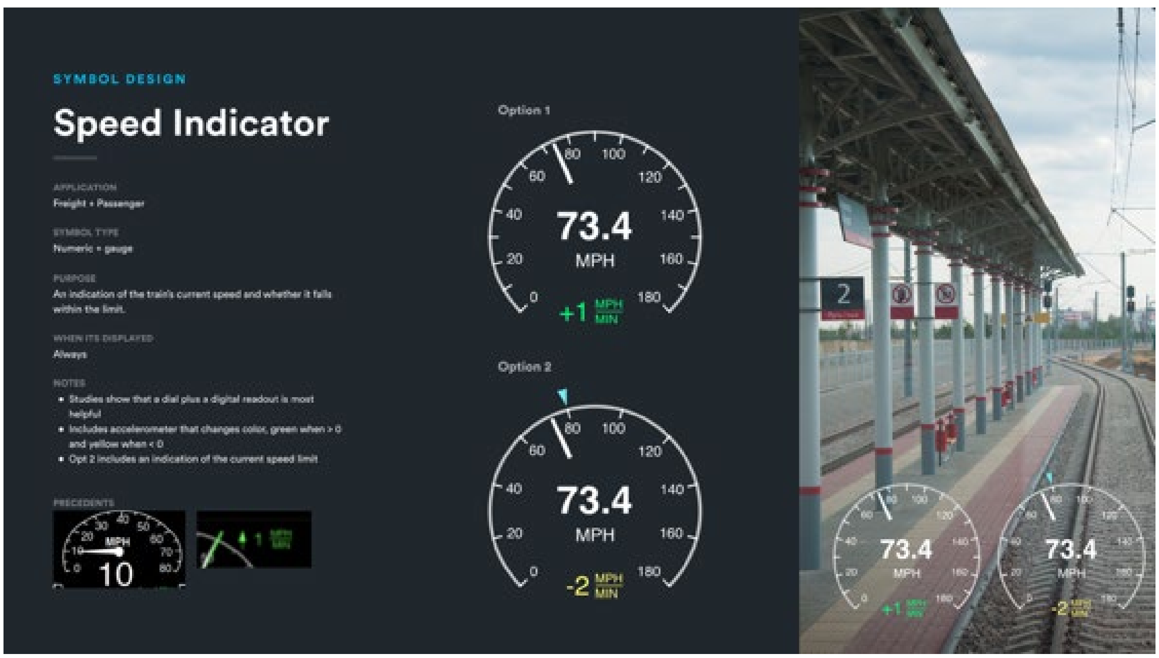


Figure 29: Draft of Speed Indicator

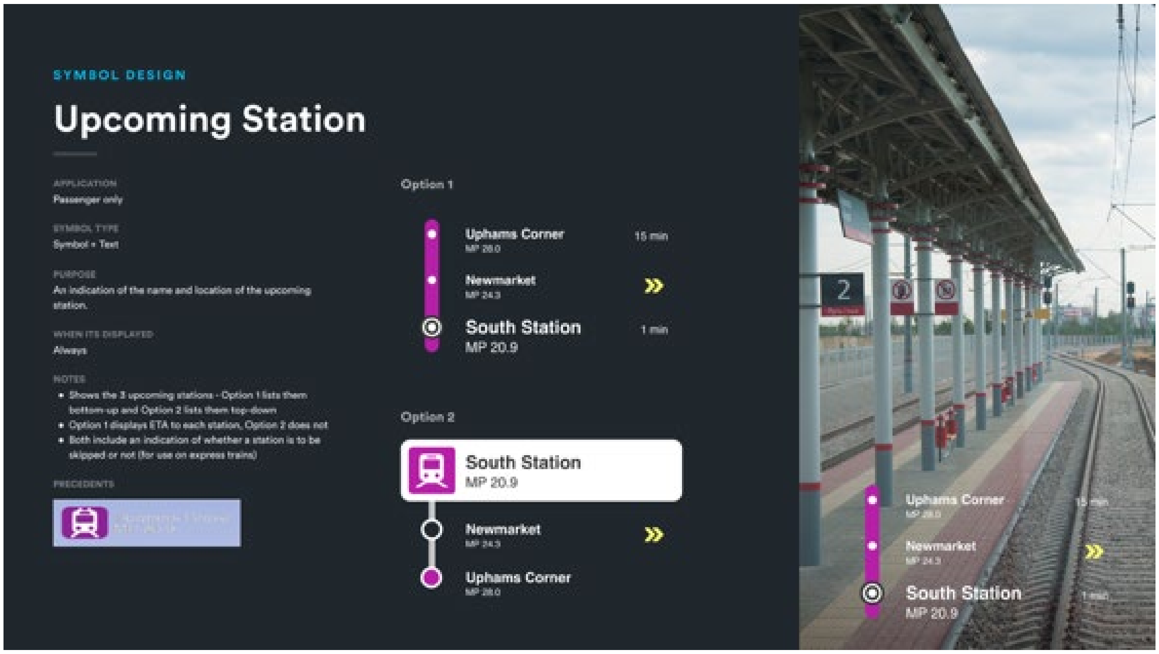


Figure 30: Draft of Upcoming Station

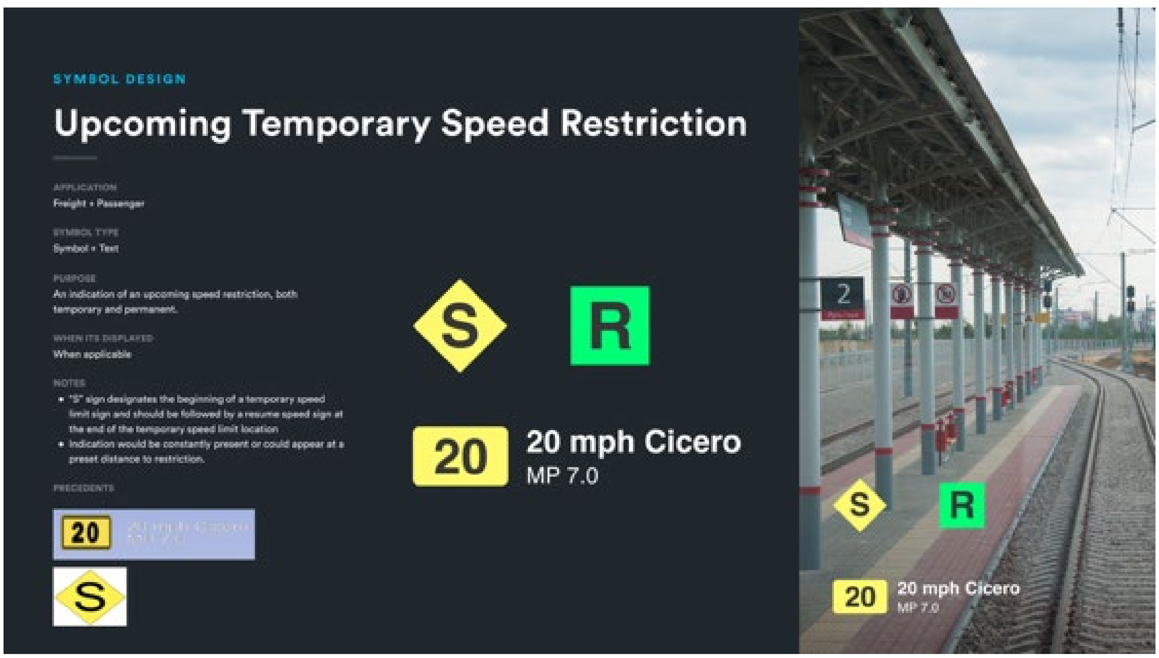


Figure 31: Draft of Upcoming Temporary Speed Restriction

Figure 32: Draft of Radio Communication Notification

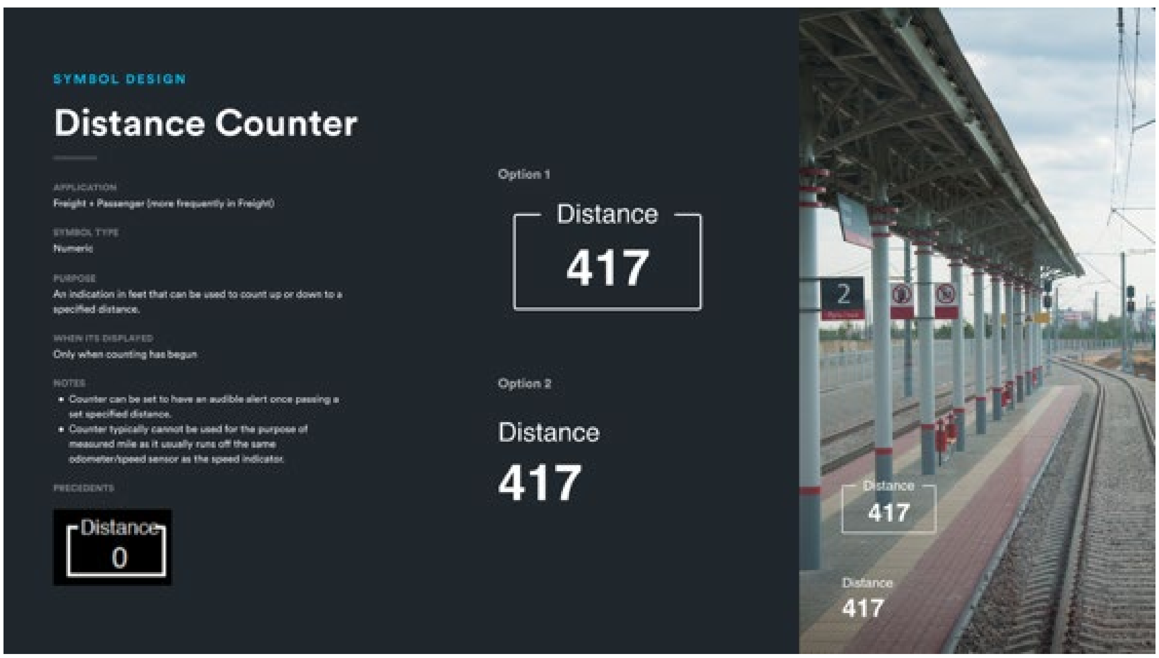


Figure 33: Draft of Distance Counter

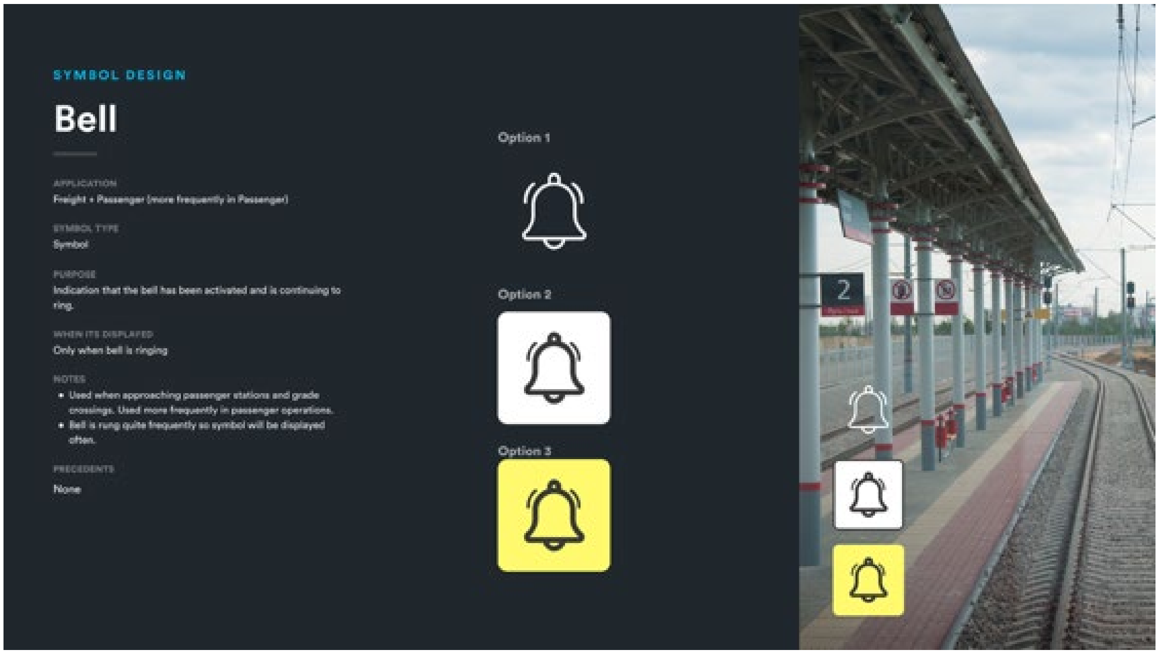


Figure 34: Draft of Bell

Figure 35: Draft of Equalizer Reservoir (ER) Air Gauge

Figure 36: Draft of Brake Pipe (BP) Pressure

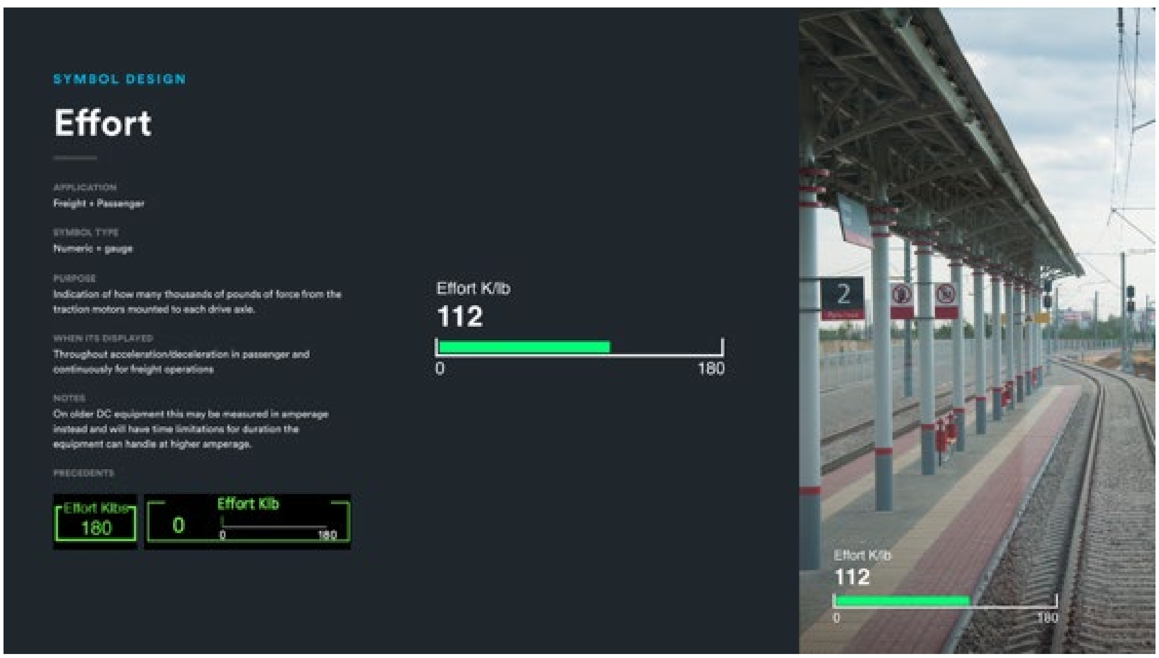


Figure 37: Draft of Effort

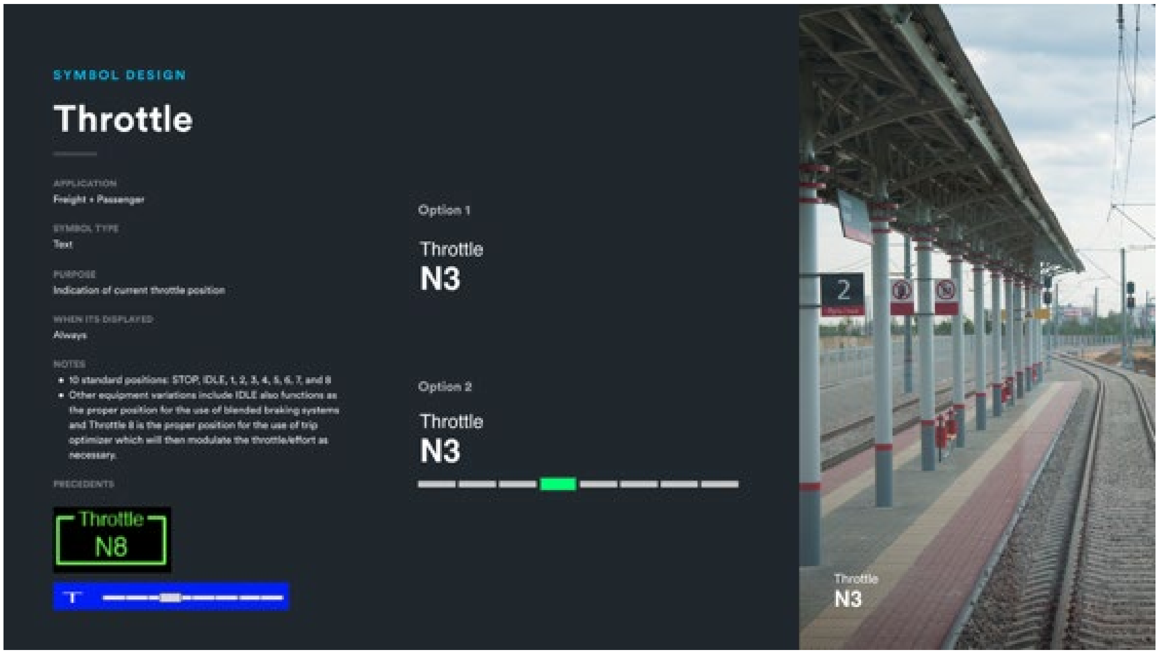


Figure 38: Draft of Throttle

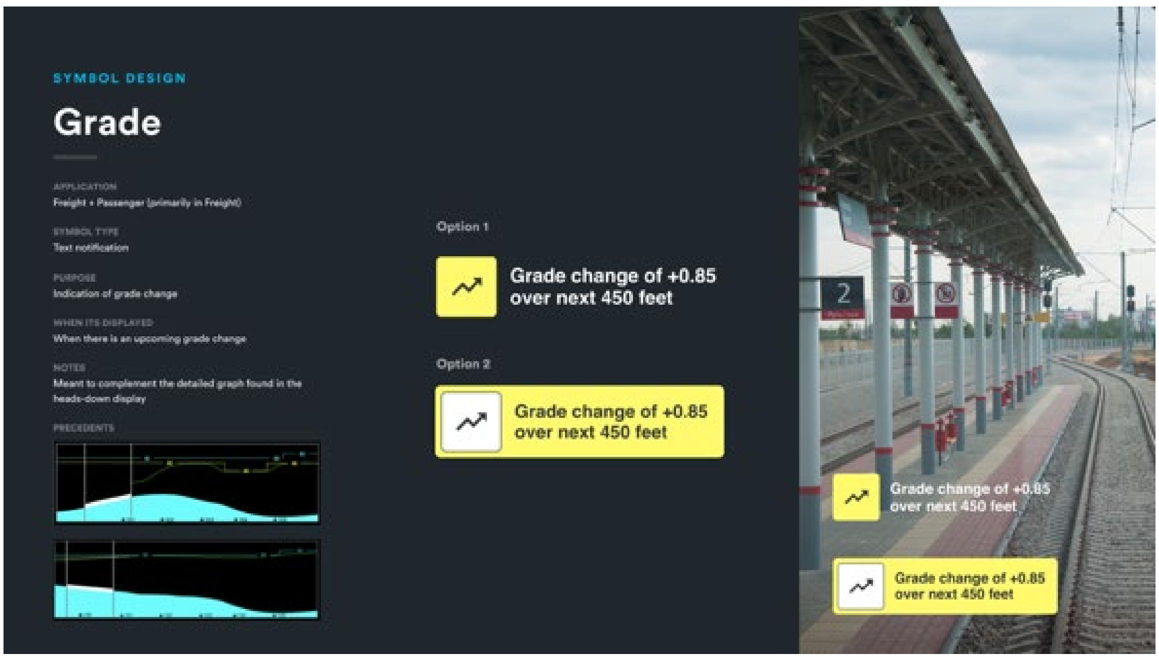


Figure 39: Draft of Grade

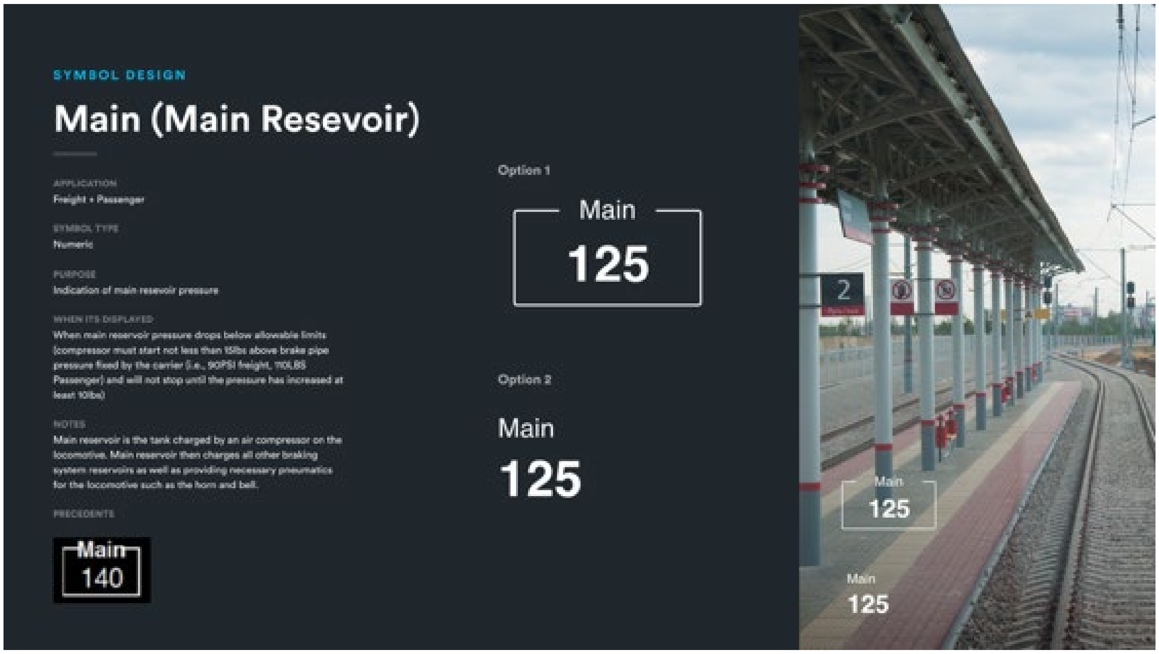


Figure 40: Draft of Main Reservoir

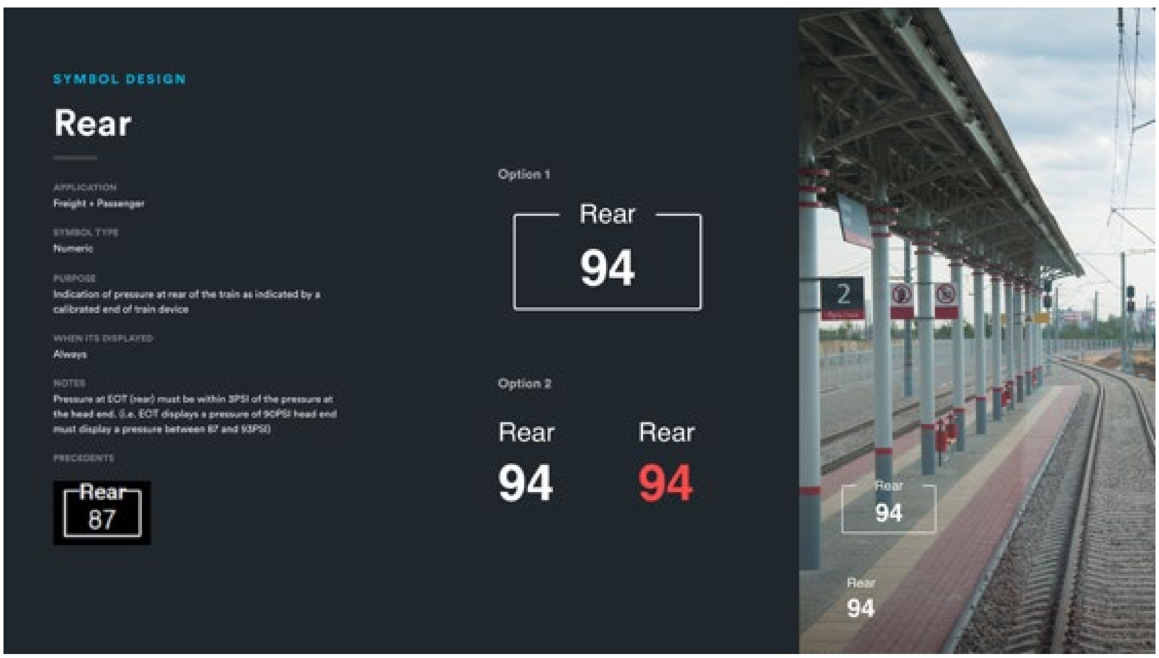


Figure 41: Draft of Rear

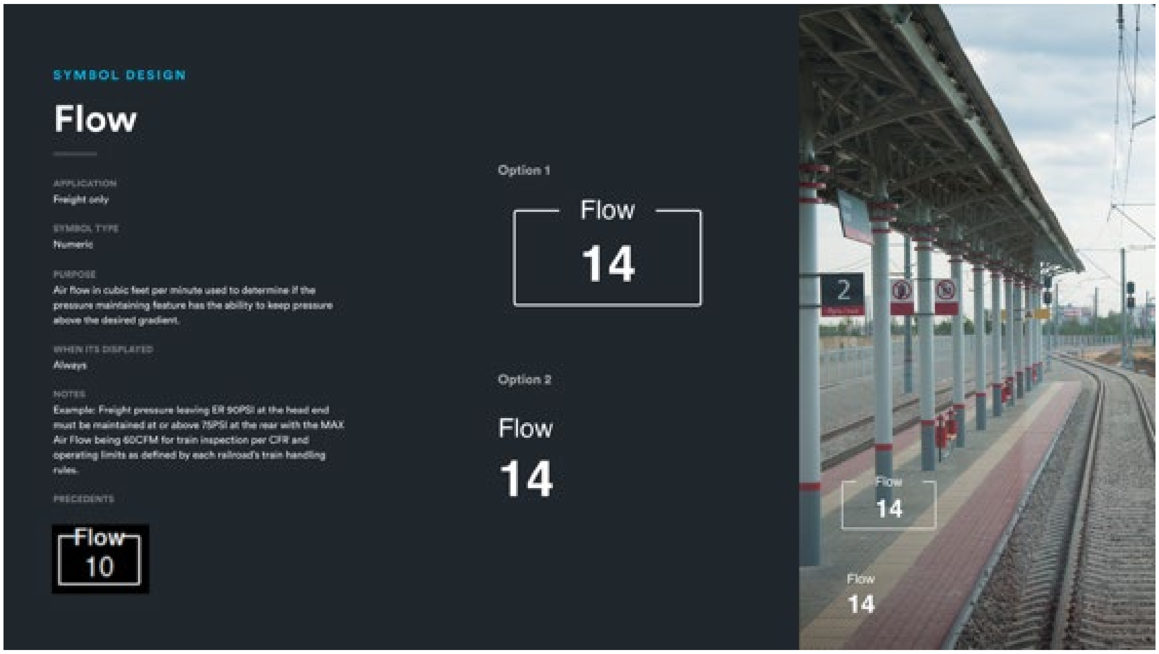


Figure 42: Draft of Flow

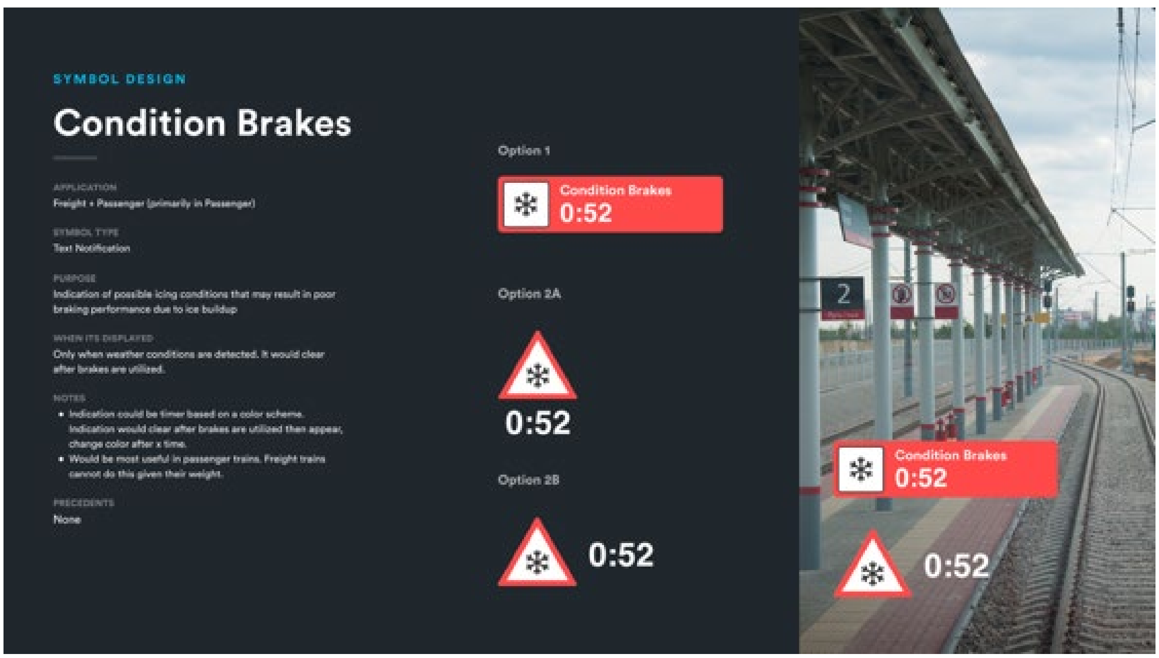


Figure 43: Draft of Condition Brakes

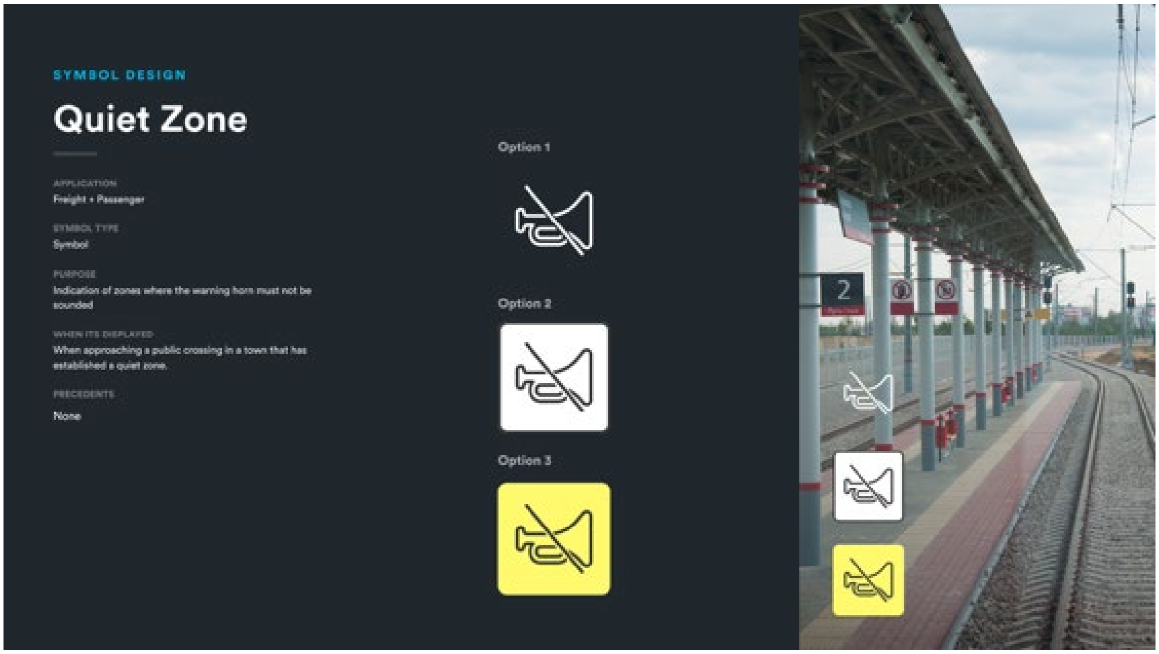


Figure 44: Draft of Quiet Zone

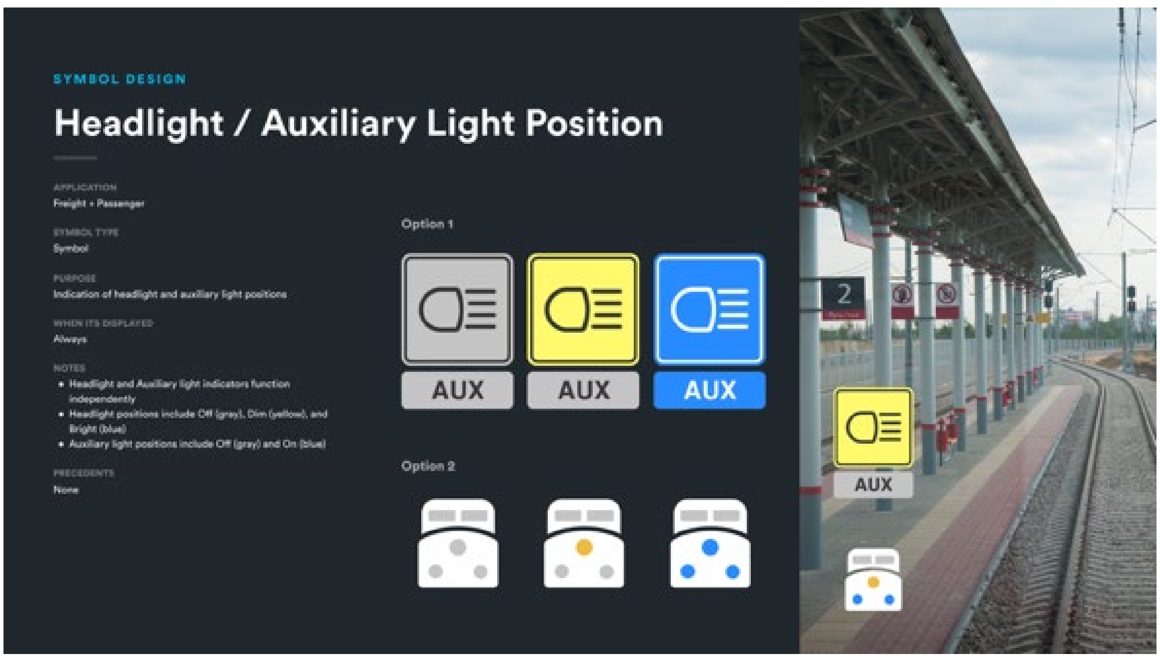


Figure 45: Draft of Headlight/Auxiliary Light Position

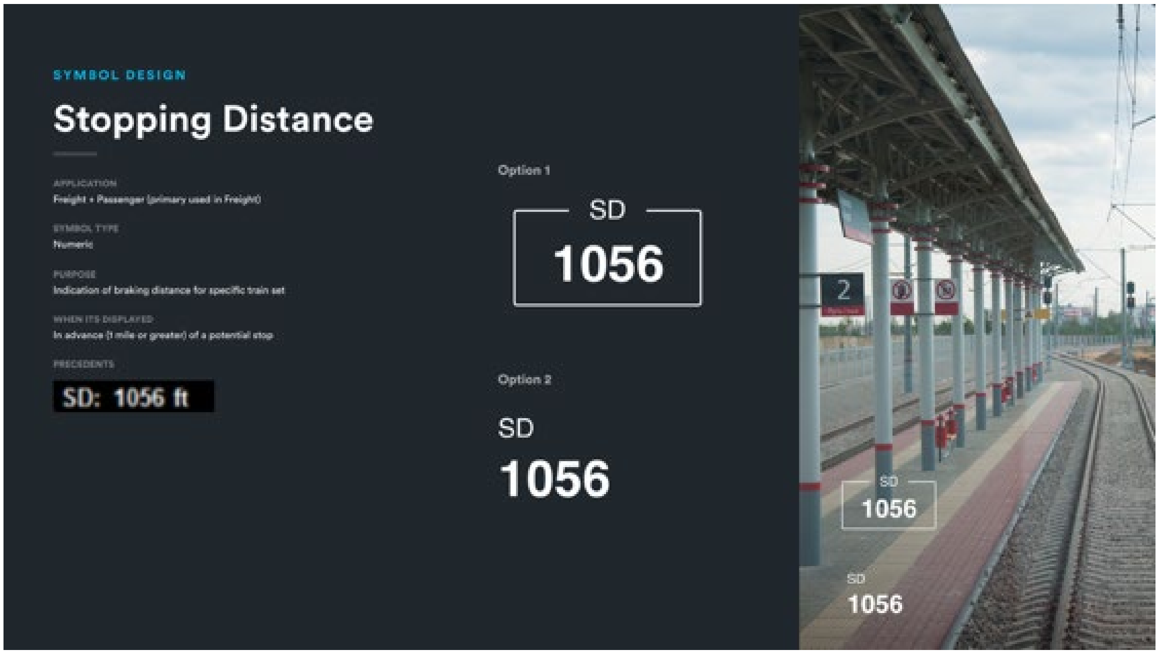


Figure 46: Draft of Stopping Distance

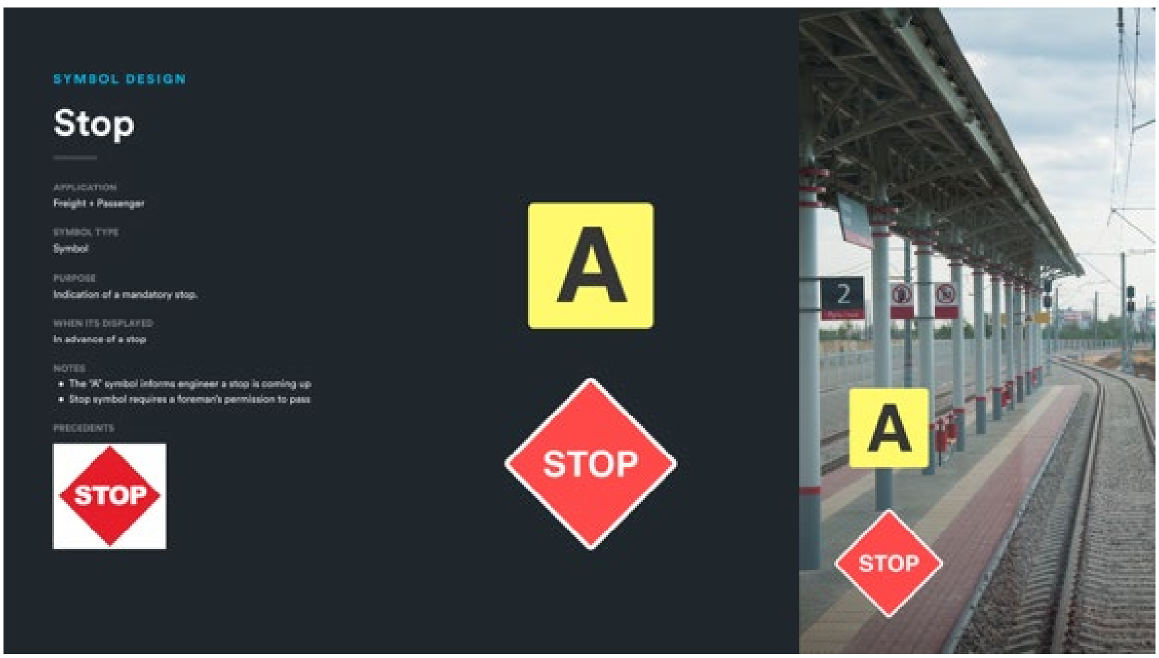


Figure 47: Draft of Stop

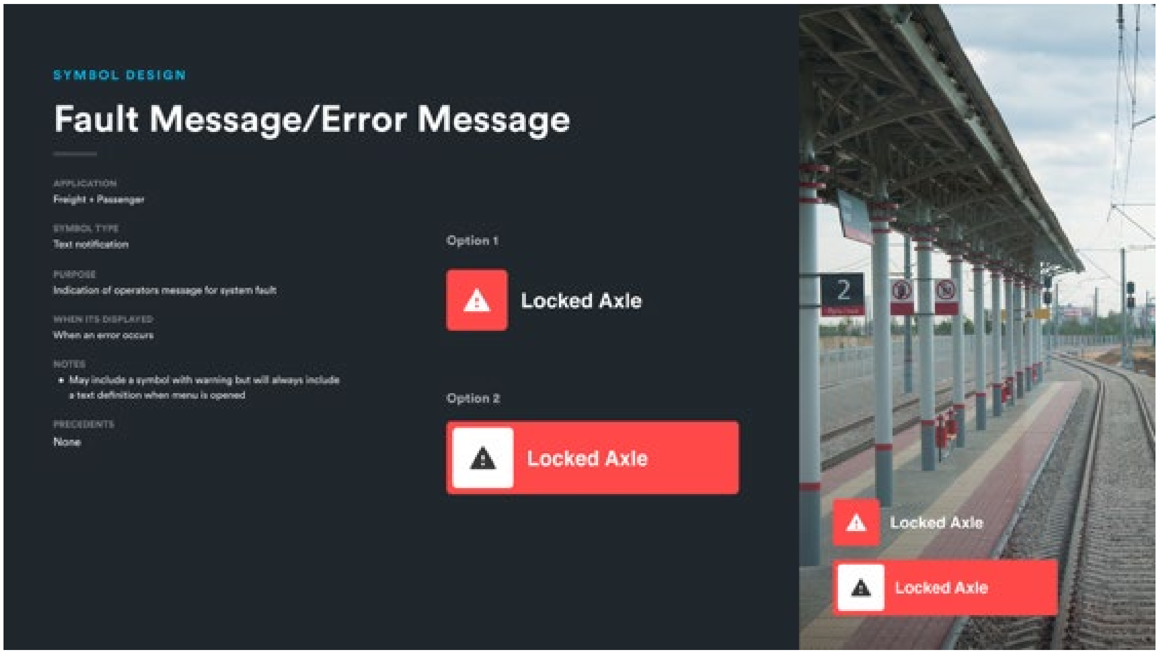


Figure 48: Draft of Fault Message/Error Message

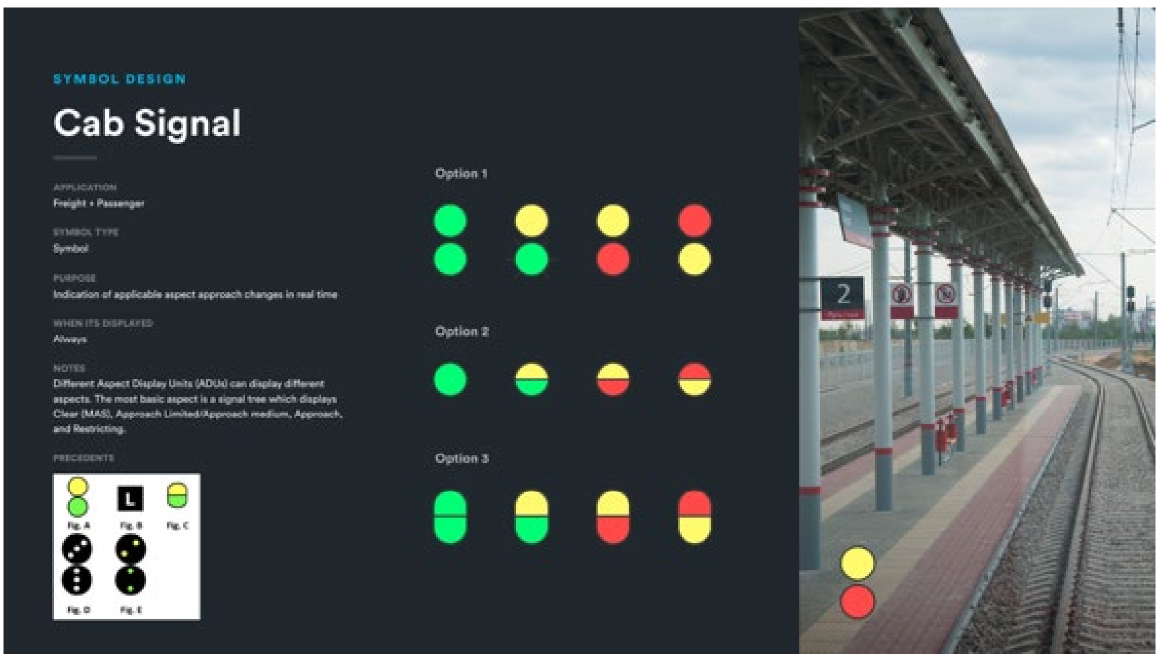


Figure 49: Draft of Cab Signal

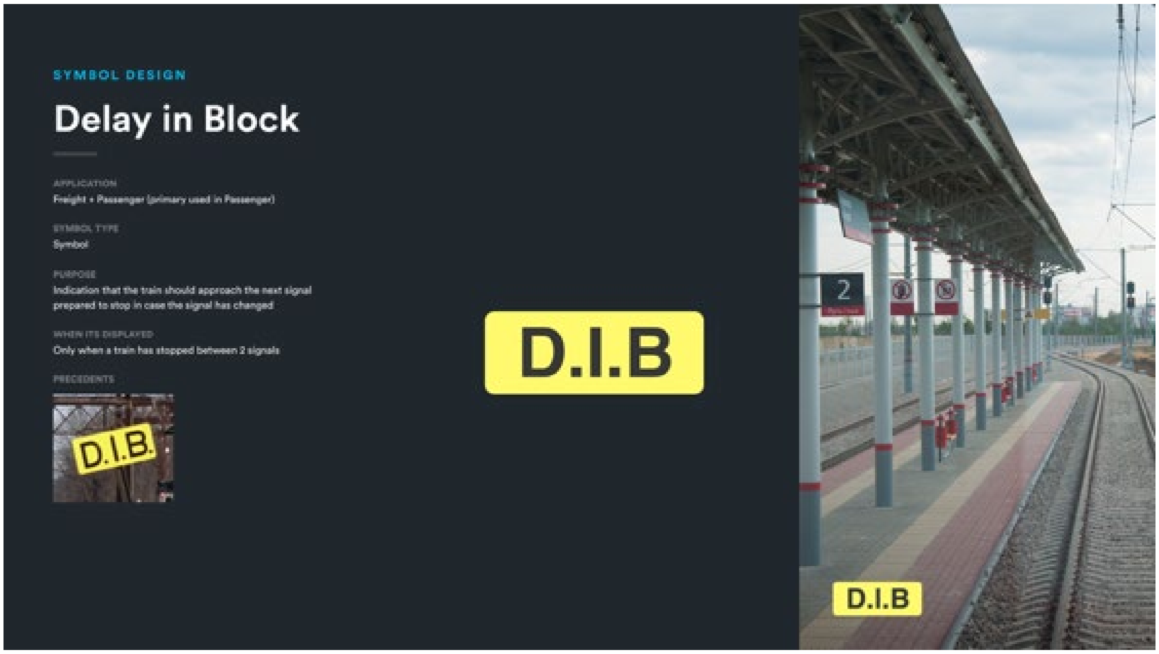


Figure 50: Draft of Delay in Block

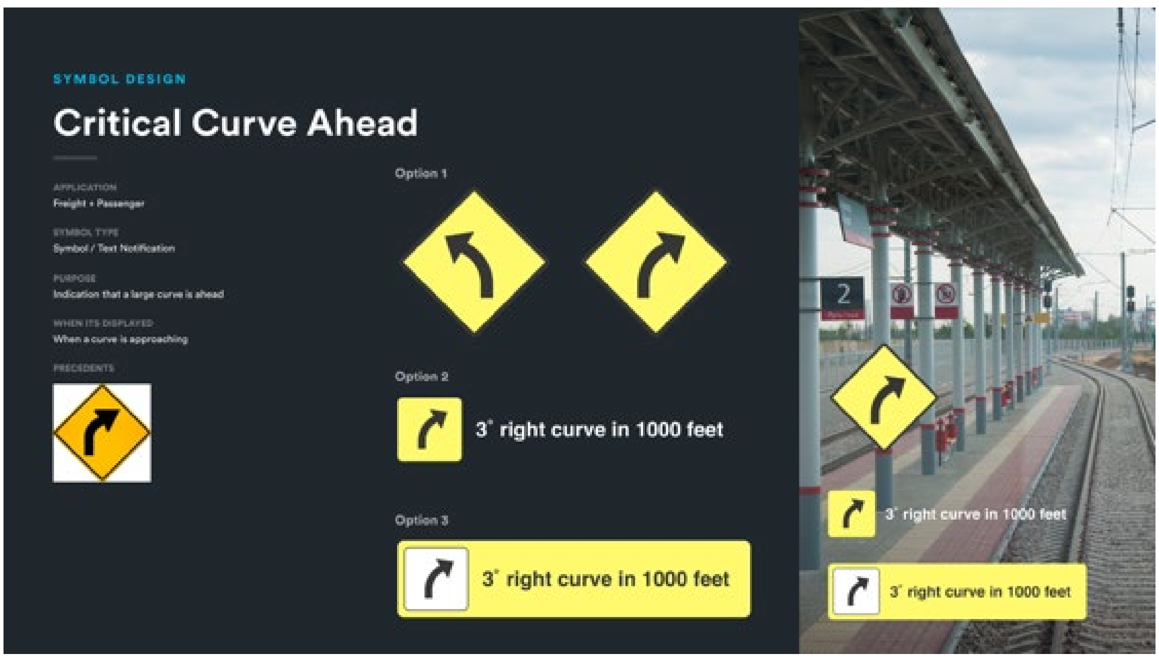


Figure 51: Draft of Critical Curve Ahead

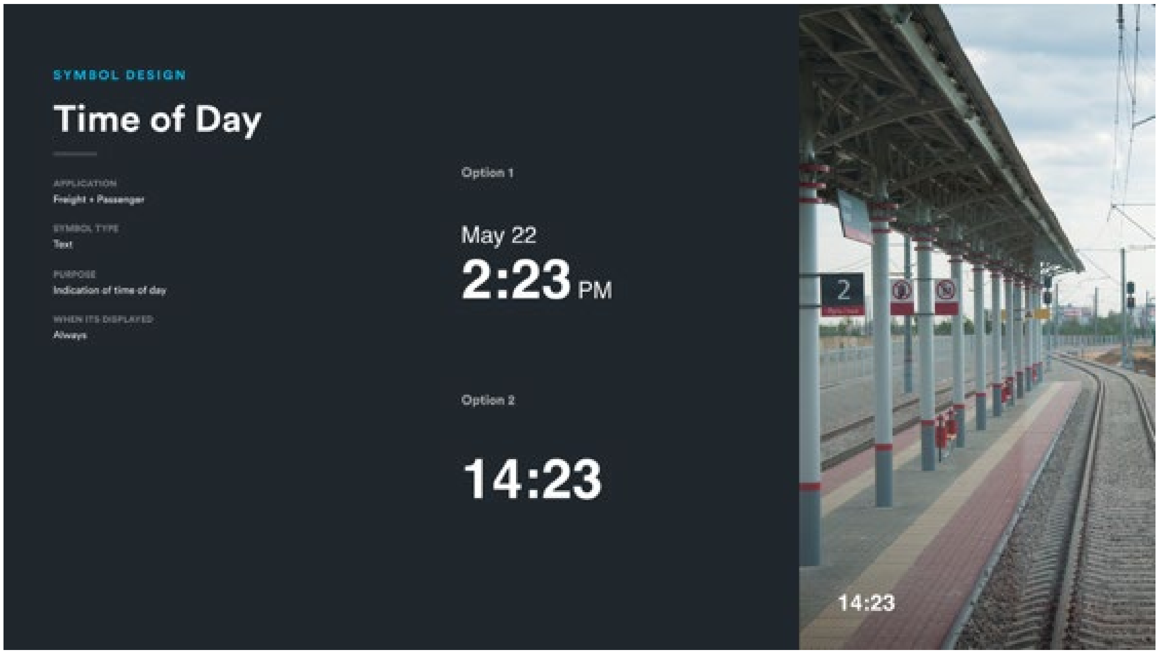


Figure 52: Draft of Time of Day

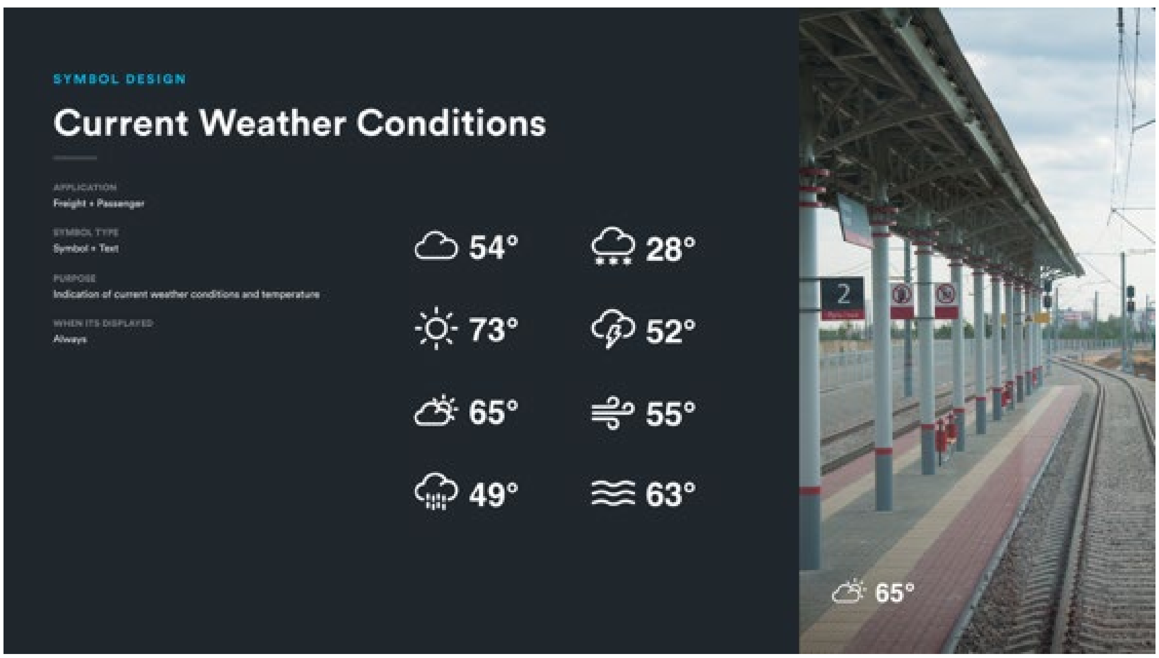


Figure 53: Draft of Current Weather Conditions

3.4 Software

It was not necessary to create any software for integration into the prototype HUD hardware. When the symbols are finalized, a PNG format will be used for each symbol to be integrated into the simulator (CTIL) at Volpe. The symbols meet all design specifications established previously.

4. Task 4 Symbology Library Design Feedback from Rail Industry

4.1 Background

For a HUD to be effective, a library of symbols must be created that are quickly recognizable and acceptable to current locomotive engineers in a HUD environment. In Task 4 of this research project, the team used the preliminary library of symbols built in Task 3 and created surveys to solicit feedback on each symbol's clarity, efficacy, and urgency. Subject matter experts providing feedback included passenger and freight locomotive engineers, locomotive conductors, rail manufacturers, rail industry managers, and researchers involved in the rail industry.

In Task 3, the research team developed designs for the most relevant icons for HUD application in both passenger and freight rail operations. These lists include symbols that are featured on main displays across rail carriers and symbols that have been used in previous HUD studies in rail and other transportation industries (e.g., the aviation and automotive fields). In Task 4, the team sought feedback from relevant stakeholders (i.e., FRA personnel, stakeholders from both freight and passenger operations, and applicable technology manufacturers) to identify preferred symbology and make edits to the designs of the icons developed in Task 3.

Two surveys were developed to collect feedback from individuals. The first was a demographic survey that captured the individual's current and past professional experience, years in each position, and years in the rail industry. There was a particular focus on understanding whether the individual was a current locomotive engineer or has ever worked as a locomotive engineer in the past, as these individuals would have pertinent operating experience.

The second survey included the library of symbols and asked questions regarding the frequency of use, perceived meaning, criticality, and overall effectiveness of the symbols. Icons that had multiple options were presented side-by-side, and the survey requested that experts report their preferences and the potential strengths and weaknesses of each example. The team also asked questions regarding the symbols' aesthetic properties, such as whether the colors, font, and size of the elements were appropriate.

The surveys were emailed to relevant stakeholders and filled out independently. The team offered $100 Visa gift cards upon survey completion to maximize the amount of feedback received and recognize the respondents' contribution of their time and expertise to the project. The surveys included the symbol name but no further explanation or notes regarding the intended use. In total, the team received 28 survey responses. Five of the responses came from individuals with experience as freight engineers, 12 came from individuals with experience as passenger engineers, 7 came from engineers with experience in both freight and passenger operations, and the remaining 4 were from people involved in locomotive research and manufacturing. Additionally, four of the previously mentioned locomotive engineers are currently in rail leadership and management positions. Several respondents had previously been conductors, brake foremen, and other relevant operational positions in rail. The average years of work experience in the rail industry was 17.08 years for all respondents, 21.4 years for freight engineers, and 12.33 years for passenger engineers.

The team used the feedback provided in the surveys to make necessary revisions to the symbology library, including removing some non-critical and ineffective symbols identified by subject matter experts and adding new symbols that were overlooked in Task 3. These changes were made prior to moving onto Task 5.

4.2 Symbols Ranked for Criticality Based on Stakeholder Feedback

Based on the survey results, Table 12 below shows the proposed freight and passenger symbols for the HUD application ranked in order of criticality. These categorizations may determine which symbols are always necessary to show on the HUD and which might only need to appear as essential or as preferred by the engineer in subsequent tasks.

To evaluate the criticality that survey respondents assigned to each symbol, researchers looked at three different subsets of data: freight locomotive engineers (n = 5), passenger locomotive engineers (n = 12), and all survey respondents (n = 28). To assign quantitative values to the freeform response question, "How critical is the information provided by this symbol to the operation of the train?" researchers interpreted responses to be "Most Critical," "Medium Critical," or "Non-critical," assigning 3, 2, or 1 point respectively. Responses were averaged within the three subset groups to create a table that ranked each symbol by criticality.

Table 12: Symbols ranked for criticality based on stakeholder feedback

Rank	All Responses	All Responses Score	Freight	Freight Score	Passenger	Passenger Score
1	Speed Indicator	3	Speed Indicator	3	Current Train Location/Signals	3
2	Current Train Location/Signals	2.92	Main Reservoir	3	Speed Indicator	3
3	Cab Signal	2.92	Rear	3	Stop	3
4	Fault Message/Error Message	2.92	Flow	3	Approach	3
5	Upcoming Temporary Speed Restriction	2.888888889	Cab Signal	3	Upcoming Temporary Speed Restriction	2.916666667
6	Stop	2.888888889	Fault Message/Error Message	2.8	Resume	2.916666667
7	Approach	2.826086957	Brake Pipe Pressure	2.75	Fault Message/Error Message	2.916666667
8	Main Reservoir	2.708333333	Current Train Location/Signals	2.6	Cab Signal	2.818181818
9	Brake Pipe Pressure	2.68	Upcoming Temporary Speed Restriction	2.6	Equalizing Reservoir	2.666666667
10	Equalizing Reservoir	2.653846154	Equalizing Reservoir	2.6	Main Reservoir	2.666666667
11	Resume	2.62962963	Effort	2.6	Brake Pipe Pressure	2.5
12	Rear	2.3	Stop	2.4	Headlight/Auxiliary Light Position	2.166666667
13	Delay in Block	2.230769231	Distance Counter	2	Time of Day	2.083333333
14	Effort	2.153846154	Throttle	2	Effort	2
15	Flow	2.111111111	Approach	2	Rear	2
16	Critical Curve Ahead	1.958333333	Resume	1.8	Delay in Block	2
17	Headlight/Auxiliary Light Position	1.925925926	Headlight/Auxiliary Light Position	1.8	Critical Curve Ahead	1.909090909
18	Time of Day	1.846153846	Stopping Distance	1.8	Grade	1.8
19	Grade	1.75	Time of Day	1.8	Radio Communication Notification	1.727272727
20	Throttle	1.730769231	Delay in Block	1.8	Throttle	1.666666667

Rank	All Responses	All Responses Score	Freight	Freight Score	Passenger	Passenger Score
21	Distance Counter	1.68	Radio Communication Notification	1.75	Bell	1.583333333
22	Stopping Distance	1.590909091	Condition Brakes	1.5	Flow	1.5
23	Radio Communication Notification	1.541666667	Critical Curve Ahead	1.5	Upcoming Station	1.416666667
24	Bell	1.518518519	Bell	1.4	Distance Counter	1.333333333
25	Upcoming Station	1.48	Upcoming Station	1.25	Condition Brakes	1.181818182
26	Condition Brakes	1.25	Grade	1.2	Quiet Zone	1.166666667
27	Quiet Zone	1.230769231	Current Weather Conditions	1.2	Stopping Distance	1.1
28	Current Weather Conditions	1.153846154	Quiet Zone	1	Current Weather Conditions	1

4.3 Feedback Summarized by Symbol

Below are summaries of the survey feedback for each symbol. Each summary image includes symbol preference (if the symbol had more than one design), criticality by all respondents and stratified by engineer type, and suggested changes to the symbol for Task 5. Summary notes included respondent suggestions and comments, whether there was a notable difference between how passenger and freight engineers interpreted the symbols, and whether respondents always wanted the symbol to appear on the HUD. The graphs show symbol clarity and criticality among all respondents and then stratify responses into grouped bar charts by engineer type (non-engineers are not included).

For a final "overall criticality" ranking of "Most Critical," "Medium Critical," or "Non-Critical," the rankings (1st-28th) for each of the three data sets (passenger, freight, and all) were averaged to evenly weigh passenger and freight feedback. Most Critical is assigned for an average rank of 1-9, Medium Critical is assigned for an average rank of 10-19, and Non-Critical is assigned for an average rank of 20-28. These rankings can be found in the top right of the summary for each symbol.

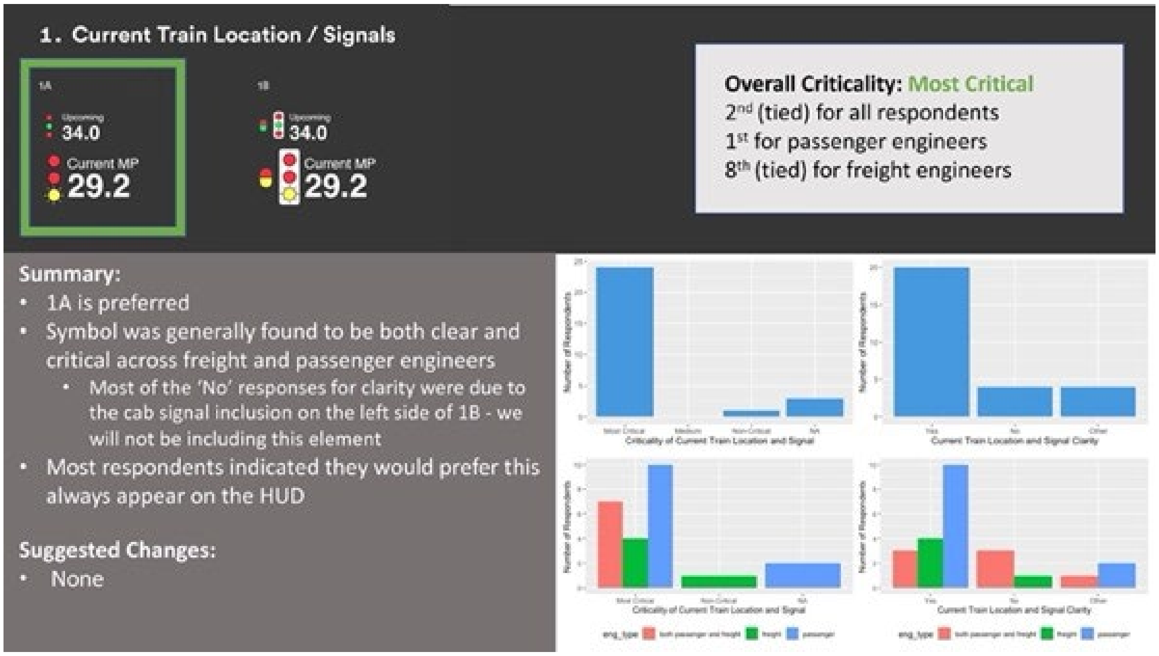


Figure 54: Stakeholder feedback on Current Train Location/Signals

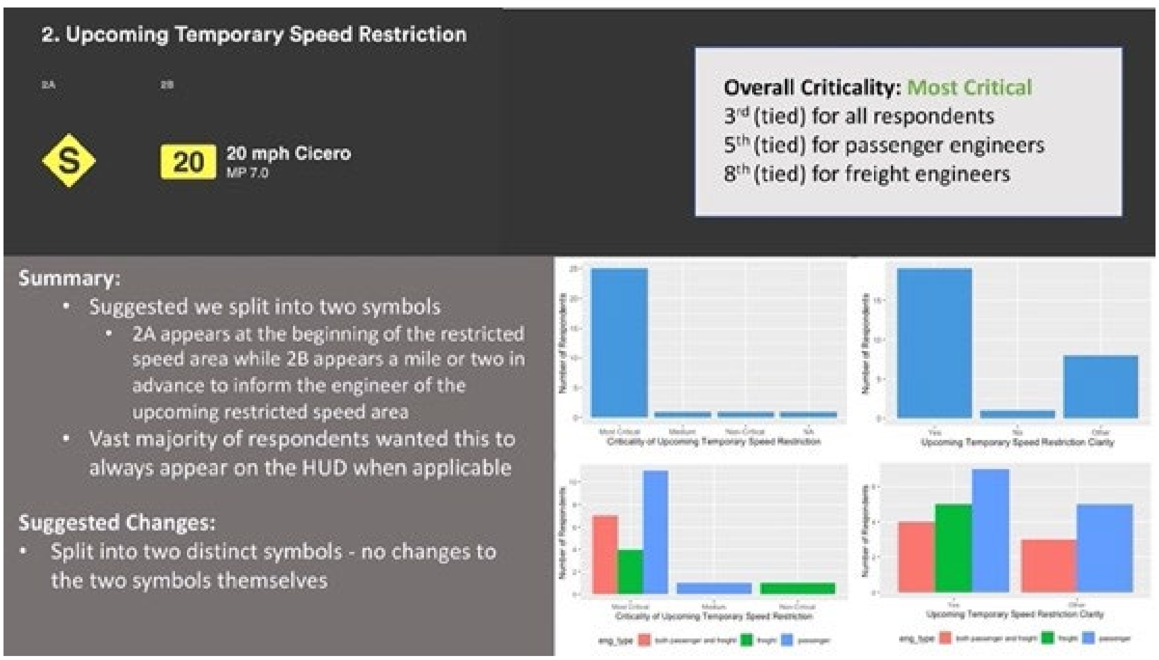


Figure 55: Stakeholder feedback on Upcoming Temporary Speed Restriction

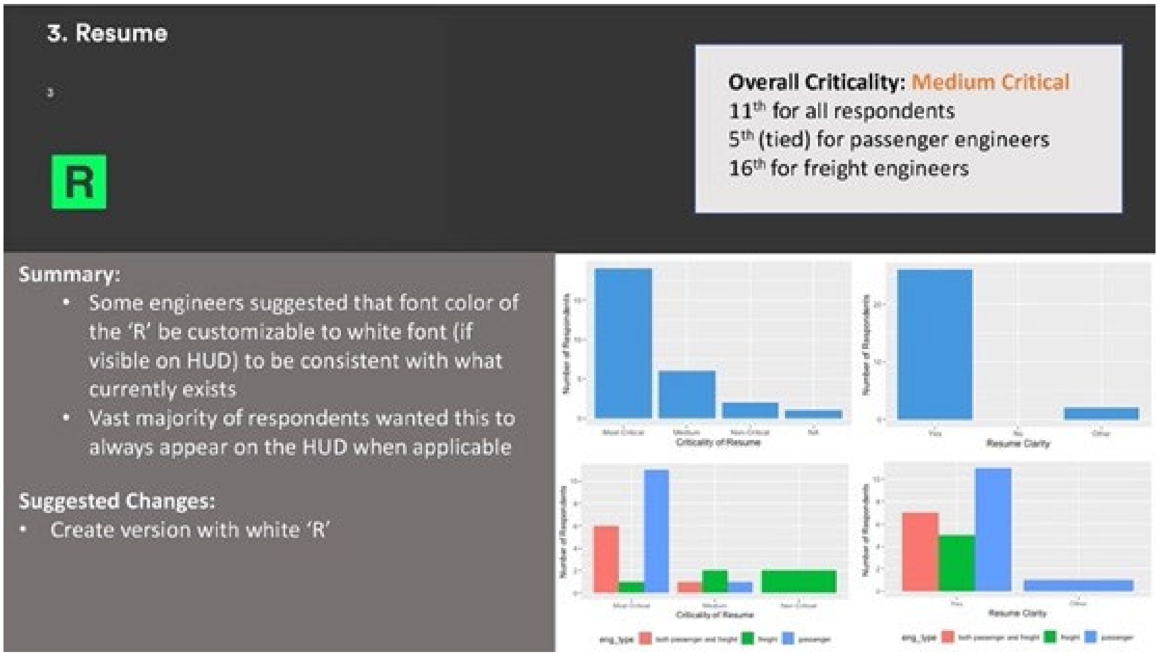


Figure 56: Stakeholder feedback on Resume

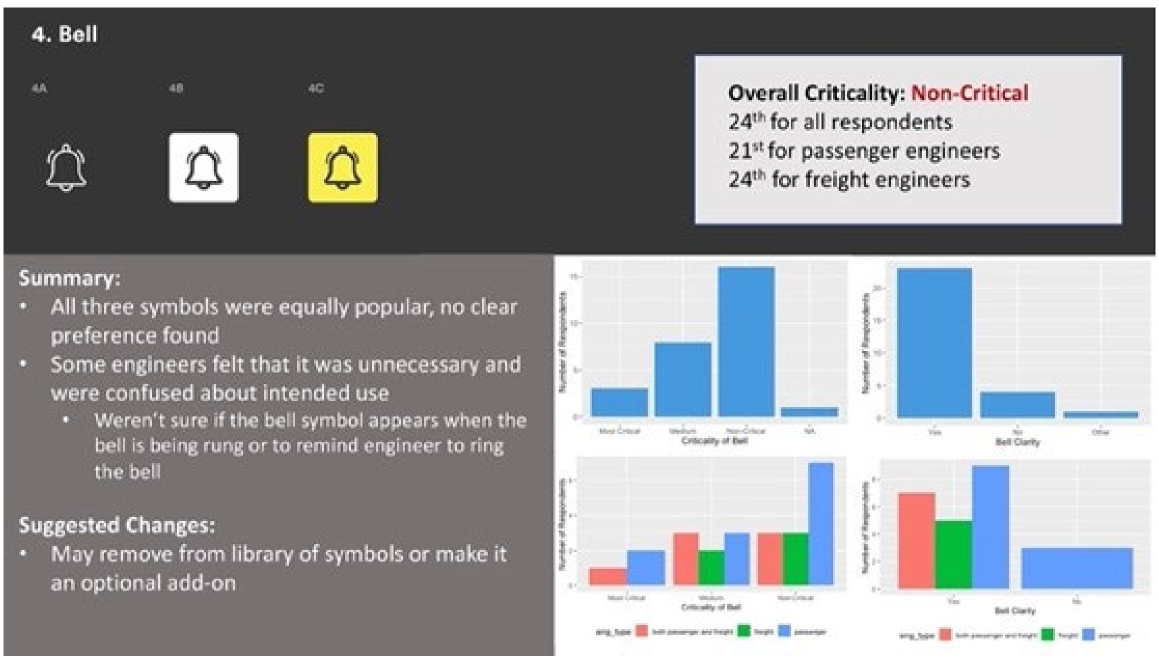


Figure 57: Stakeholder feedback on Bell

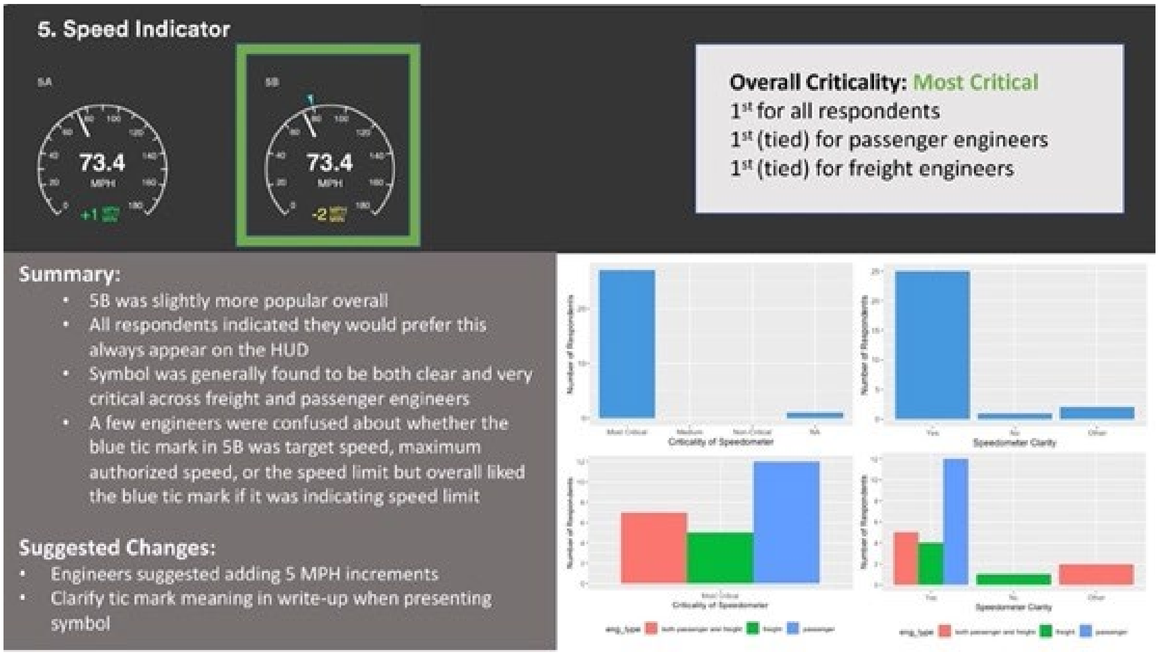


Figure 58: Stakeholder feedback on Speed Indicator

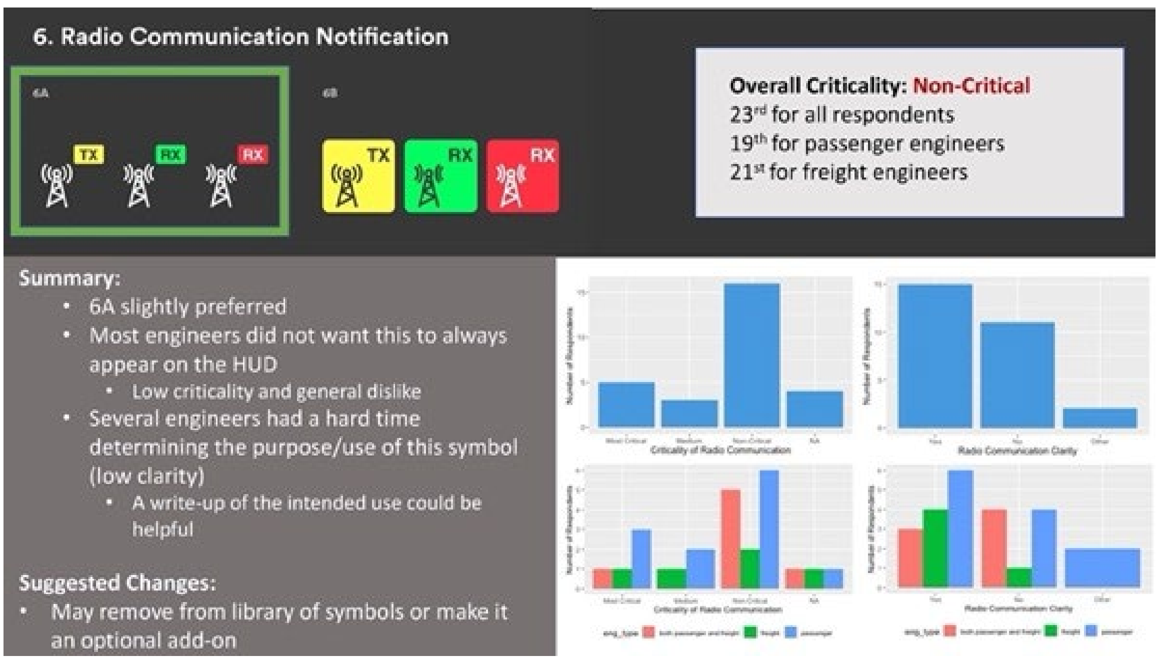


Figure 59: Stakeholder feedback on Radio Communication Notification

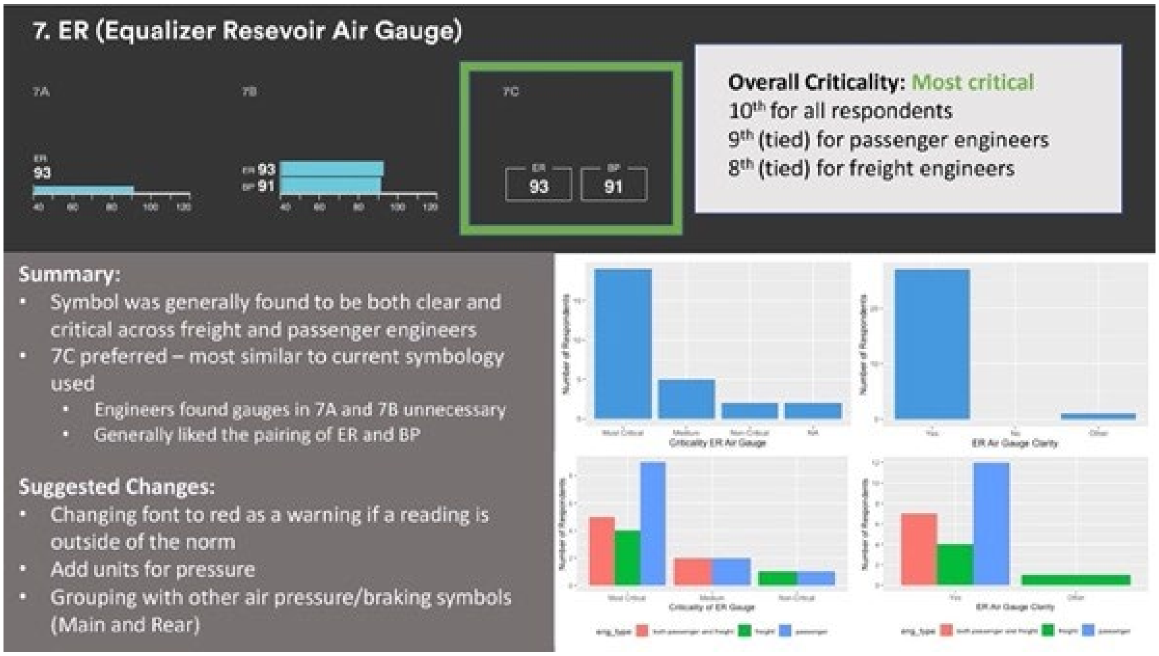


Figure 60: Stakeholder feedback on ER Air Gauge

Figure 61: Stakeholder feedback on Upcoming Station

Figure 62: Stakeholder feedback on Distance Counter

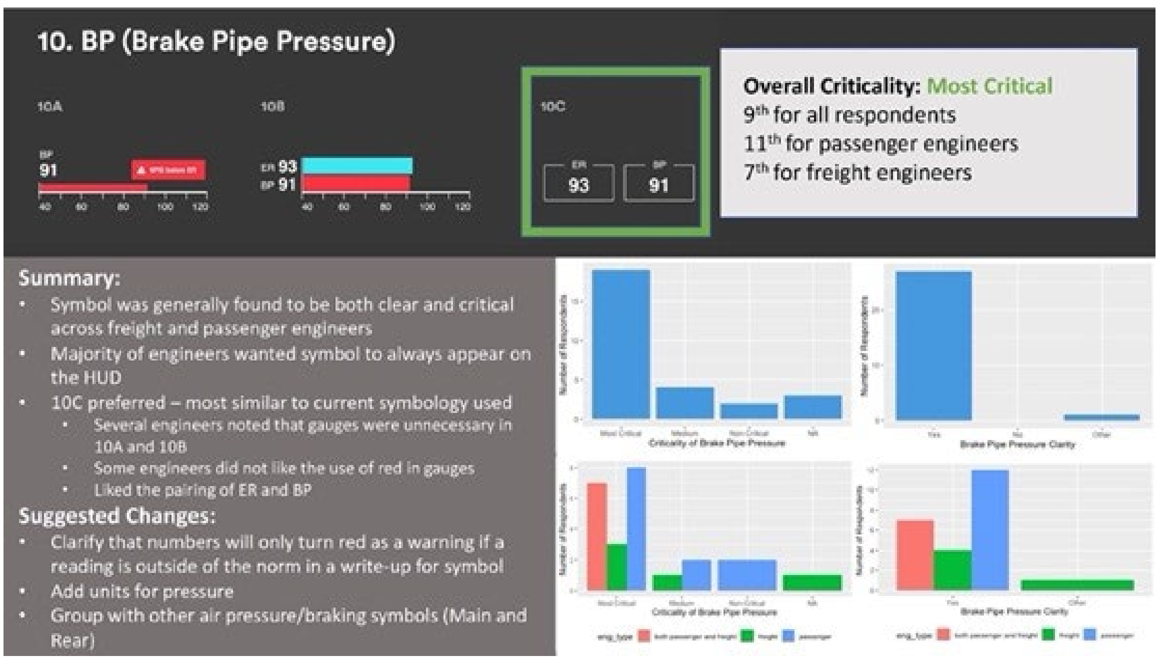


Figure 63: Stakeholder feedback on BP Pressure

Figure 64: Stakeholder feedback on Effort

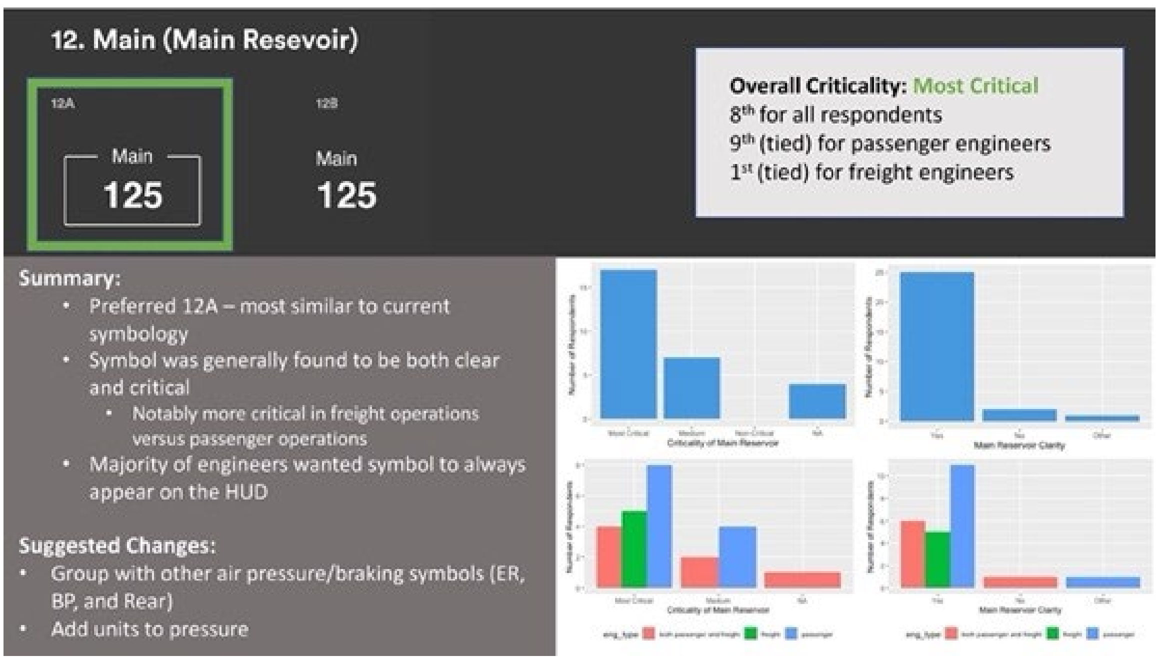


Figure 65: Stakeholder feedback on Main Reservoir

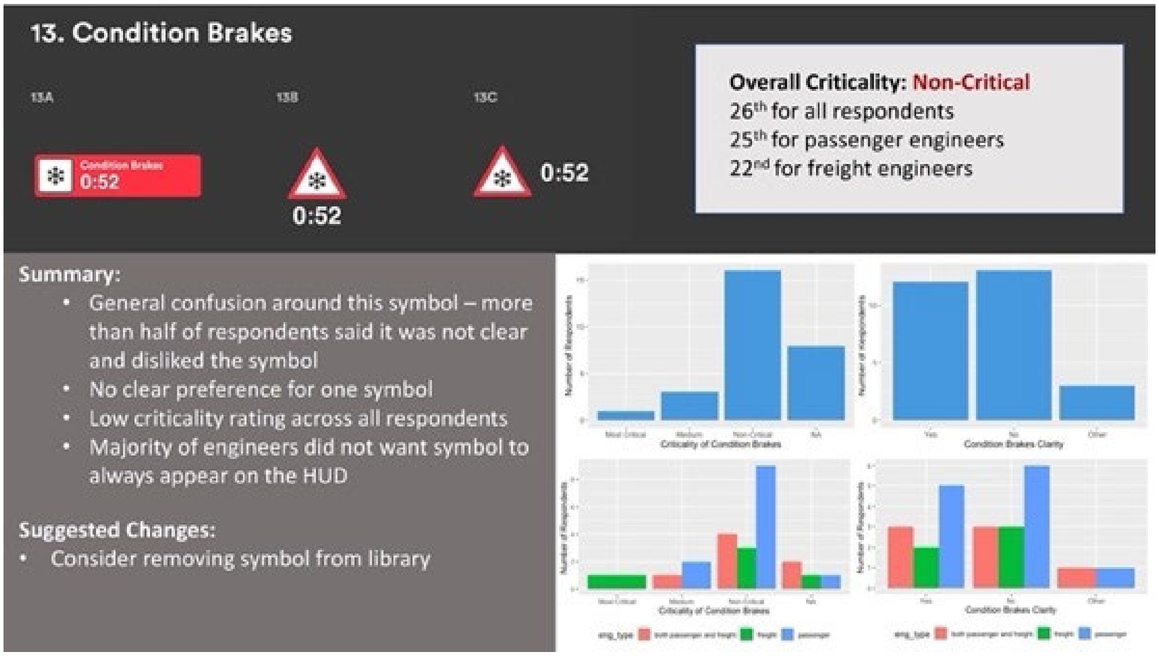


Figure 66: Stakeholder feedback on Condition Brakes

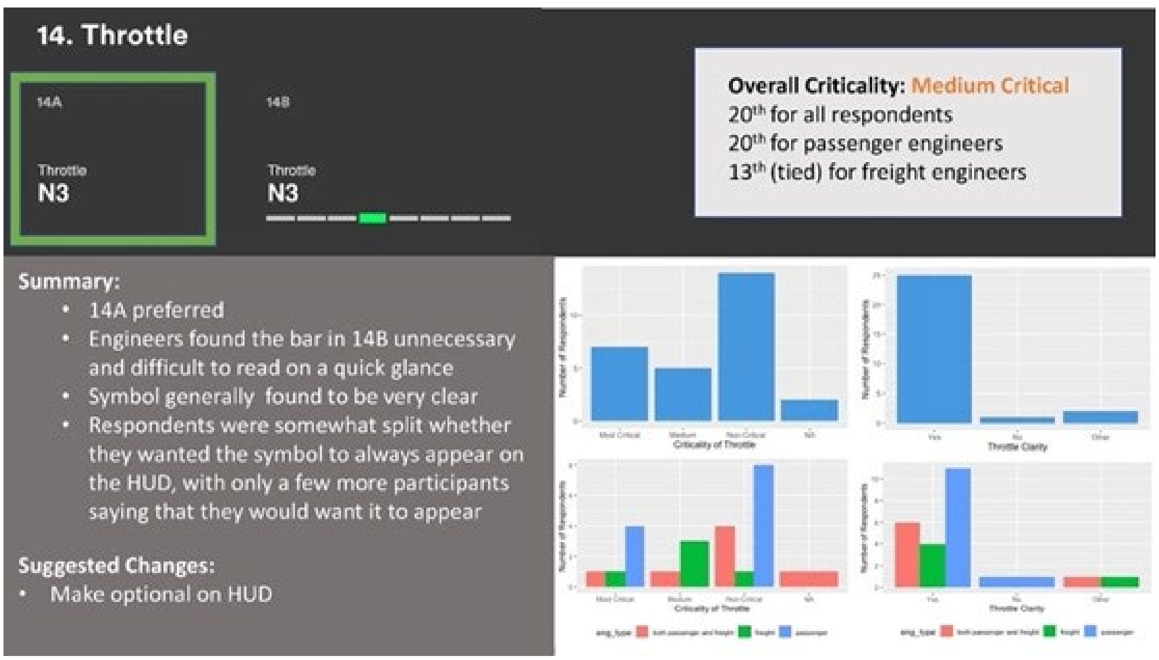


Figure 67: Stakeholder feedback on Throttle

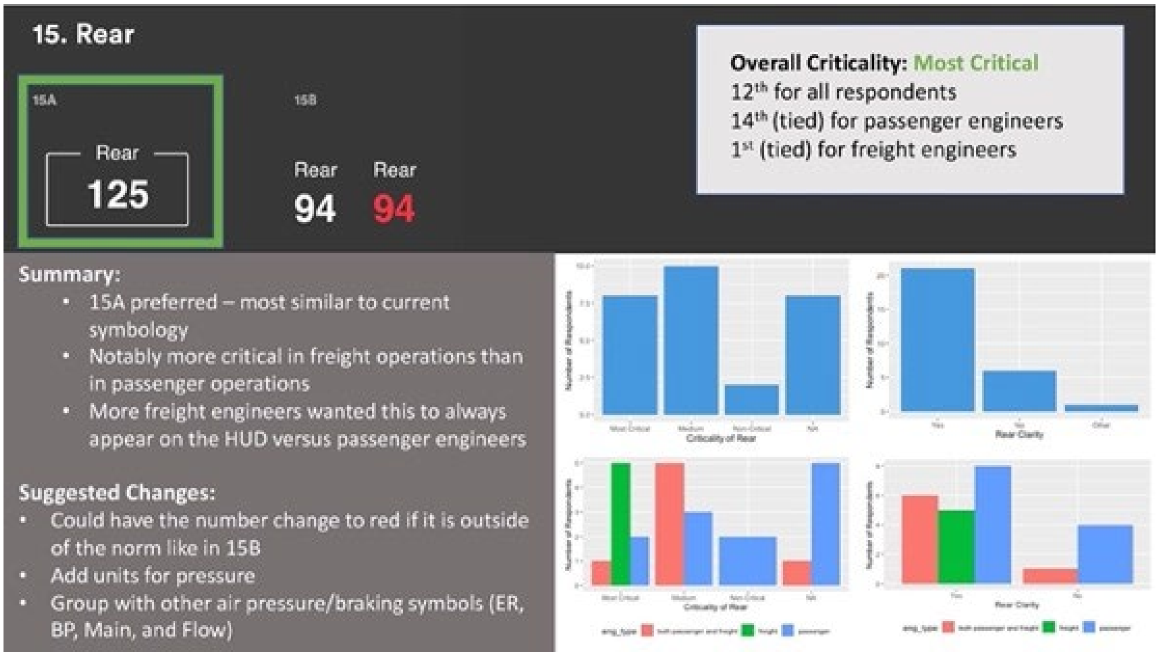


Figure 68: Stakeholder feedback on Rear

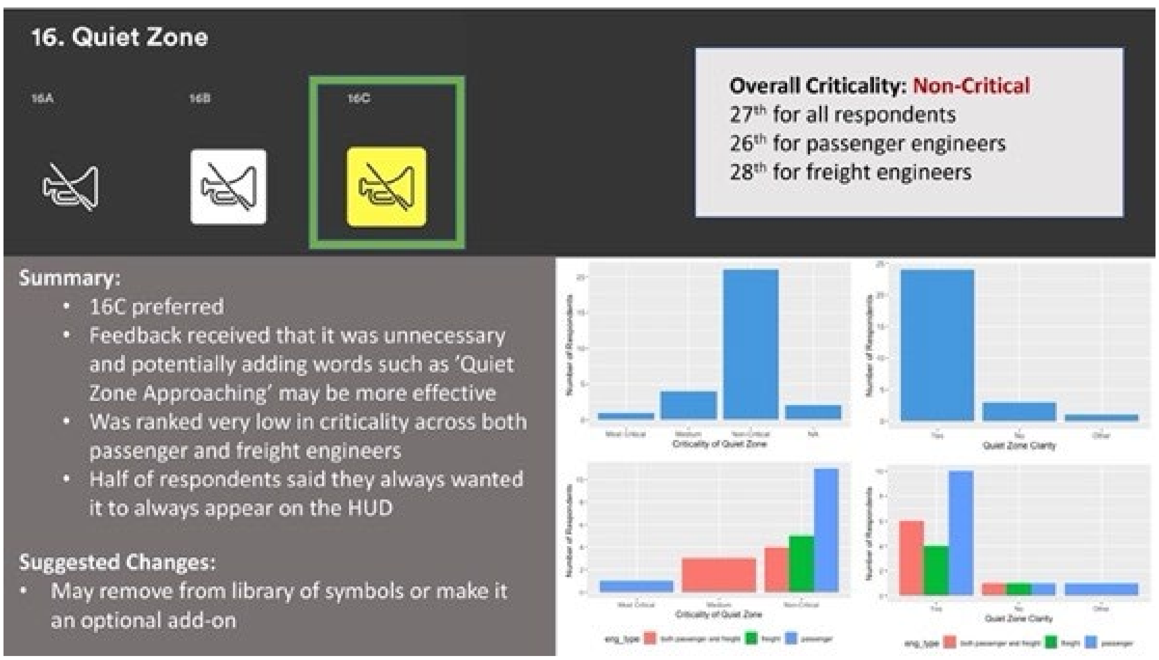


Figure 69: Stakeholder feedback on Quiet Zone

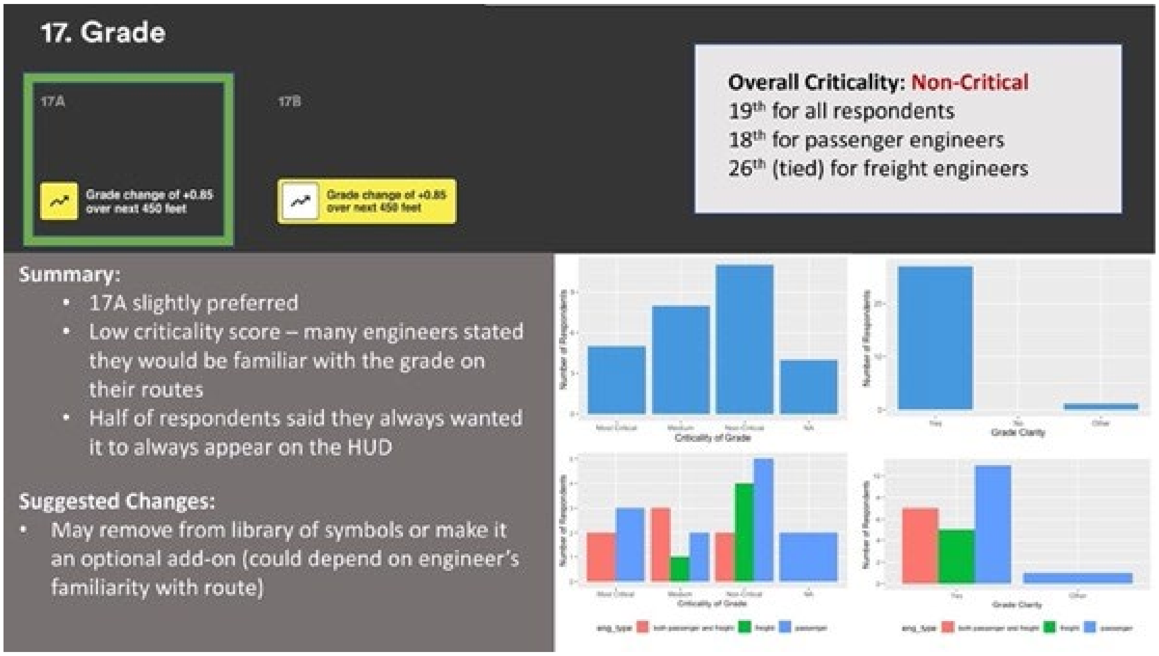


Figure 70: Stakeholder feedback on Grade

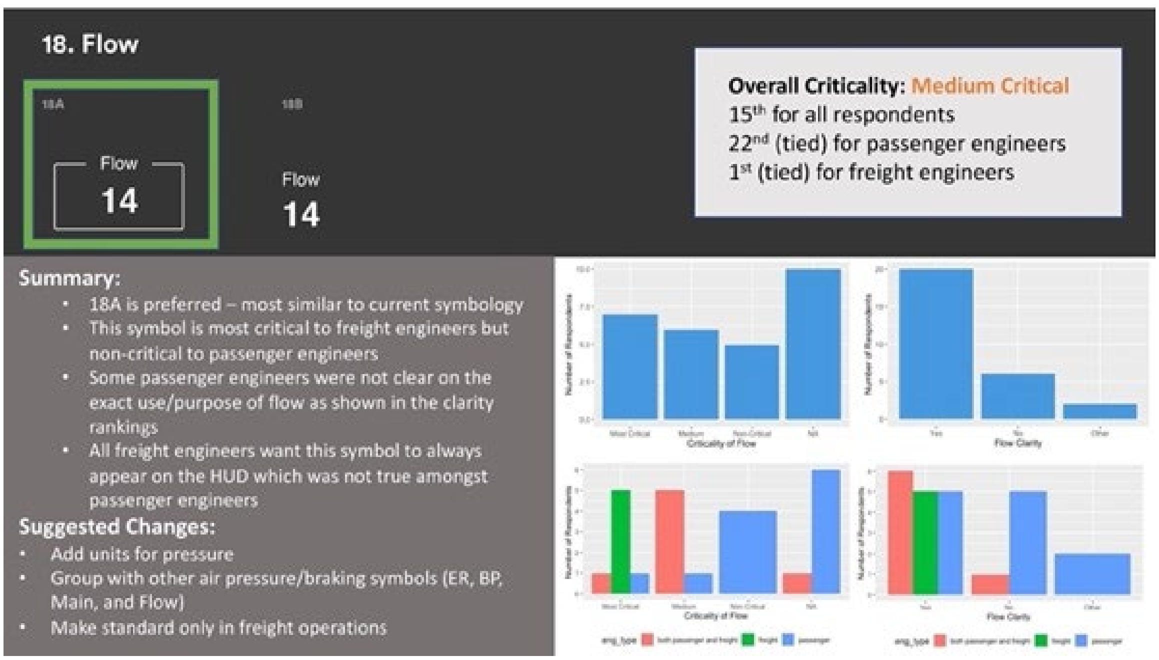


Figure 71: Stakeholder feedback on Flow

Figure 72: Stakeholder feedback on Headlight/Auxiliary Light Position

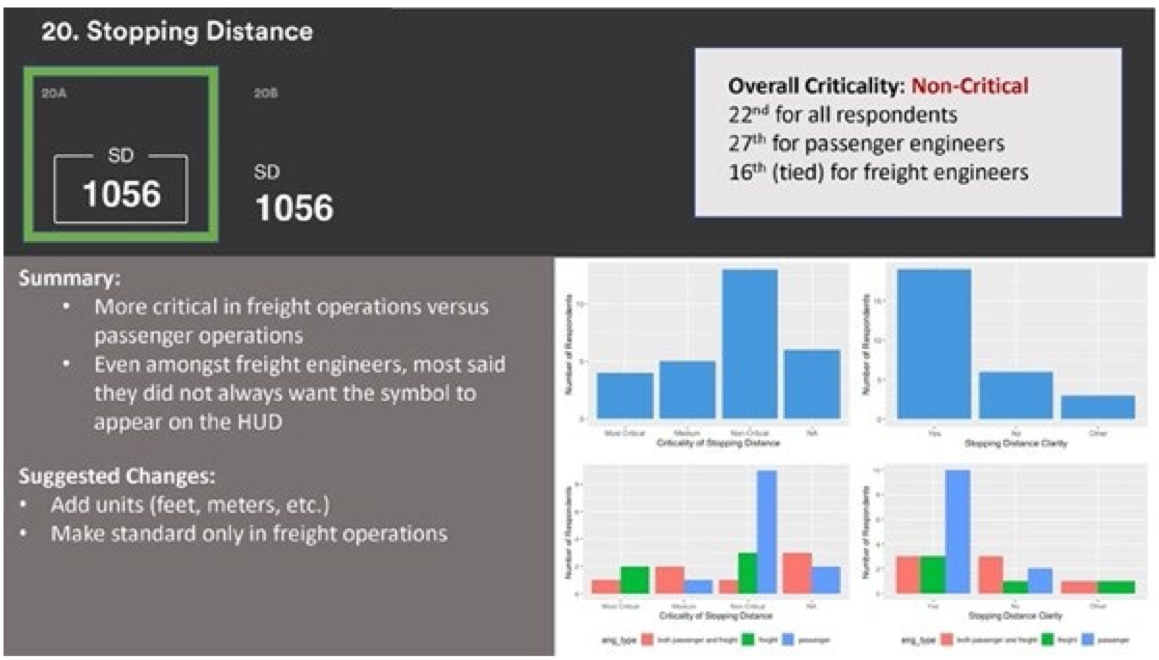


Figure 73: Stakeholder feedback on Stopping Distance

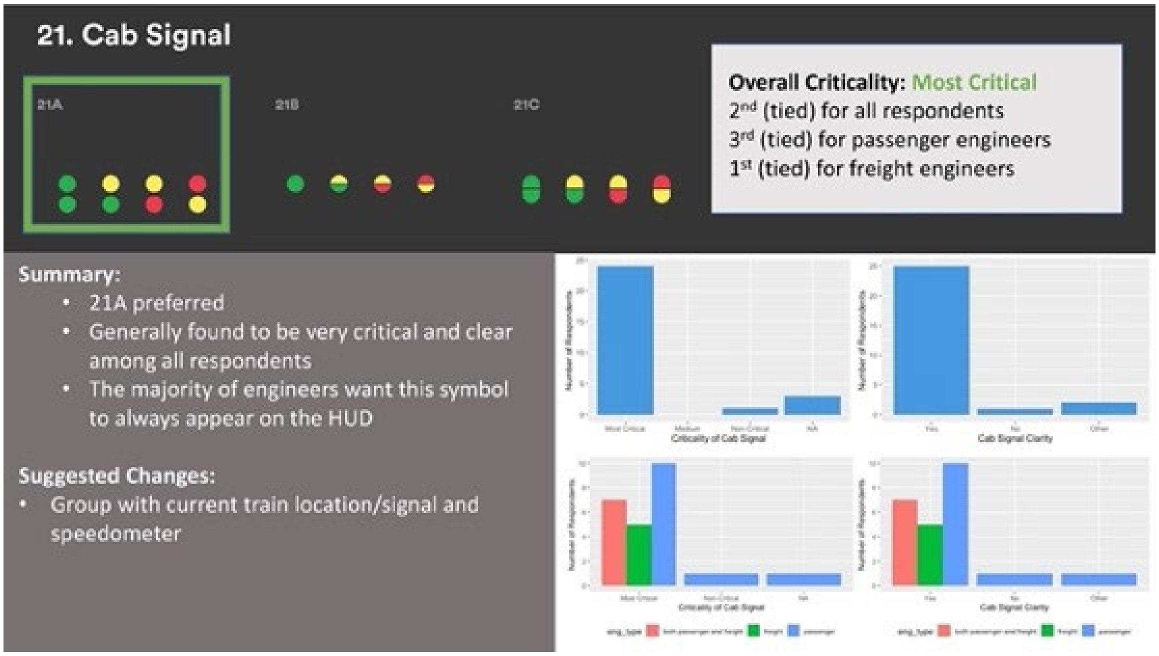


Figure 74: Stakeholder feedback on Cab Signal

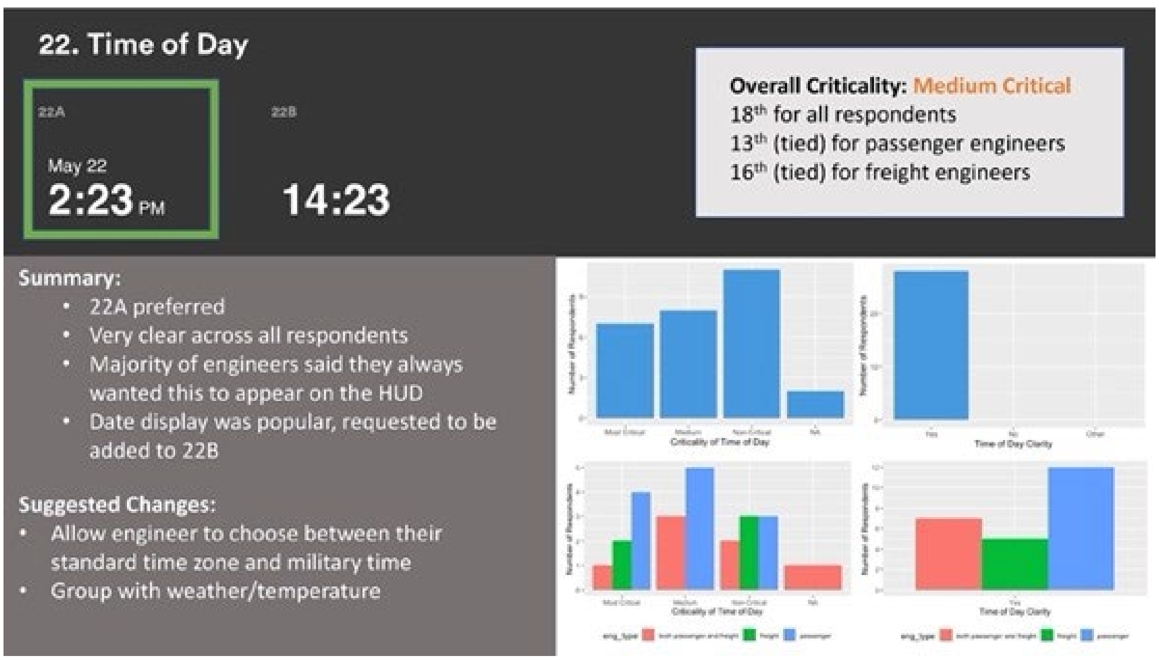


Figure 75: Stakeholder feedback on Time of Day

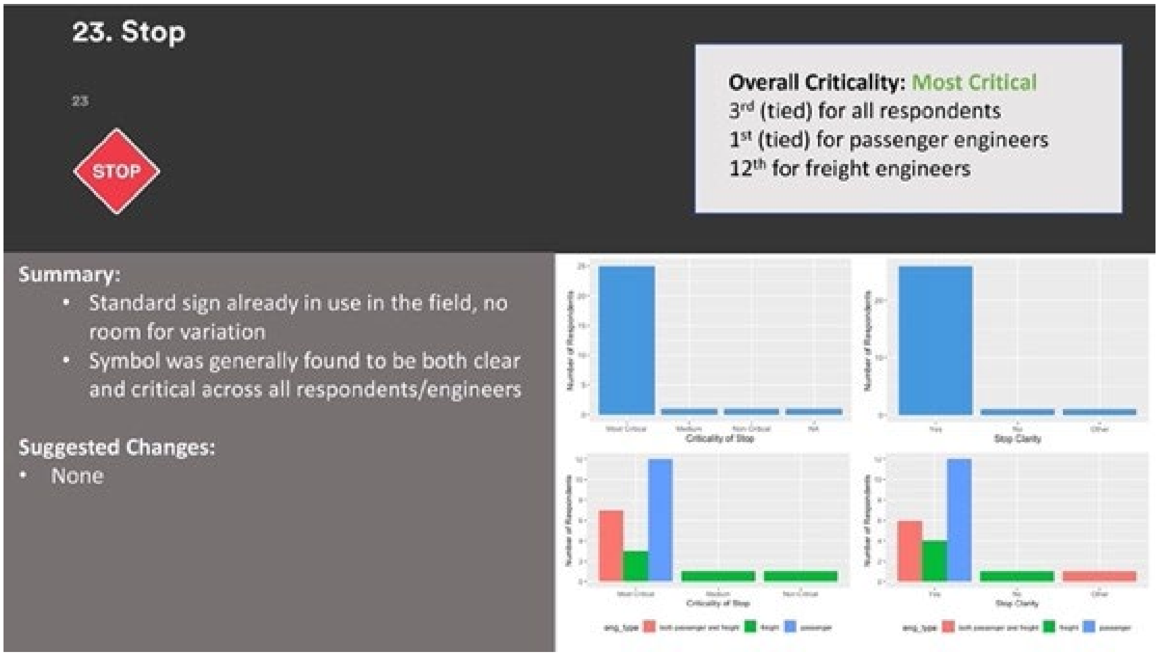


Figure 76: Stakeholder feedback on Stop

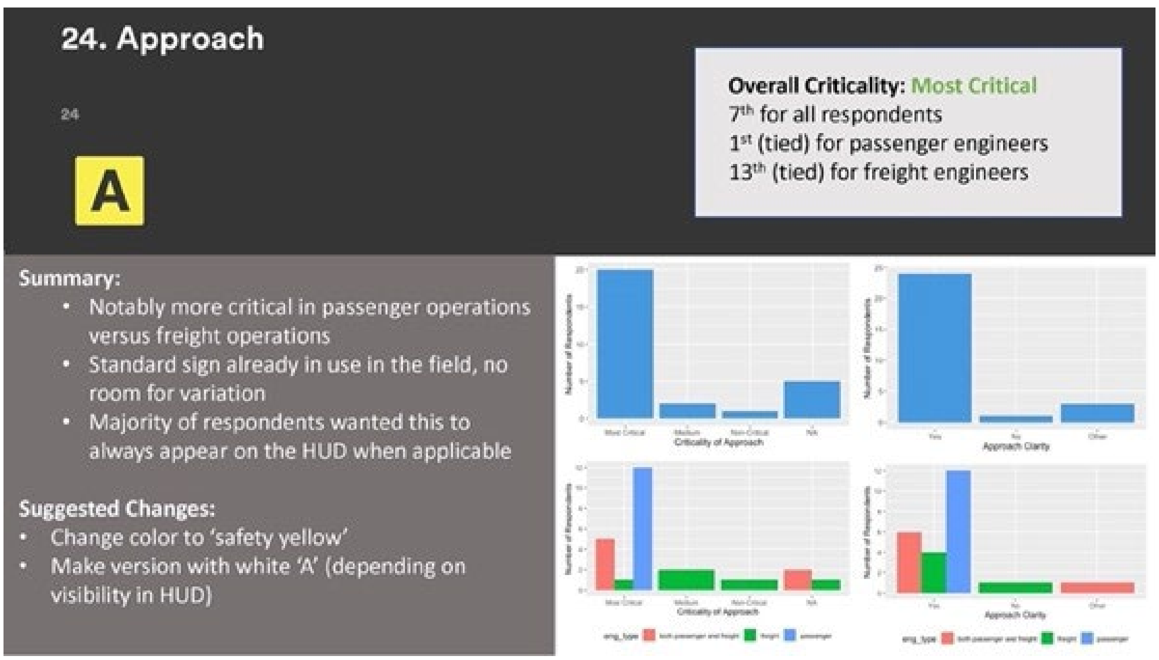


Figure 77: Stakeholder feedback on Approach

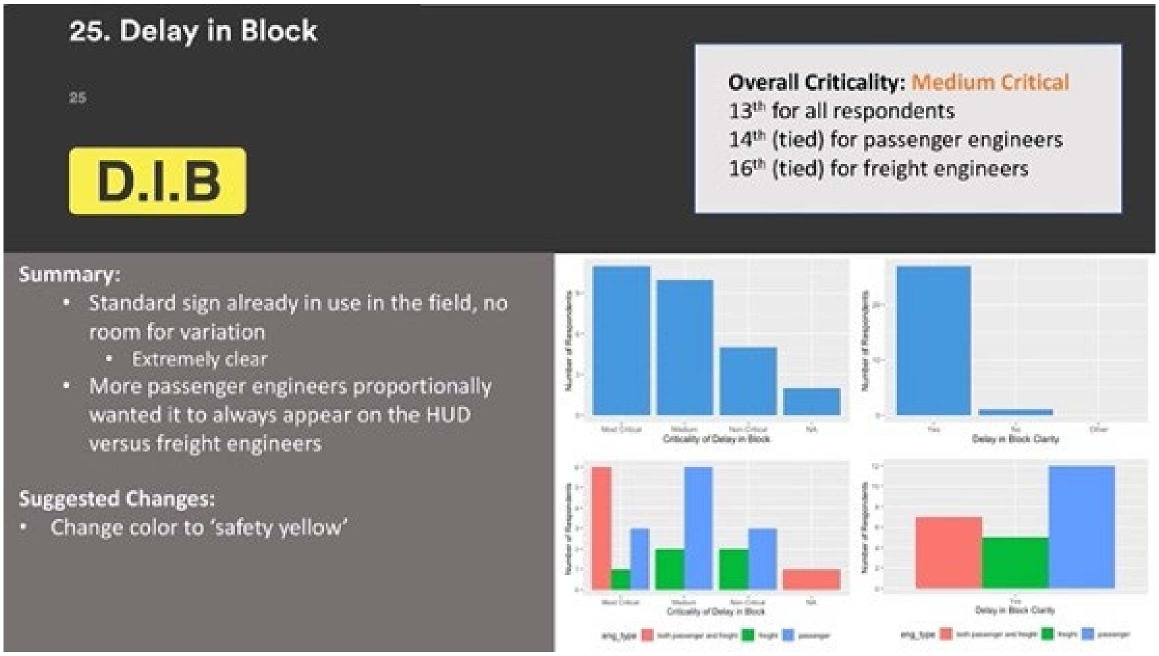


Figure 78: Stakeholder feedback on Delay in Block

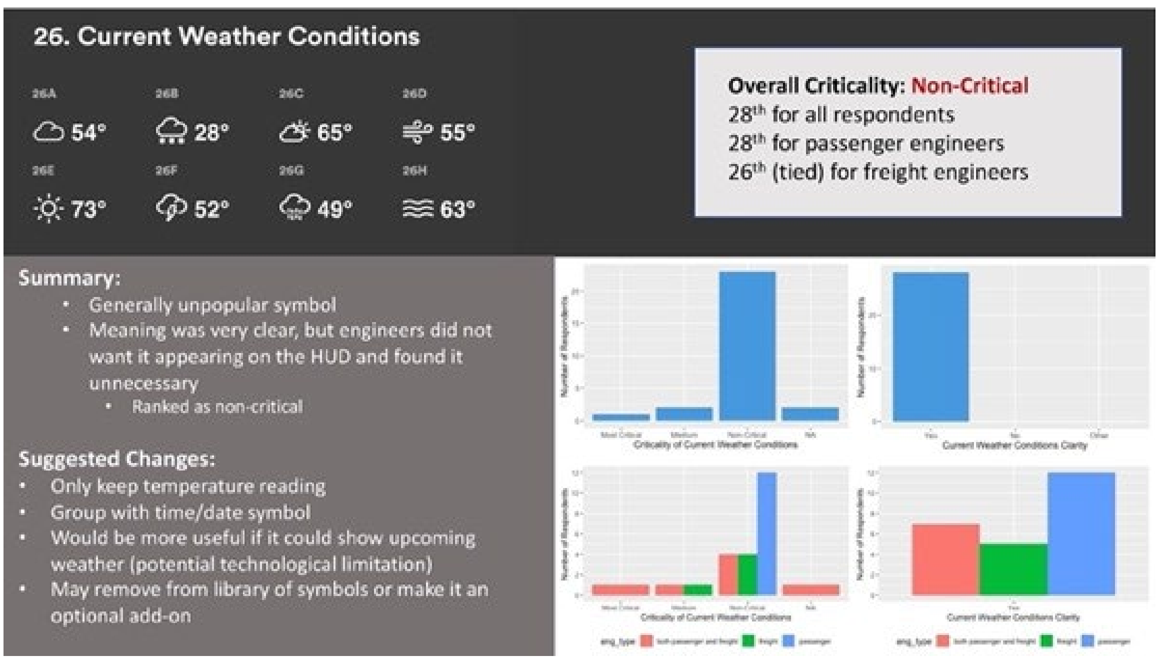


Figure 79: Stakeholder feedback on Current Weather Conditions

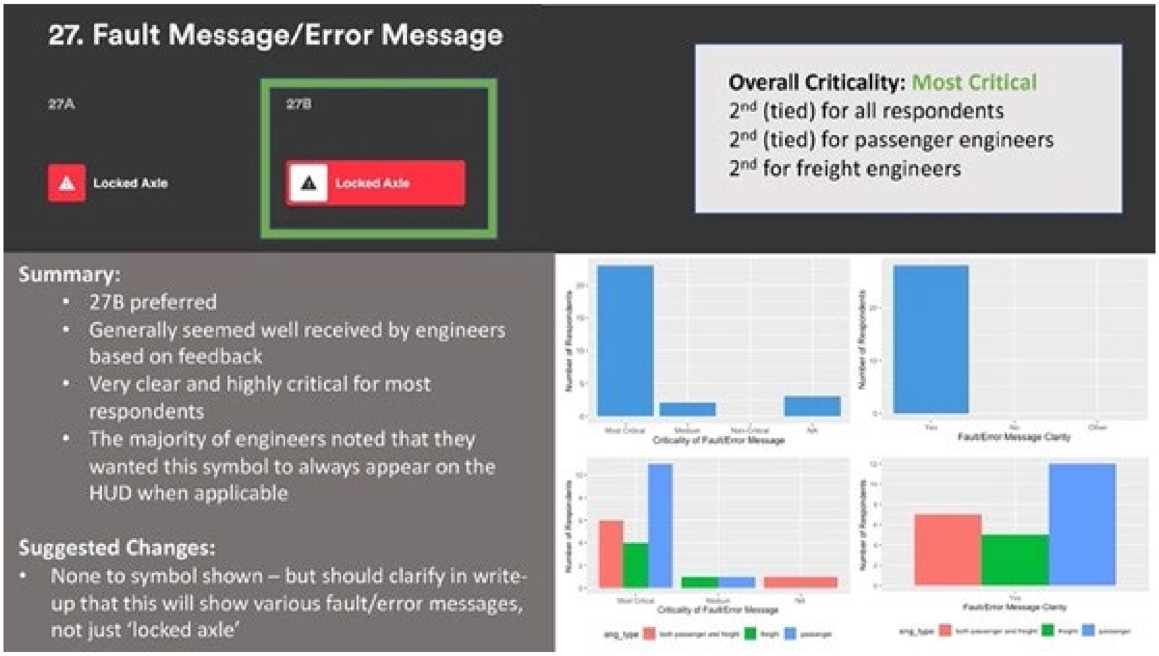


Figure 80: Stakeholder feedback on Fault Message/Error Message

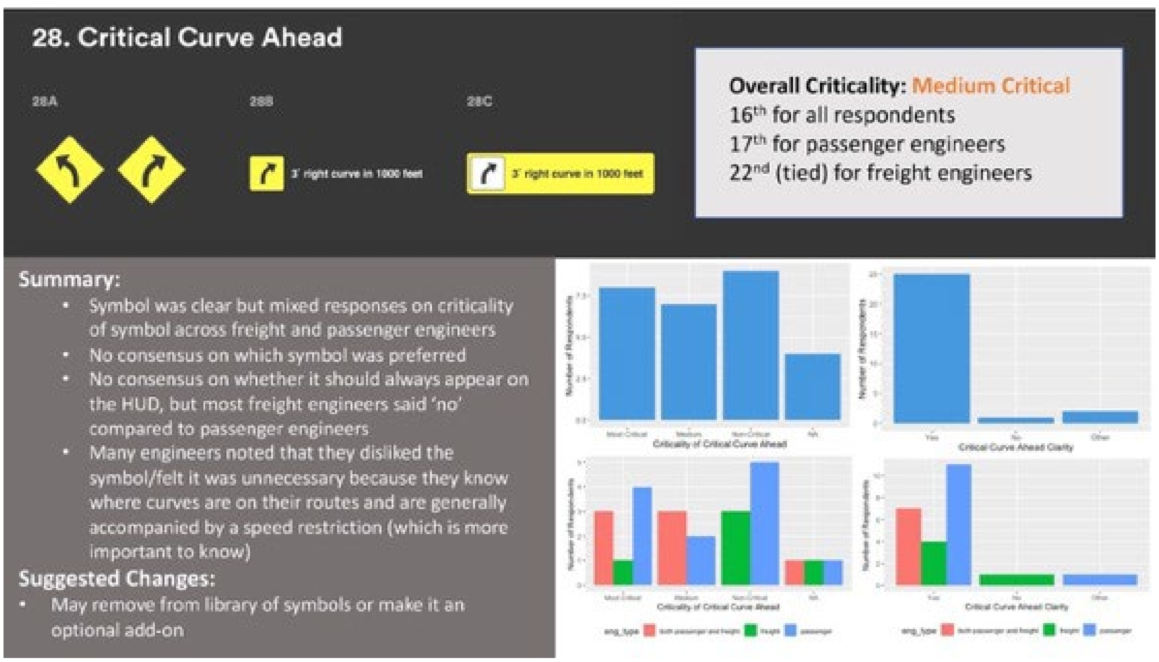


Figure 81: Stakeholder feedback on Critical Curve Ahead

4.4 New Symbols Based on Stakeholder Feedback

In addition to providing feedback on the current set of symbols, survey respondents were asked whether there were any additional symbols they would like to see incorporated into the HUD. Other symbols offered were icons related to dynamic braking and wheel slip. A few respondents suggested producing symbols, like symbol 2B in Figure 55 above, that would alert an engineer to the location (MP) of an upcoming sign such as stop, approach, resume, or D.I.B. The research team will consult with at least one passenger engineer and one freight engineer to determine how best to design and add these to the current library subsets.

4.5 Limitations of Surveys

One of the limitations of the survey was the wording of the question, “Would you prefer this symbol always appear on the windscreen when using a Head-Up Display (HUD)?” The question had a binary yes/no answer selected through a dropdown menu. As the research team began analyzing survey results, it became clear that respondents had interpreted the question differently, with some answering the question, “Should it *always* appear?” and some answering the question, “Should it be included on the HUD?” Additionally, researchers suspect that some people forgot to change the answer in the dropdown menu when providing feedback for each symbol. The default answer to the question appeared as "Yes." Due to this inconsistency, the answers to that question were not weighted as heavily as other questions and only investigated further if a large majority answered yes or no or if the answer was inconsistent with responses regarding the symbol's clarity or criticality.

Another limitation was that more passenger engineers (12) than freight engineers (5) provided survey feedback. While seven engineers with both passenger and freight experience participated, it was not apparent whether they considered the symbols’ criticality and intended use from a passenger or freight operations perspective.

A third limitation was that the team chose not to provide explanations of the symbols or details on their intended use on the surveys. Researchers only included the symbol name to measure the clarity and effectiveness of the symbol without providing background information or priming the respondent. However, some elements appeared to be confusing to participants on some of the novel symbols (6, 13, and 19) and even known symbols (5). If explanations for symbols and their specific elements were provided, the team believes some symbols might have been more positively received by respondents.

4.6 Supplemental Information

4.6.1 Demographic Survey

Note: The dropdown response options for Question 1a are “Passenger,” “Freight,” or “Both.” The dropdown options for Question 5 are “Yes” or “No.”

Demographic Questionnaire

1. What is your current position?

   a. If you are an engineer, you have experience operating:

      Passenger

      i. How many years have you been an engineer?

      ii. Which rail carrier(s) do you have experience operating on?

2. How many years have you been in your current position?

3. How many years have you worked in the rail industry?

4. What positions have you held?

5. If you are in leadership or a mid-level managerial position, have you ever had an operations or craft position earlier in your career?

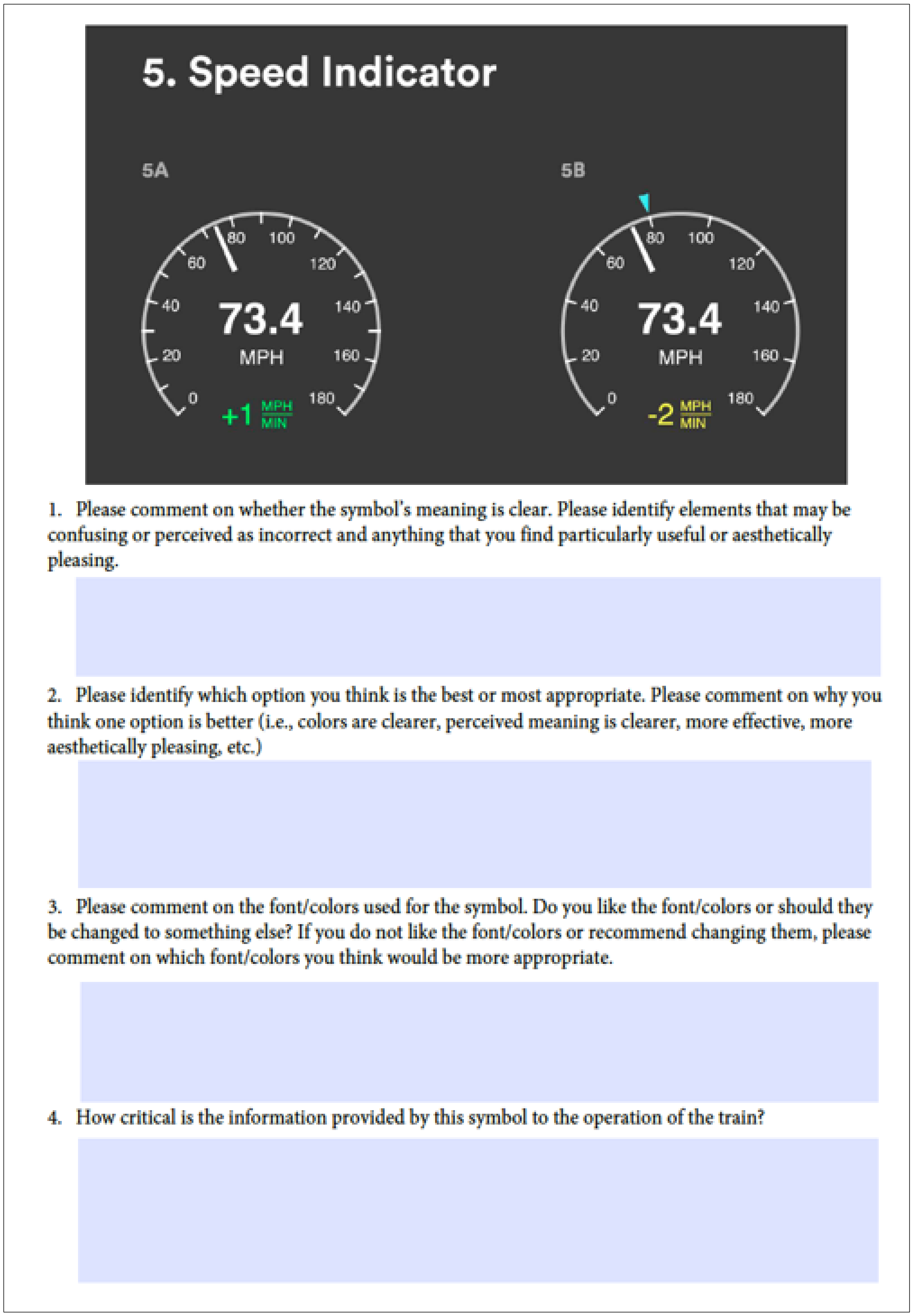
   No

   a. If YES, please identify that position and how long you held that position.

Figure 82: Task 4 Demographic Questionnaire

4.6.2 Symbol Library Survey

Survey respondents were asked the same questions about each symbol, with the only variation occurring for symbols with more than one design option. The questions asked for symbols with two options are shown in the Symbol 5 (Speed Indicator) example below. Questions asked for symbols with just one option are shown in the Symbol 11 (Effort) example below. Note: The dropdown response options for Questions 5 and 4, respectively, are “Yes” or “No.”



5. Speed Indicator

5A

80 100 60 120 40 140 20 160 0 180

73.4

MPH

+1 MPH/MIN

5B

80 100 60 120 40 140 20 160 0 180

73.4

MPH

-2 MPH/MIN

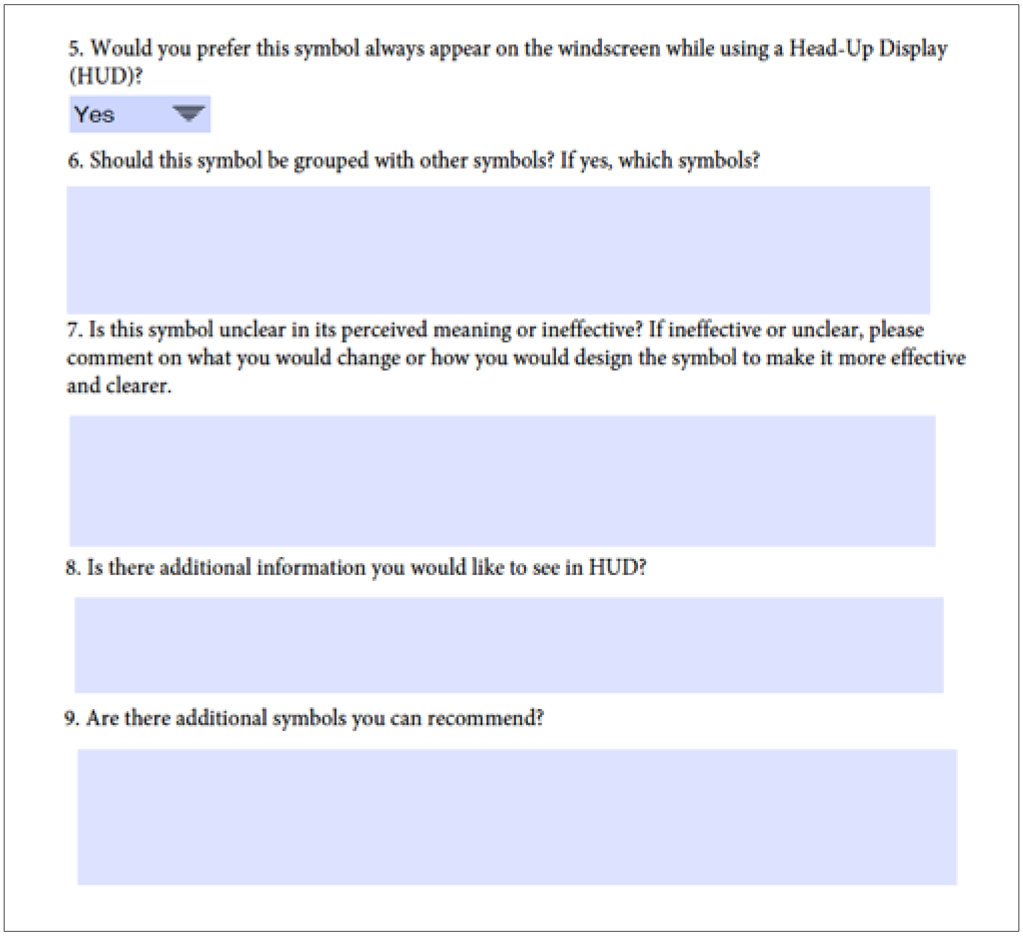
1. Please comment on whether the symbol's meaning is clear. Please identify elements that may be confusing or perceived as incorrect and anything that you find particularly useful or aesthetically pleasing.

2. Please identify which option you think is the best or most appropriate. Please comment on why you think one option is better (i.e., colors are clearer, perceived meaning is clearer, more effective, more aesthetically pleasing, etc.)

3. Please comment on the font/colors used for the symbol. Do you like the font/colors or should they be changed to something else? If you do not like the font/colors or recommend changing them, please comment on which font/colors you think would be more appropriate.

4. How critical is the information provided by this symbol to the operation of the train?

Figure 83: Task 4 Symbol Library Survey for items with two design options



5. Would you prefer this symbol always appear on the windscreen while using a Head-Up Display (HUD)?

Yes

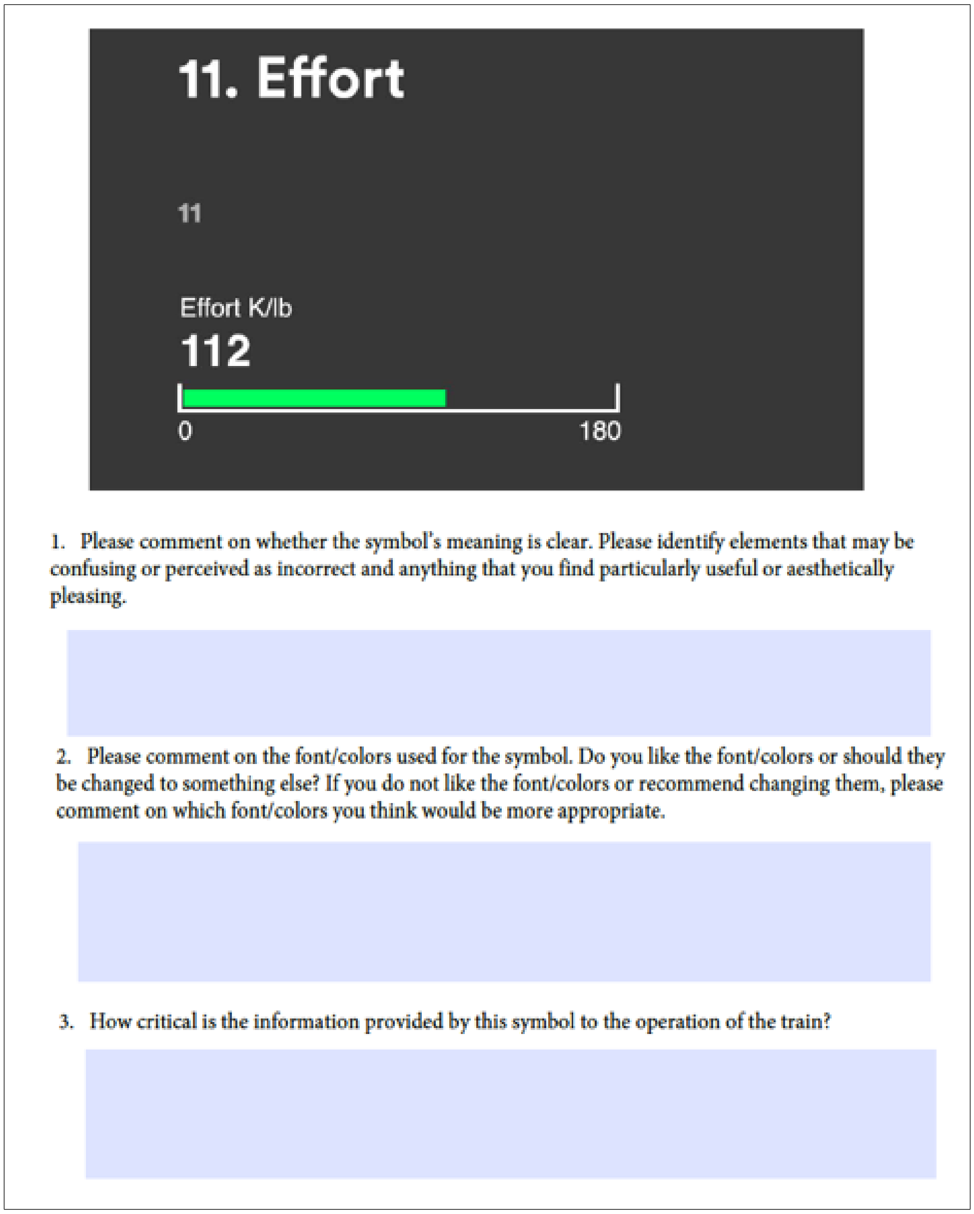
6. Should this symbol be grouped with other symbols? If yes, which symbols?

7. Is this symbol unclear in its perceived meaning or ineffective? If ineffective or unclear, please comment on what you would change or how you would design the symbol to make it more effective and clearer.

8. Is there additional information you would like to see in HUD?

9. Are there additional symbols you can recommend?

Figure 98 (continued): Task 4 Symbol Library Survey for items with two design options



1. Please comment on whether the symbol's meaning is clear. Please identify elements that may be confusing or perceived as incorrect and anything that you find particularly useful or aesthetically pleasing.

2. Please comment on the font/colors used for the symbol. Do you like the font/colors or should they be changed to something else? If you do not like the font/colors or recommend changing them, please comment on which font/colors you think would be more appropriate.

3. How critical is the information provided by this symbol to the operation of the train?

Figure 84: Task 4 Symbol Library Survey for items with one design option

4. Would you prefer this symbol always appear on the windscreen while using a Head-Up Display (HUD)?

Yes

5. Should this symbol be grouped with other symbols? If yes, which symbols?

6. Is this symbol unclear in its perceived meaning or ineffective? If ineffective or unclear, please comment on what you would change or how you would design the symbol to make it more effective and clearer.

7. Is there additional information you would like to see in HUD?

8. Are there additional symbols you can recommend?

Figure 99 (continued): Task 4 Symbol Library Survey for items with one design option

5. Task 5: Integration with HUD Prototype

5.1 Background

In Task 5 of this research project, researchers used the survey responses and feedback collected in Task 4 to finalize the library of symbols, design any symbols that were missing from the initial library, and integrate the symbols in the prototype HUD. The team verified that the symbology library correctly translates into the user interface based on the HUD user interface design and hardware capabilities. A documented test procedure reflecting the test integration was not necessary because the prototype HUD is still in very early phases of design and currently all that is required is a PNG image of each symbol to display on a computer. Future verification should be conducted to examine the exact overlay of symbology in the dedicated locations and ensure the icons in the library look the way they should for human interactions. The research team has provided Dr. Andy Liu with PNG images for each symbol with recommendations of use and symbol grouping to integrate with the prototype HUD his team is developing.

5.2 Final Library

In Task 4, the team sought feedback from relevant stakeholders (i.e., FRA personnel, stakeholders from both freight and passenger operations, and applicable technology manufacturers) to identify preferred symbology and make edits to the designs of the icons developed in Task 3. Two surveys were developed to collect feedback from individuals.

The team used the feedback provided in the surveys to make necessary revisions to the symbology library including adding new symbols that were overlooked in Task 4. In lieu of removing some non-critical and ineffective symbols identified by subject matter experts in Task 4, the team recommended that Dr. Liu include the symbols as optional or add-ons in testing with engineers to confirm that they are not desired for HUD application.

The figures below show the final library of symbols aggregated and then split by a single summary image for each symbol. The summary image for each symbol includes Application (freight, passenger, or both), Symbol Type (numeric, symbol, graphic, text, etc.), Purpose, and When It's Displayed (always, when applicable, etc.). Some summary images also include relevant notes and existing precedents for the symbol. Final symbol design, the relevant notes, when it's displayed, and the designated application are based on the feedback received from industry experts during the Task 4 surveys.

5.2.1 Final Library Aggregated

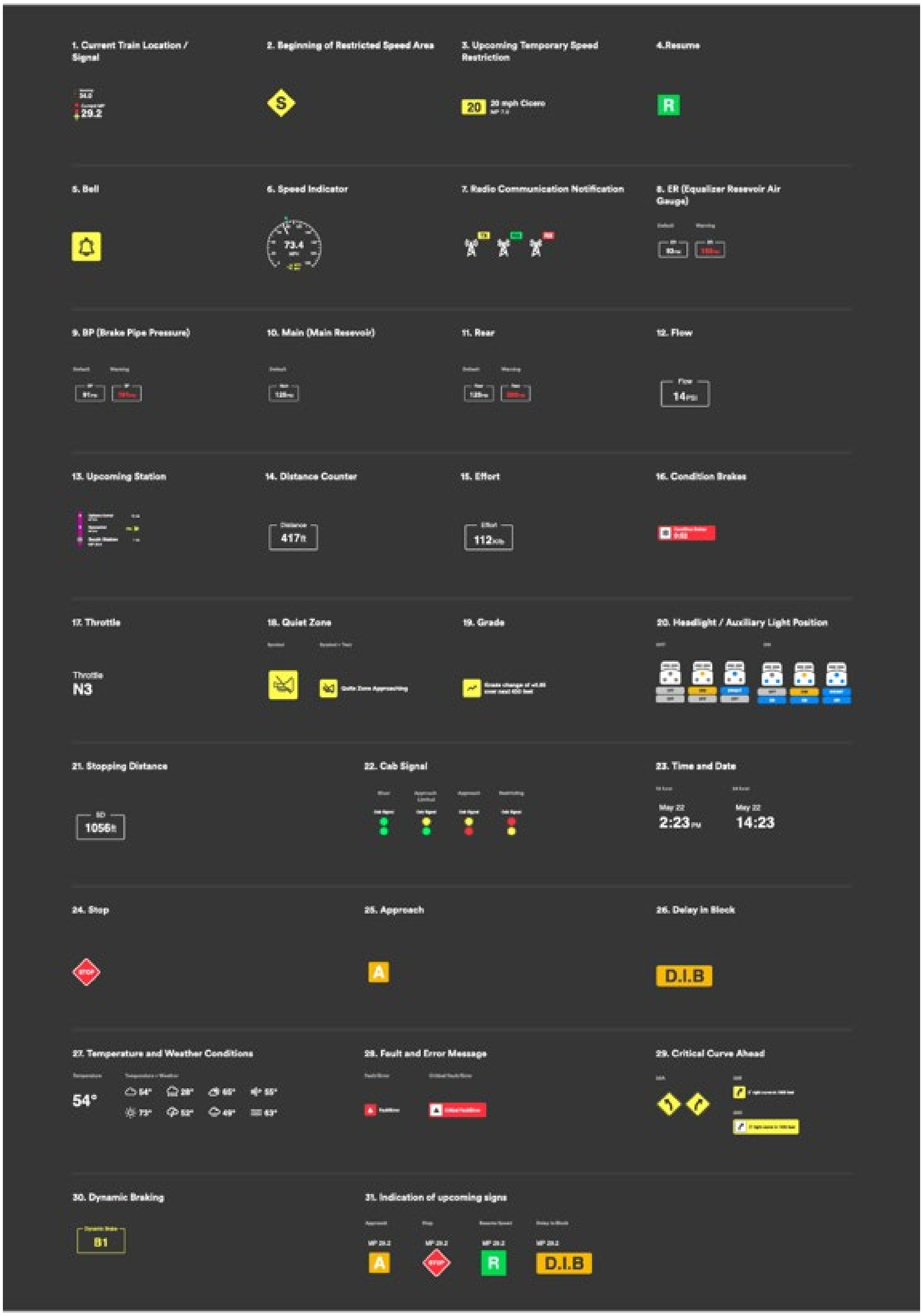


Figure 85: Task 5 Final Aggregated Symbology Library

5.2.2 Summary Image for Each Symbol

Figure 86: Task 5 Final Symbol for Current Train Location/Signal

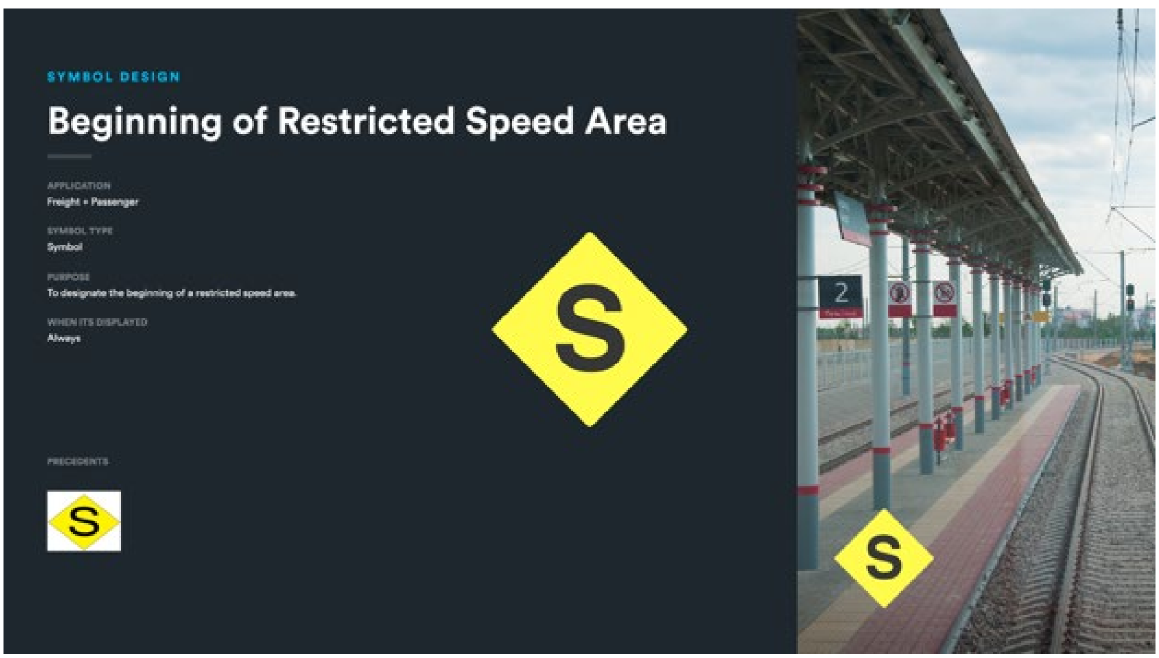


Figure 87: Task 5 Final Symbol for Beginning of Restricted Speed Area

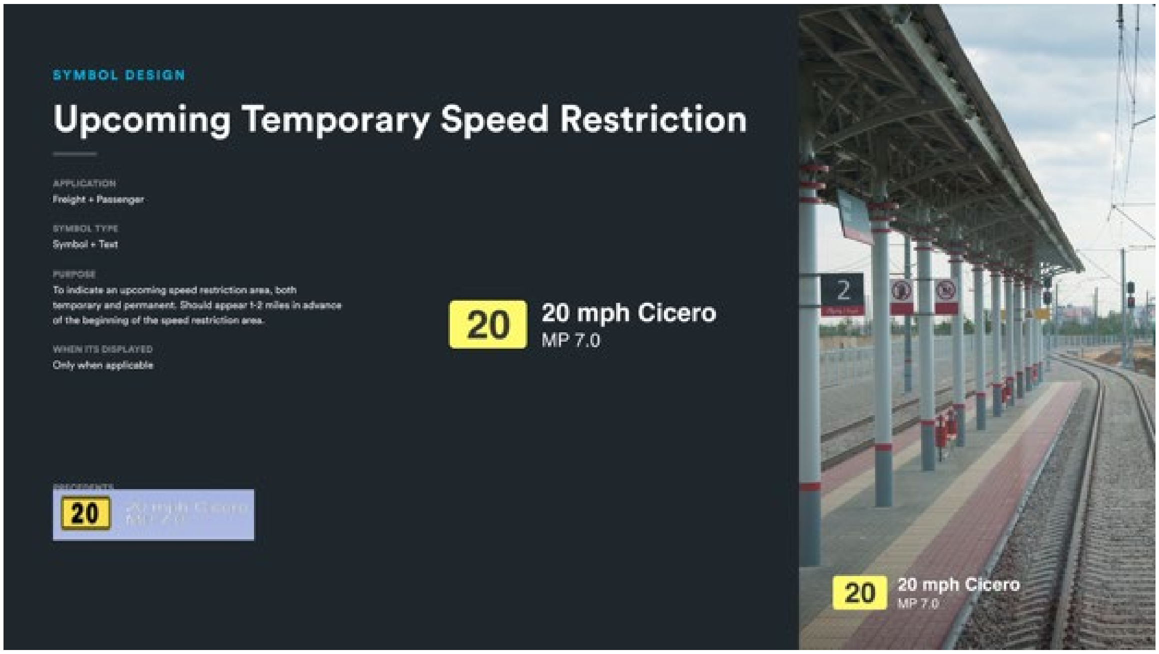


Figure 88: Task 5 Final Symbol for Upcoming Temporary Speed Restriction

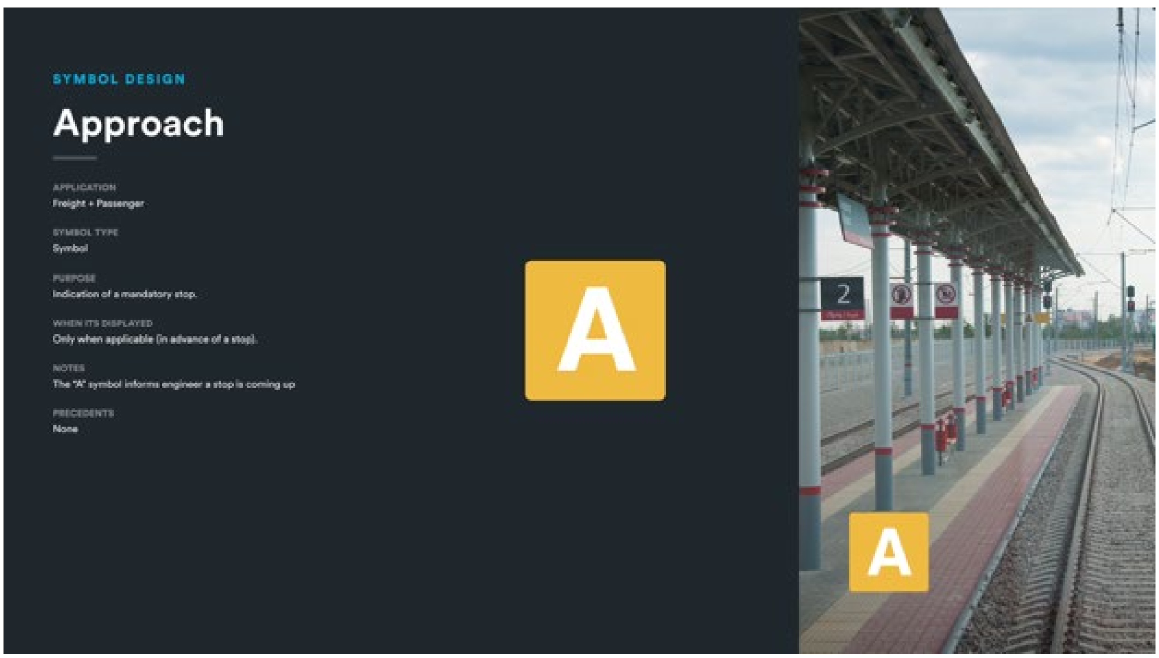


Figure 89: Task 5 Final Symbol for Approach

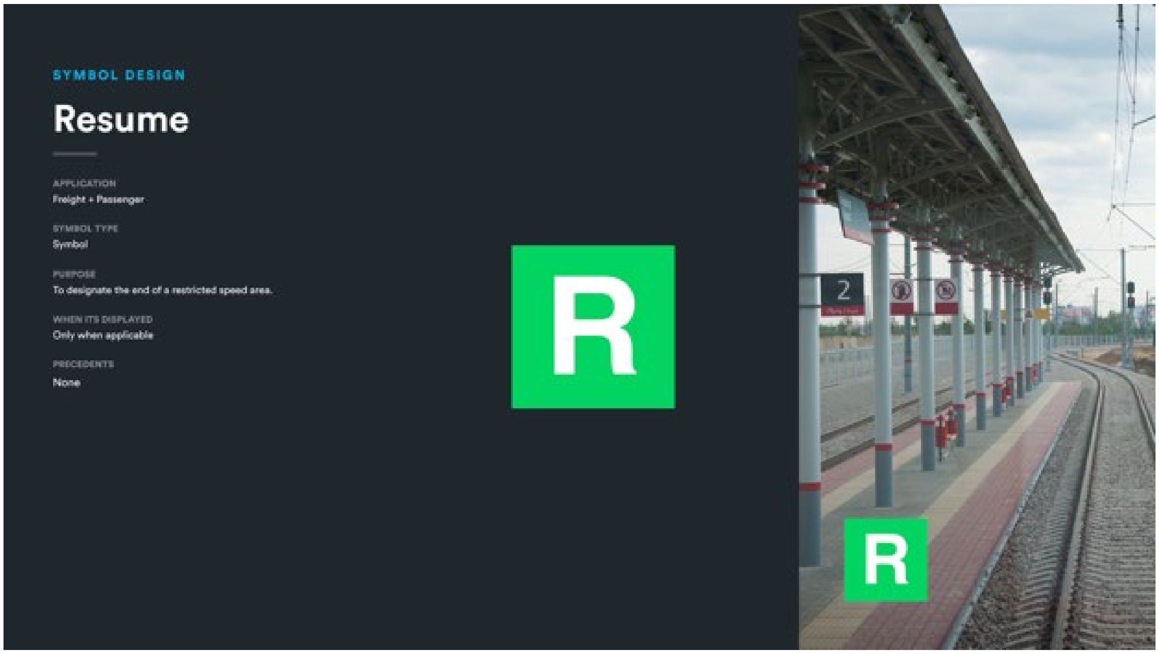


Figure 90: Task 5 Final Symbol for Resume

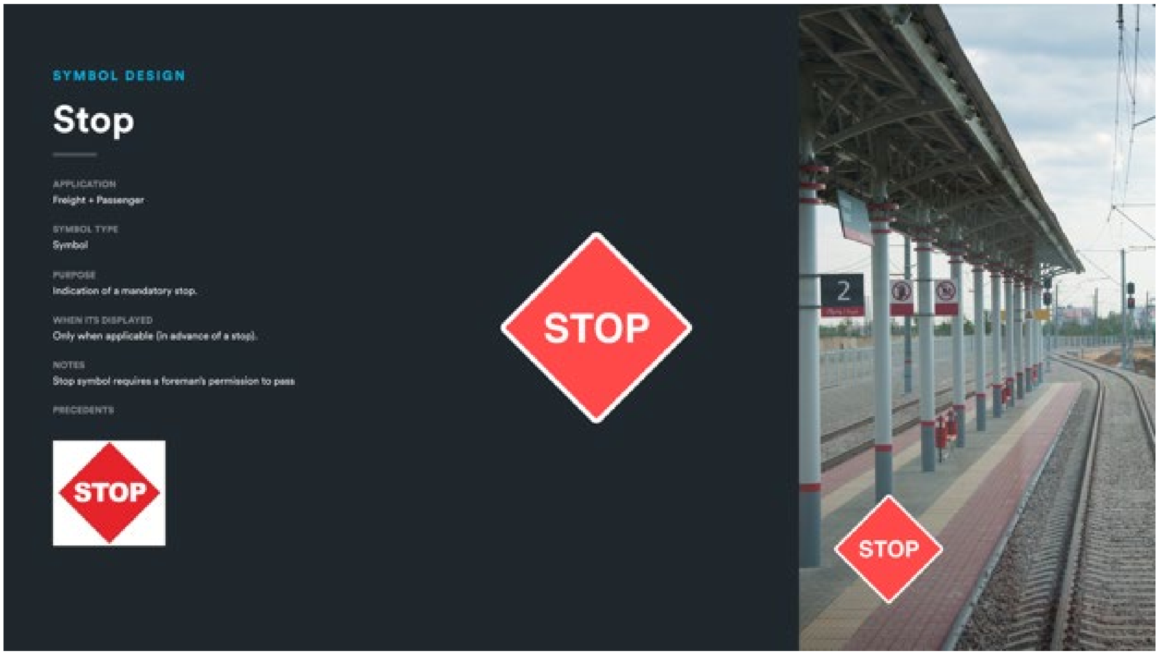


Figure 91: Task 5 Final Symbol for Stop

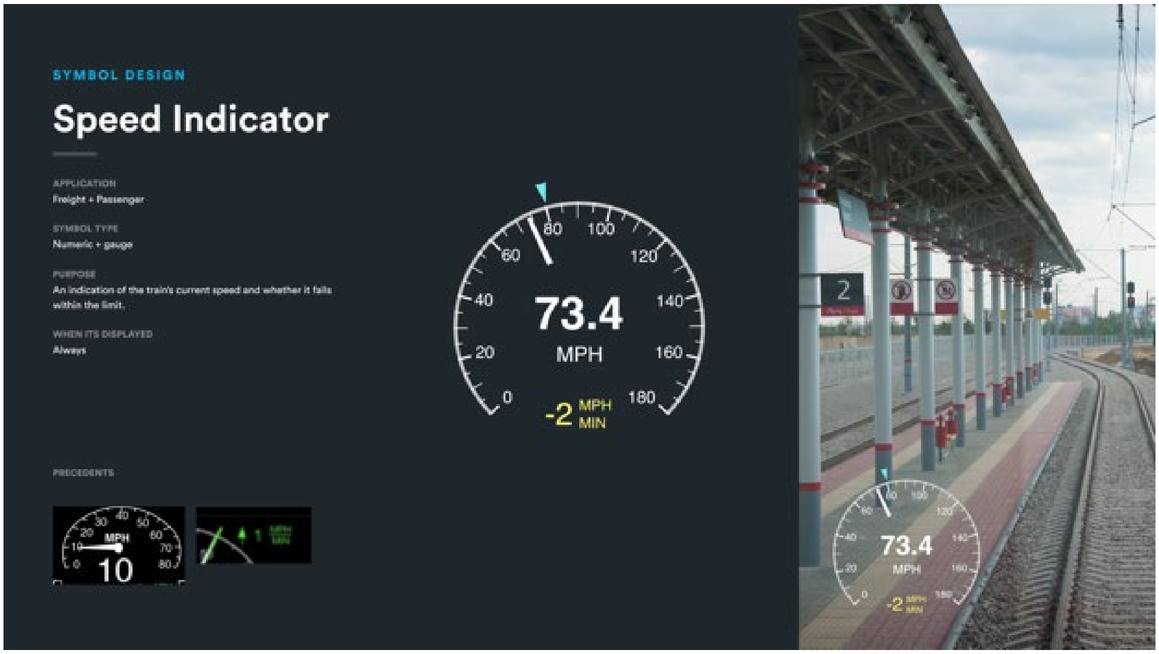


Figure 92: Task 5 Final Symbol for Speed Indicator

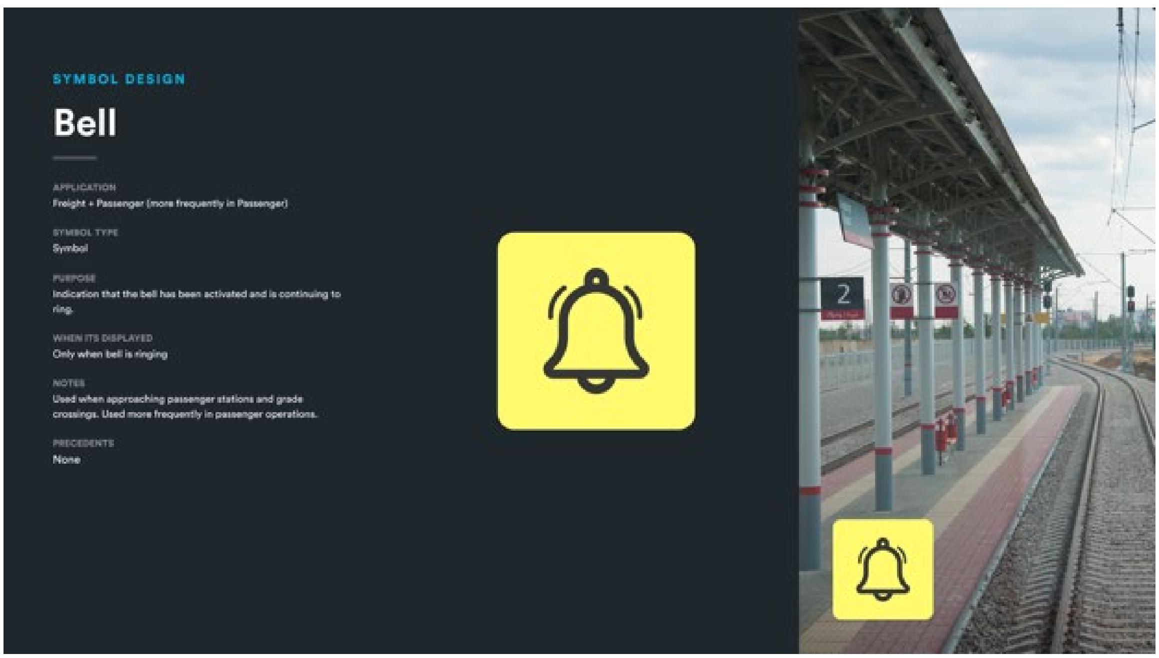


Figure 93: Task 5 Final Symbol for Bell

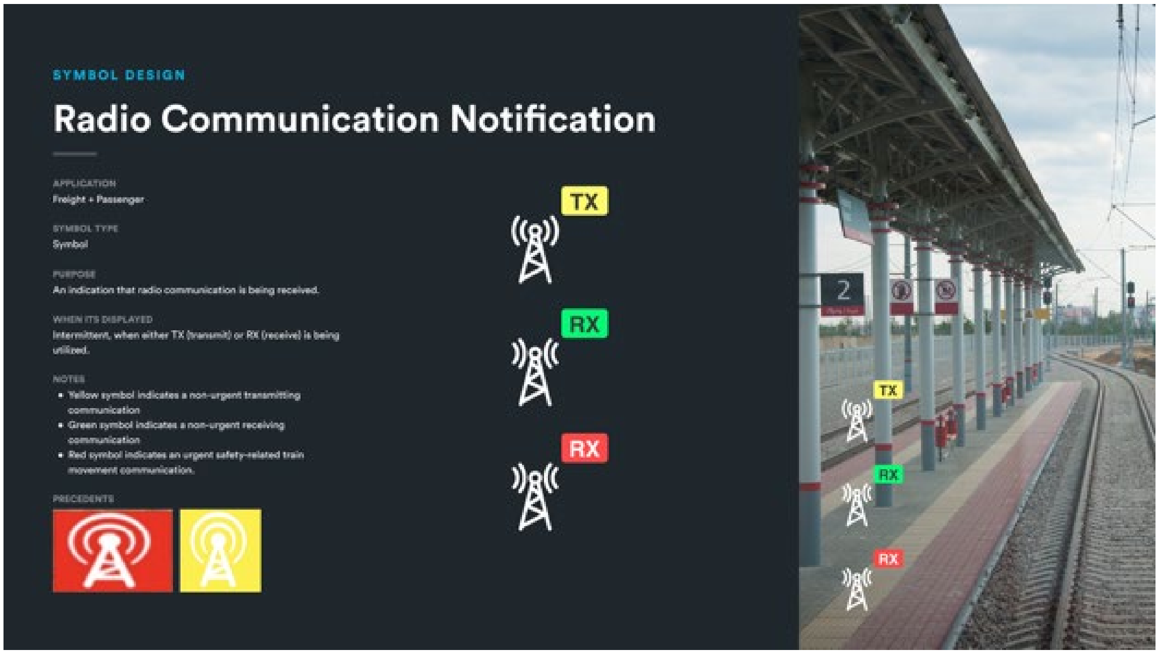


Figure 94: Task 5 Final Symbol for Radio Communication Notification

Figure 95: Task 5 Final Symbol for Equalizer Reservoir (ER)

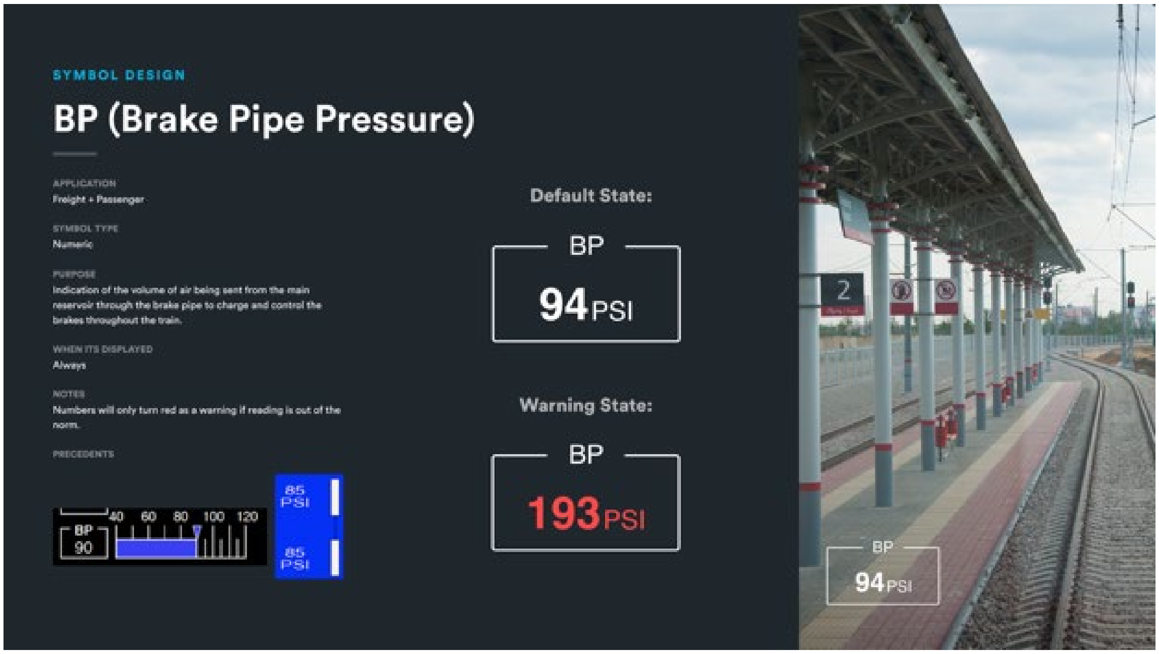


Figure 96: Task 5 Final Symbol for Brake Pipe (BP) Pressure

Figure 97: Task 5 Final Symbol for Main Reservoir

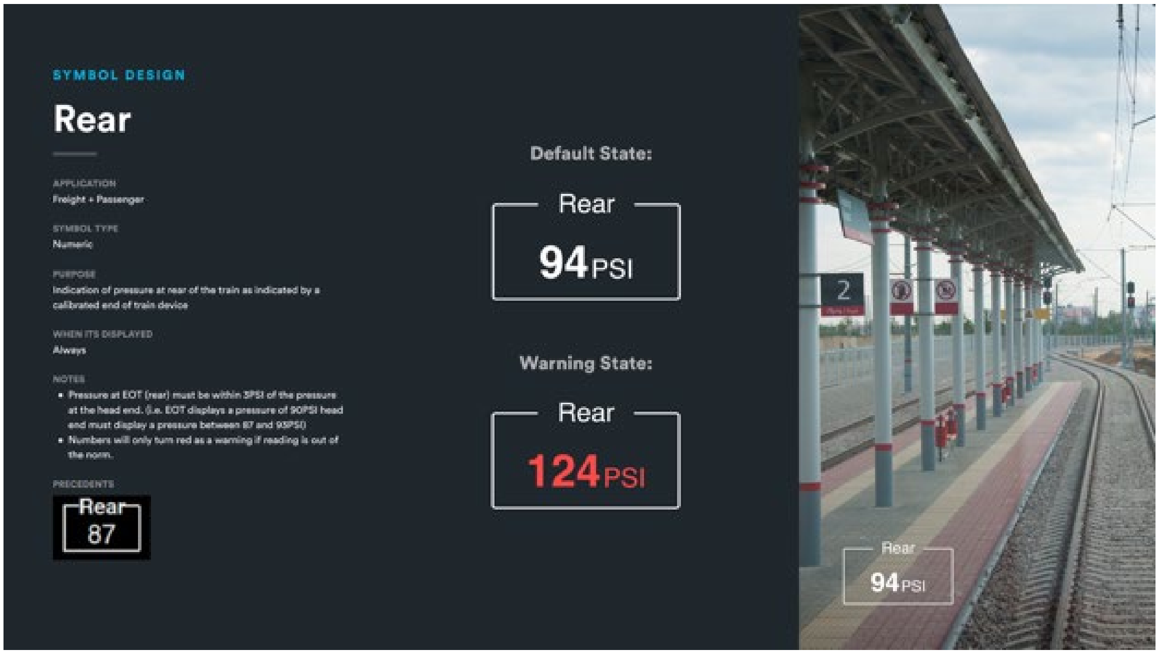


Figure 98: Task 5 Final Symbol for Rear

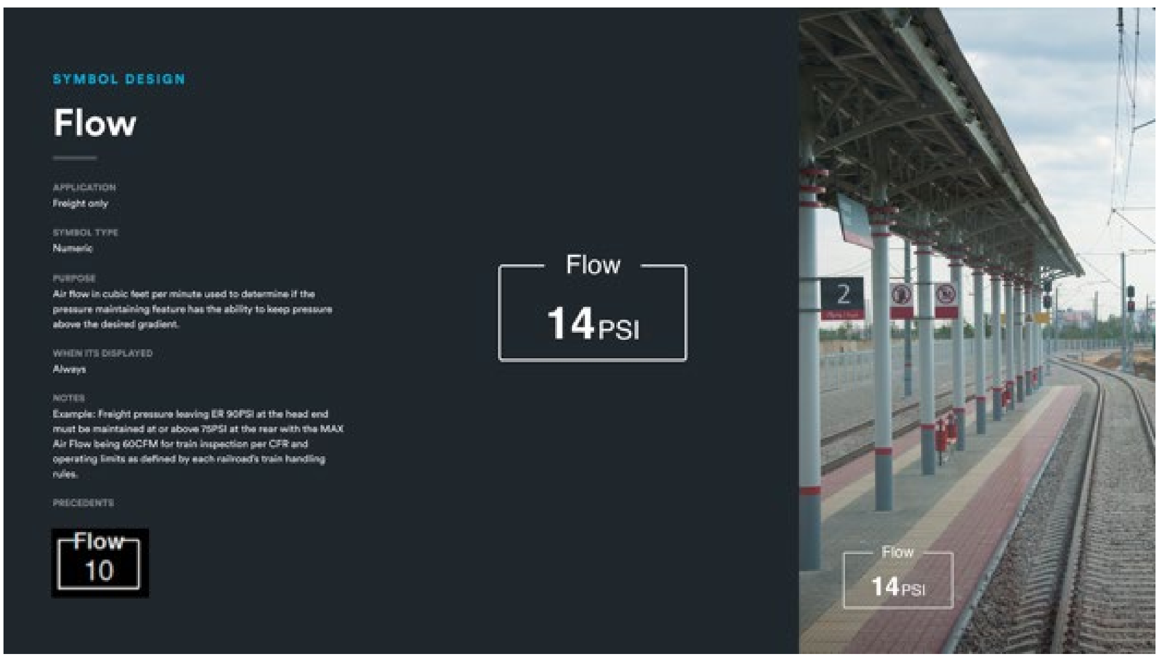


Figure 99: Task 5 Final Symbol for Flow

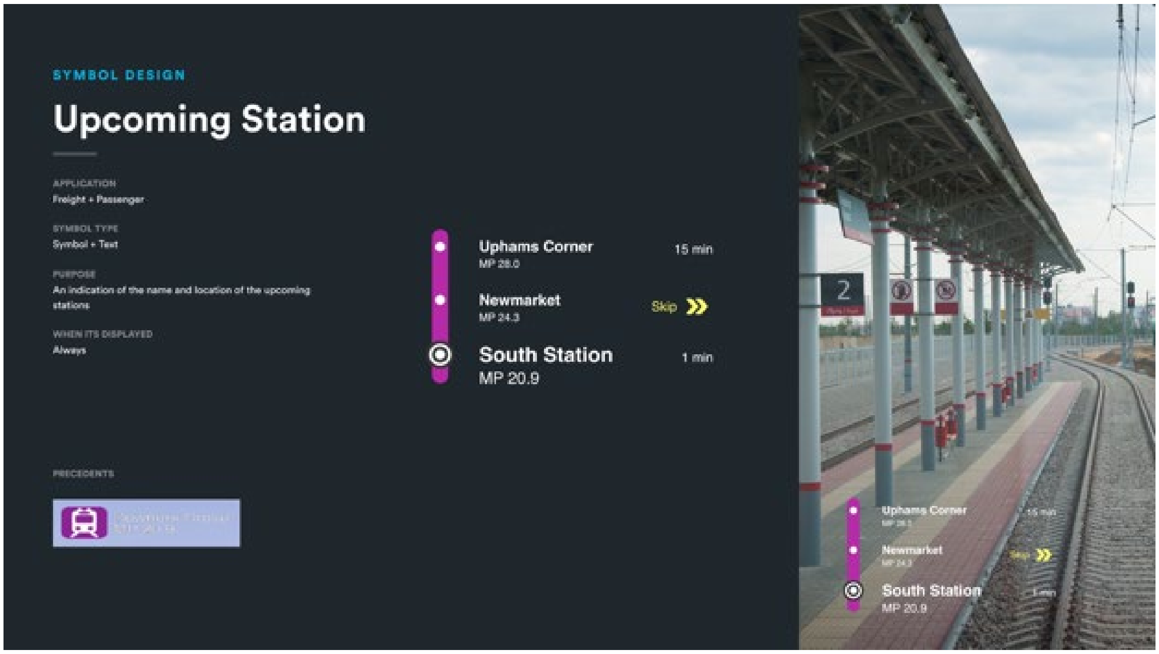


Figure 100: Task 5 Final Symbol for Upcoming Station

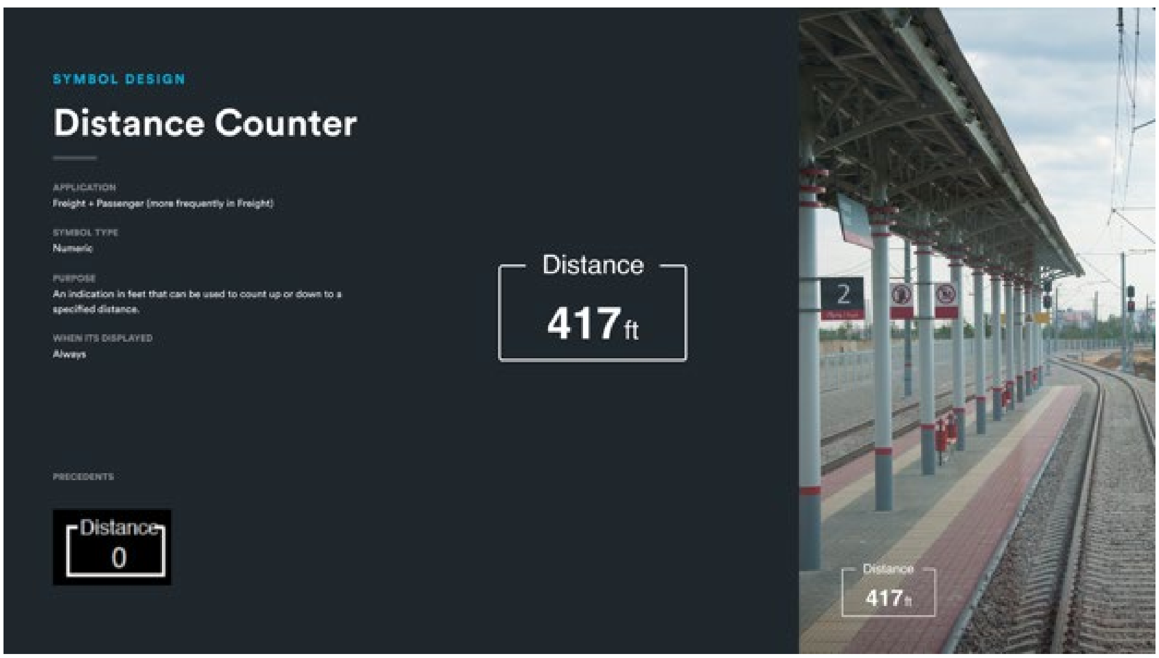


Figure 101: Task 5 Final Symbol for Distance Counter

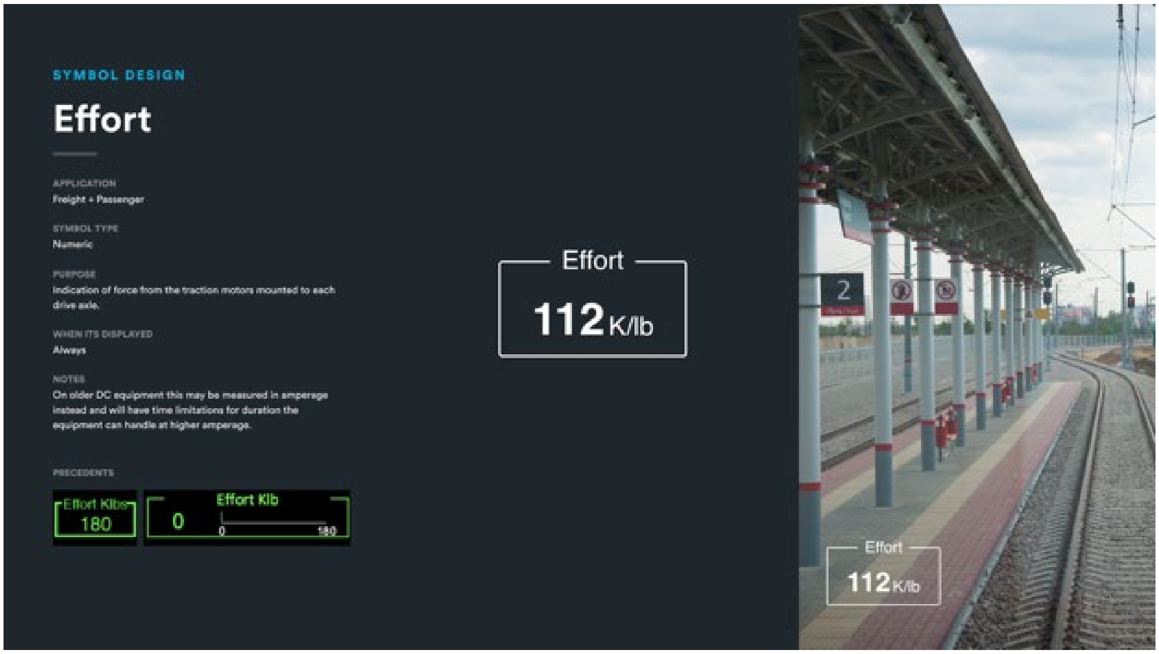


Figure 102: Task 5 Final Symbol for Effort

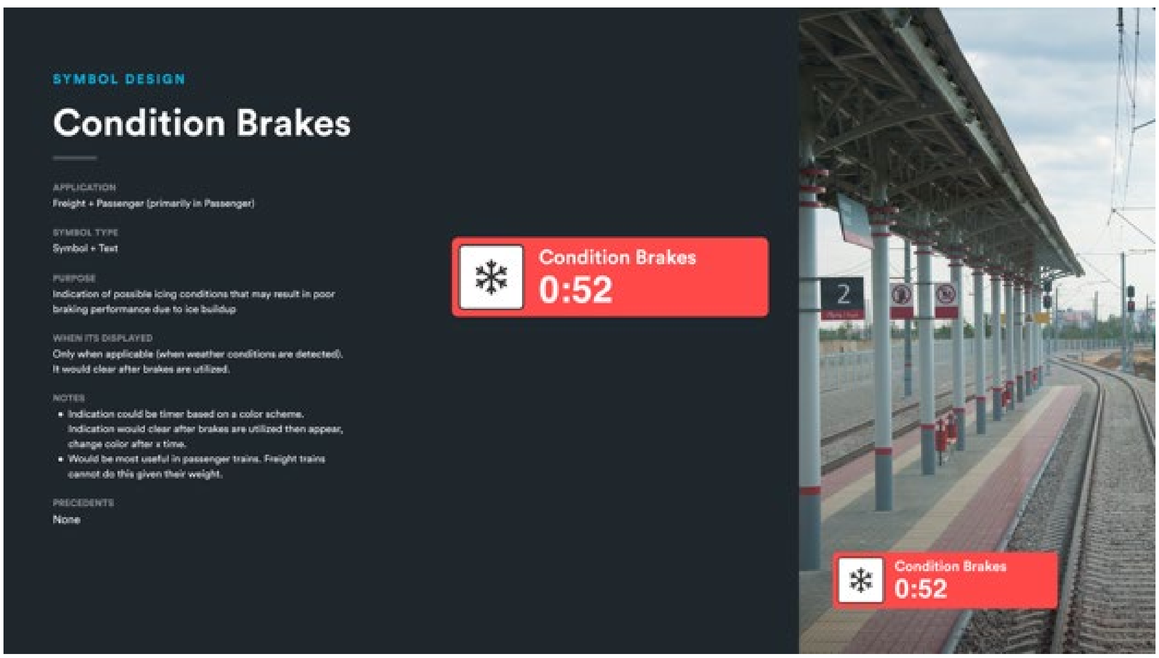


Figure 103: Task 5 Final Symbol for Condition Brakes

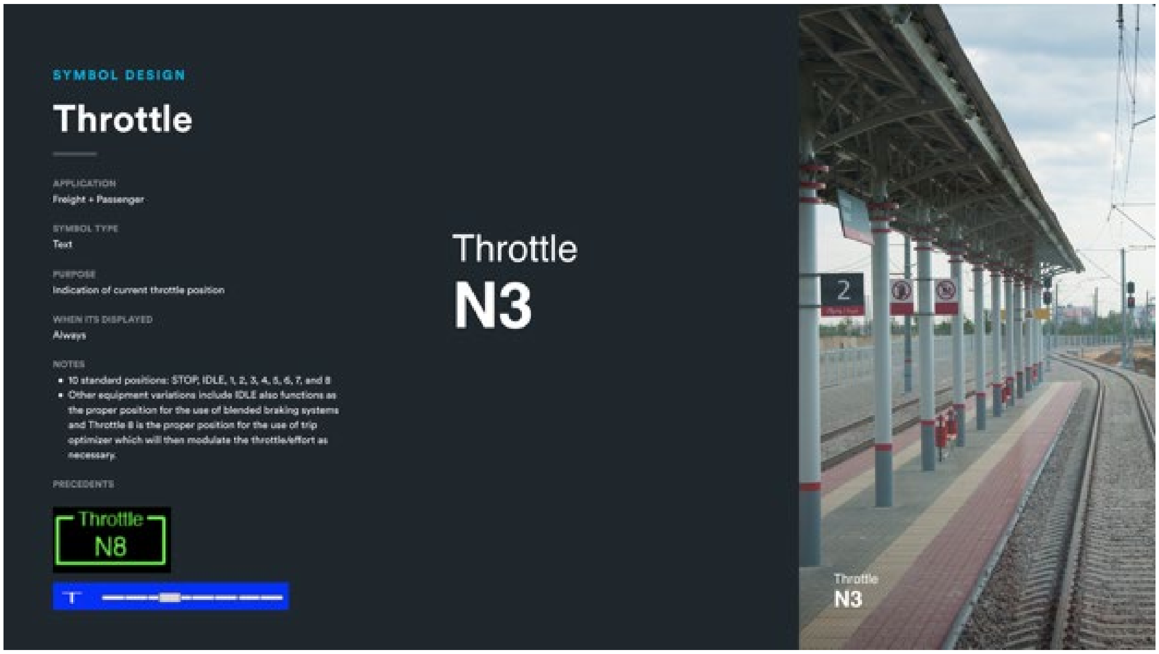


Figure 104: Task 5 Final Symbol for Throttle

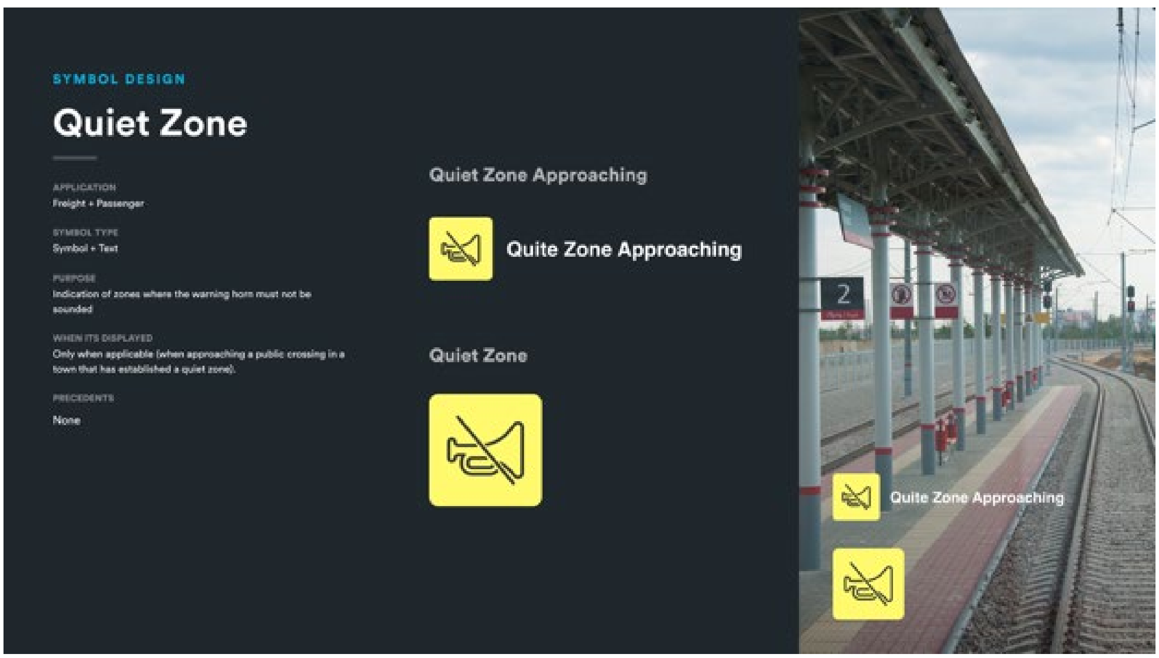


Figure 105: Task 5 Final Symbol for Quiet Zone

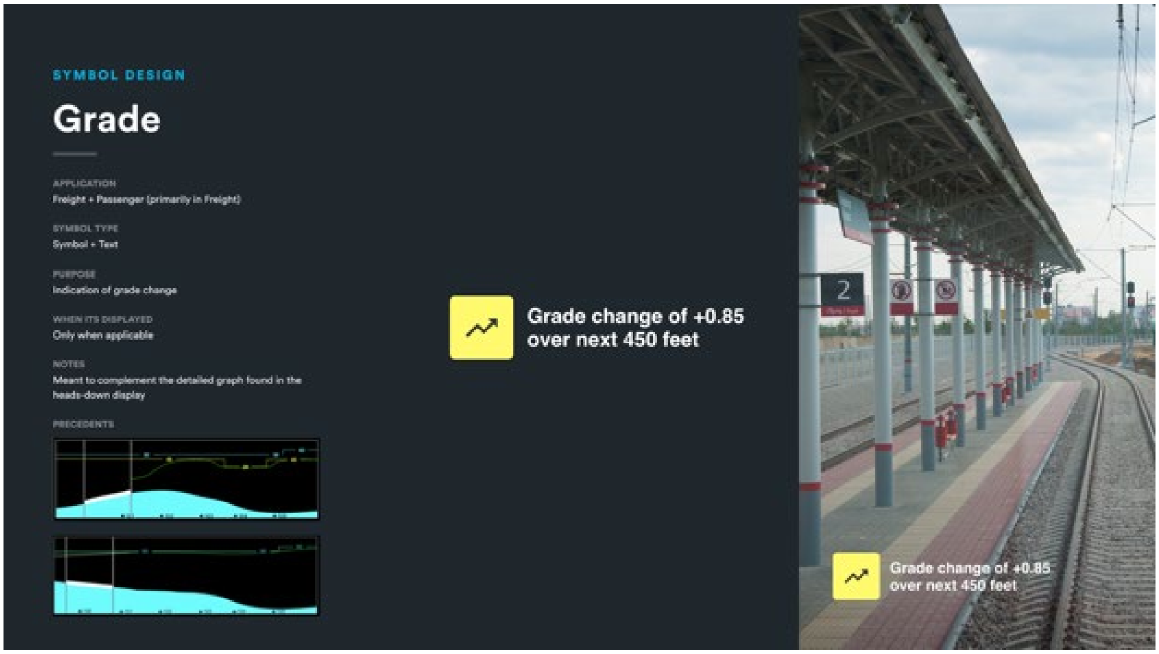


Figure 106: Task 5 Final Symbol for Grade

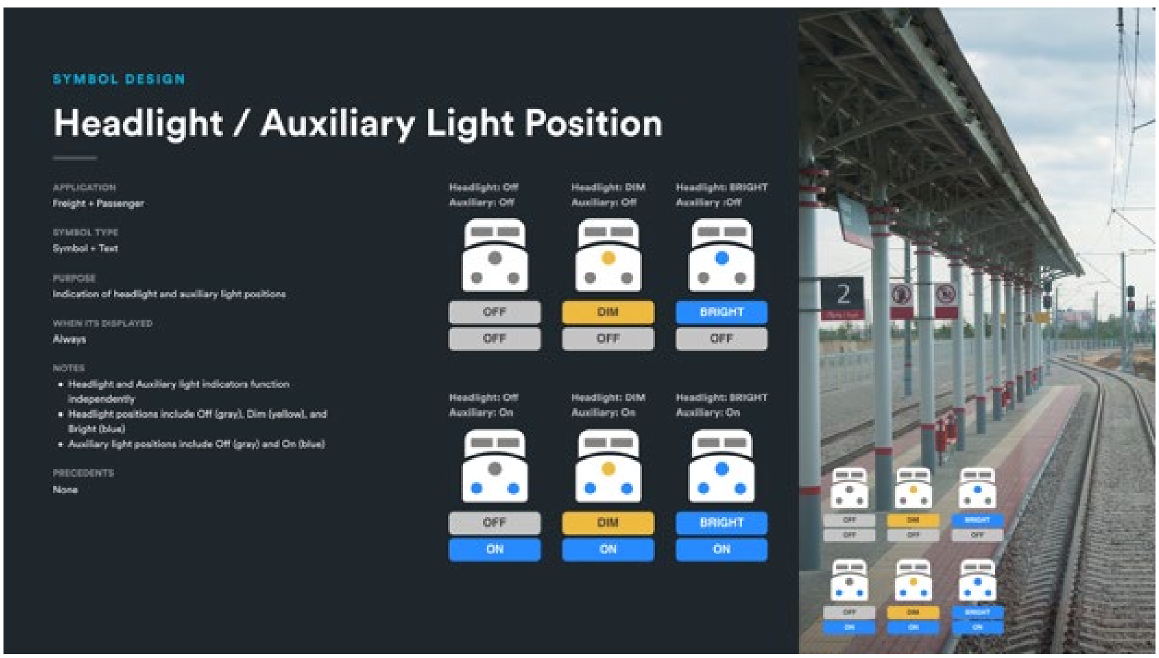


Figure 107: Task 5 Final Symbol for Headlight/Auxiliary Light Position

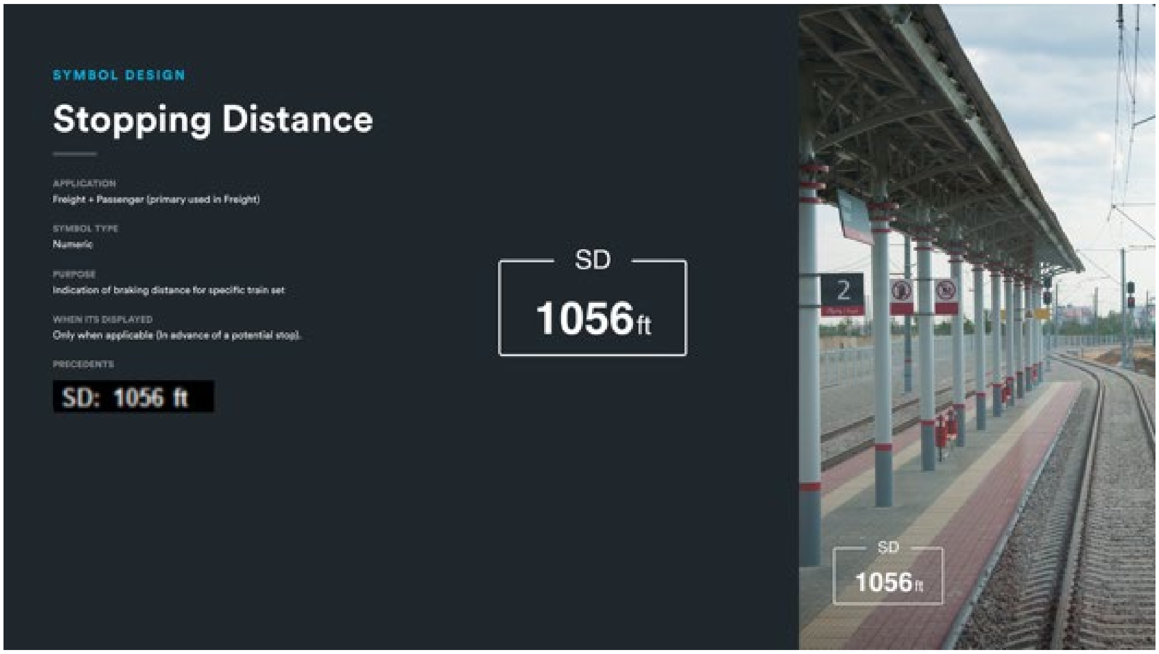


Figure 108: Task 5 Final Symbol for Stopping Distance

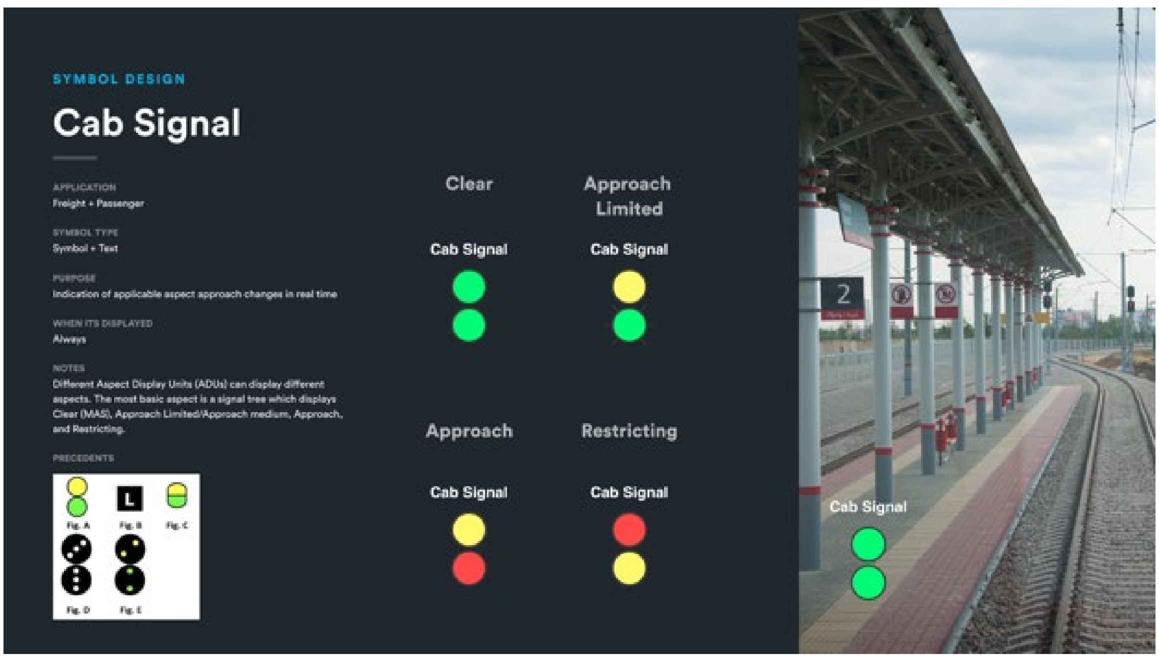


Figure 109: Task 5 Final Symbol for Cab Signal

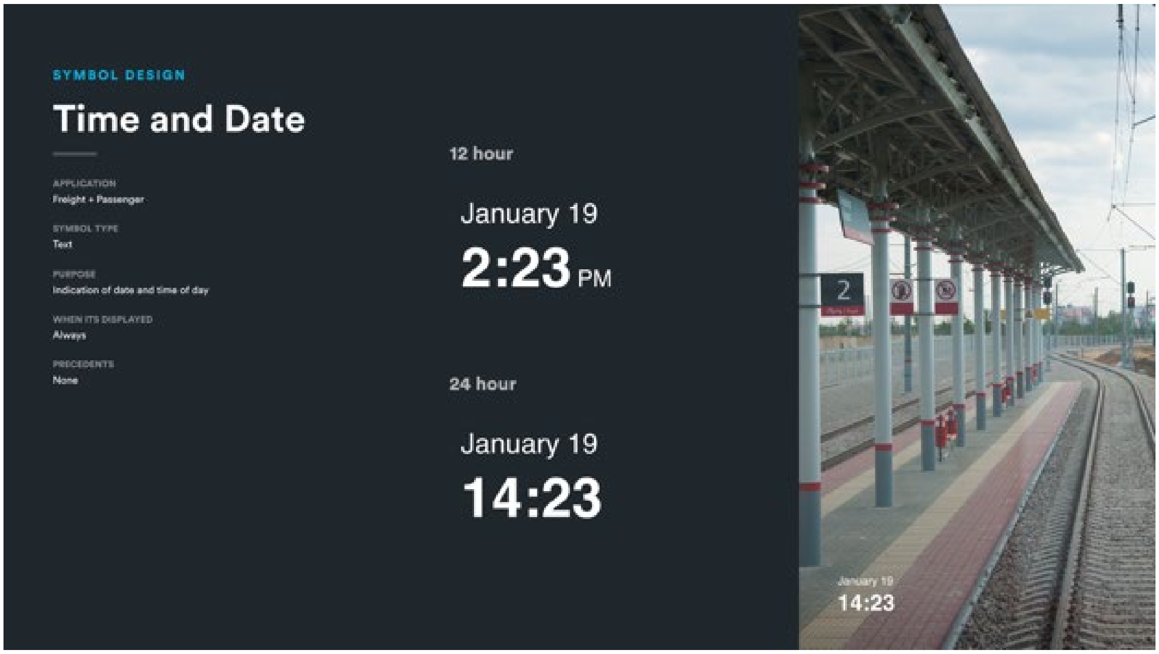


Figure 110: Task 5 Final Symbol for Time and Date

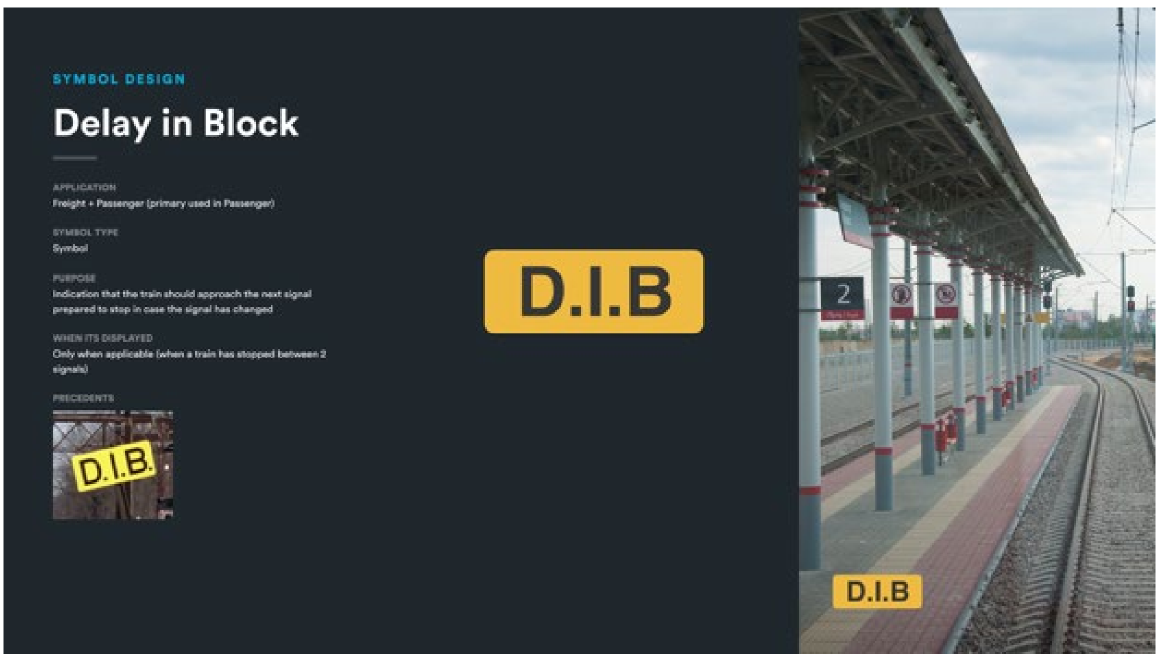


Figure 111: Task 5 Final Symbol for Delay in Block

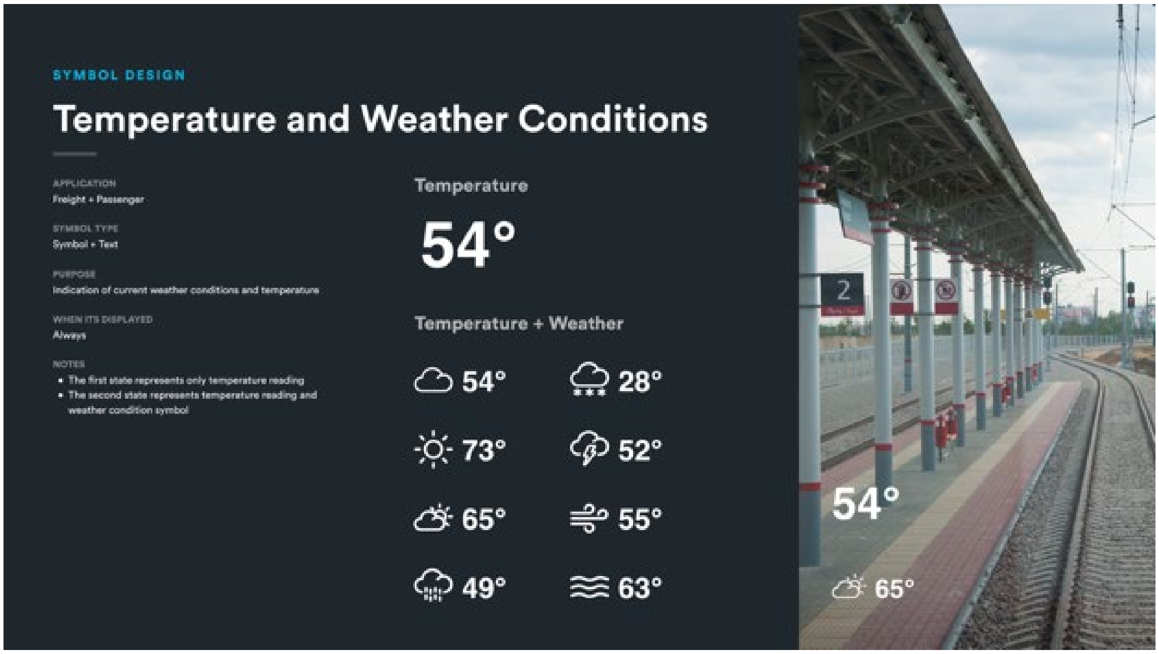


Figure 112: Task 5 Final Symbol for Temperature and Weather Conditions

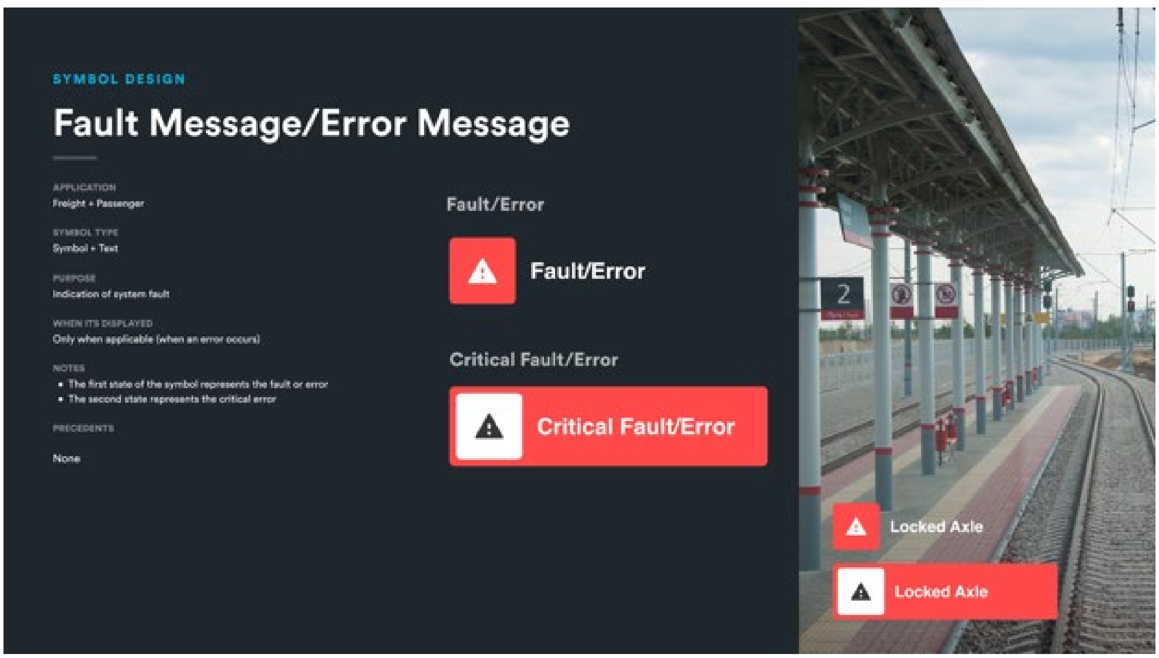


Figure 113: Task 5 Final Symbol for Fault Message/Error Message

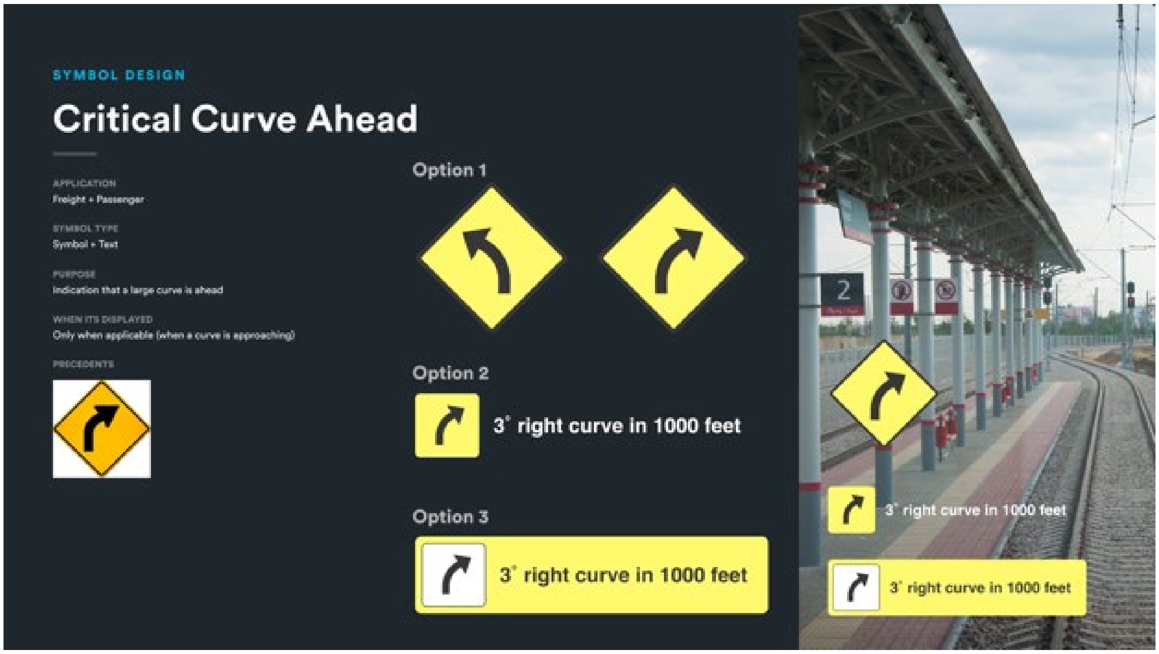


Figure 114: Task 5 Final Symbol for Critical Curve Ahead

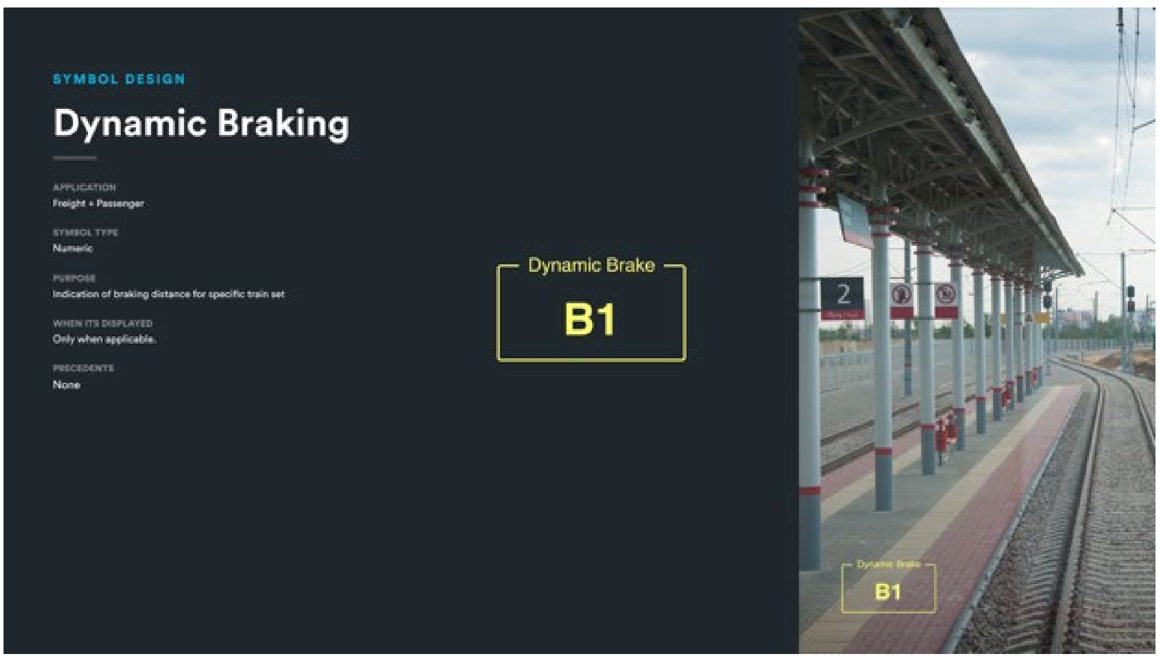


Figure 115: Task 5 Final Symbol for Dynamic Braking

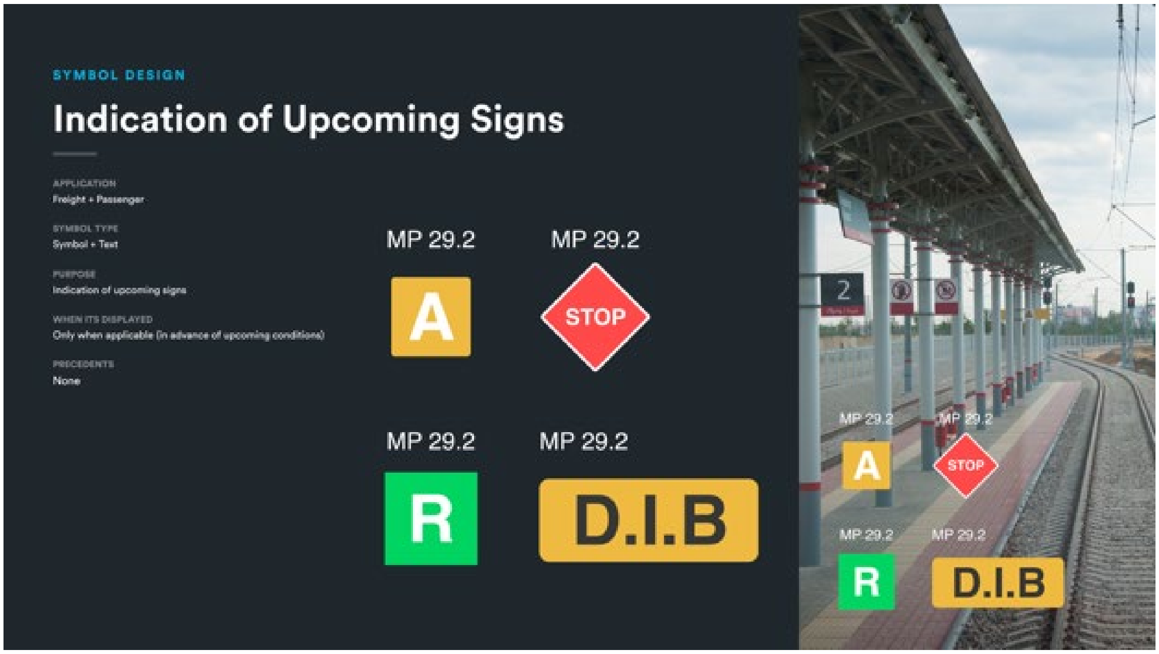


Figure 116: Task 5 Final Symbol for Indication of Upcoming Signals

5.3 New and Updated Symbols Based on Stakeholder Feedback from Task 4

Using the feedback from survey respondents in Task 4, researchers and partners designed symbols that were not included in Task 3 and 4, including a dynamic brake symbol. The team also created a view of the symbols with an upcoming milepost to indicate an upcoming symbol in the field, which was requested by many stakeholders during Task 4. The team designed a combined view of all the pressure gauges, as many engineers noted that the gauges should be grouped together for HUD application. Additionally, a new "Headlight/Auxiliary Light Position" symbol was created based on survey feedback indicating confusion with the originally designed symbol for Task 4. The research team consulted with at least one passenger engineer and one freight engineer to get approval of the design of these new and updated symbols.

Minor changes based on survey results are listed below.

- Changed the "Resume" symbol (#4 on the aggregated list) to appear with a white R
- Changed the "Approach" symbol (#25) to appear with a white A
- Manufacturers or rail carriers can decide if they prefer the blue tic mark on the "Speed Indicator" symbol (#6) to indicate maximum authorized speed or current speed limit
    - Lines were also added to the speedometer in 5 mph increments
- Split the "Upcoming Temporary Speed Restriction" symbol into two distinct symbols:
    - Symbol #2 on the aggregated list appears at the start of a restricted speed area
    - Symbol #3 appears a mile or two in advance of the restricted speed area as a warning
- All applicable pressure gauges (symbols #8, 9, and 11) will show readings in red when they are out of normal range to better warn the engineer

- On the upcoming station symbol (#13), clarifying text that reads “skip” was added next to the two yellow arrows to indicate when a station should be skipped (due to construction, express passenger train, etc.)
    - The order in which stations appear will be customizable based on manufacturer or carrier preference or can be left up to the locomotive engineer
- Added a “Quiet Zone Approaching” symbol to “Quiet Zone” (#18) so the engineer has a warning of the upcoming quiet zone; the symbol will appear without the warning text once in the quiet zone
- Text was added to symbol #22, “Cab Signal,” so users can distinguish between cab signals and interlocking signals (symbol #1)
- Symbol #23, “Time and Date,” will be customizable to display AM/PM or military time
- Symbol #28, “Fault and Error Message,” received an additional symbol option so an error can appear as critical or not
- Symbol #27, “Temperature and Weather Conditions,” was updated to show the temperature more prominently and include a symbol option for temperature with no weather indicator
- The “Approach” (#25) and “Delay in Block” (#26) symbols’ color was changed to “safety yellow”
- Units were added to all applicable symbols; these units will be customizable in case they are different across carriers (i.e., pressure gauges, stopping distance, effort, etc.)
- All symbols’ size, shape, units, and appearance on HUD will be customizable by manufacturers and carriers

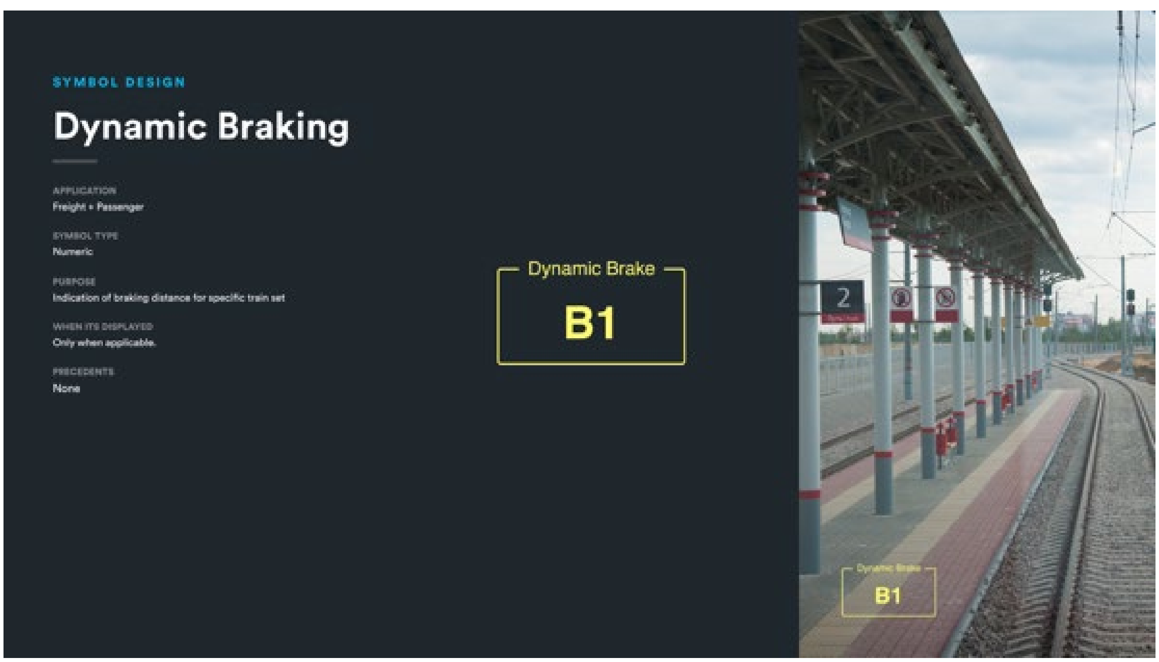


Figure 117: Task 5 Additional Symbol – Dynamic Braking

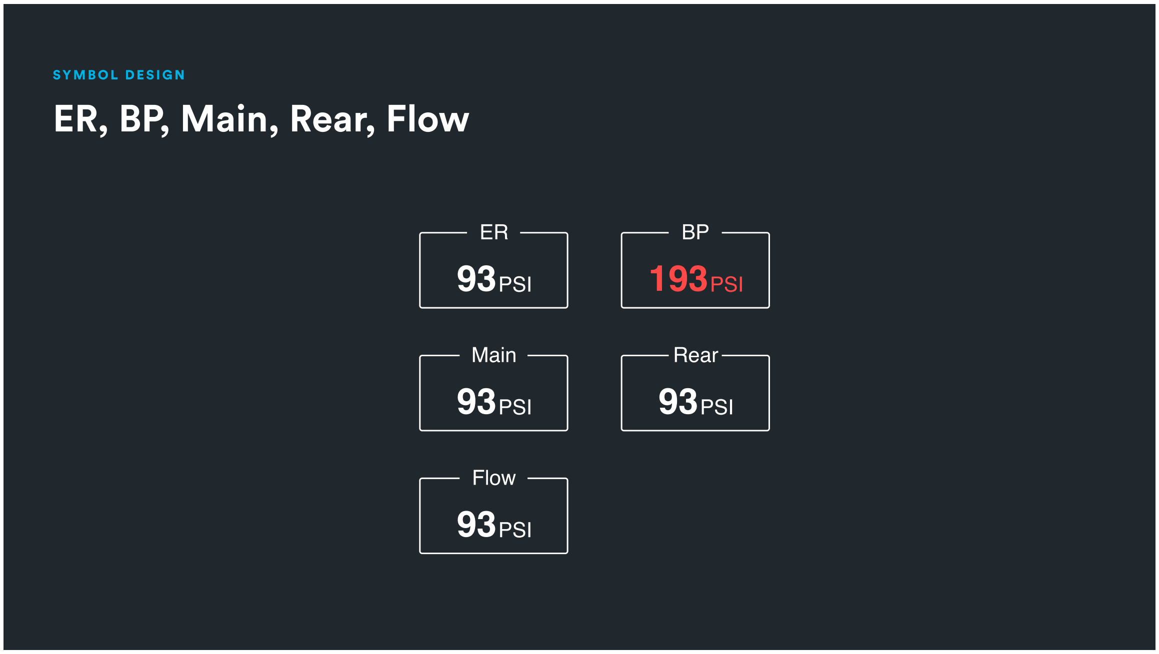


Figure 118: Task 5 Grouping Symbols – Air Gauges

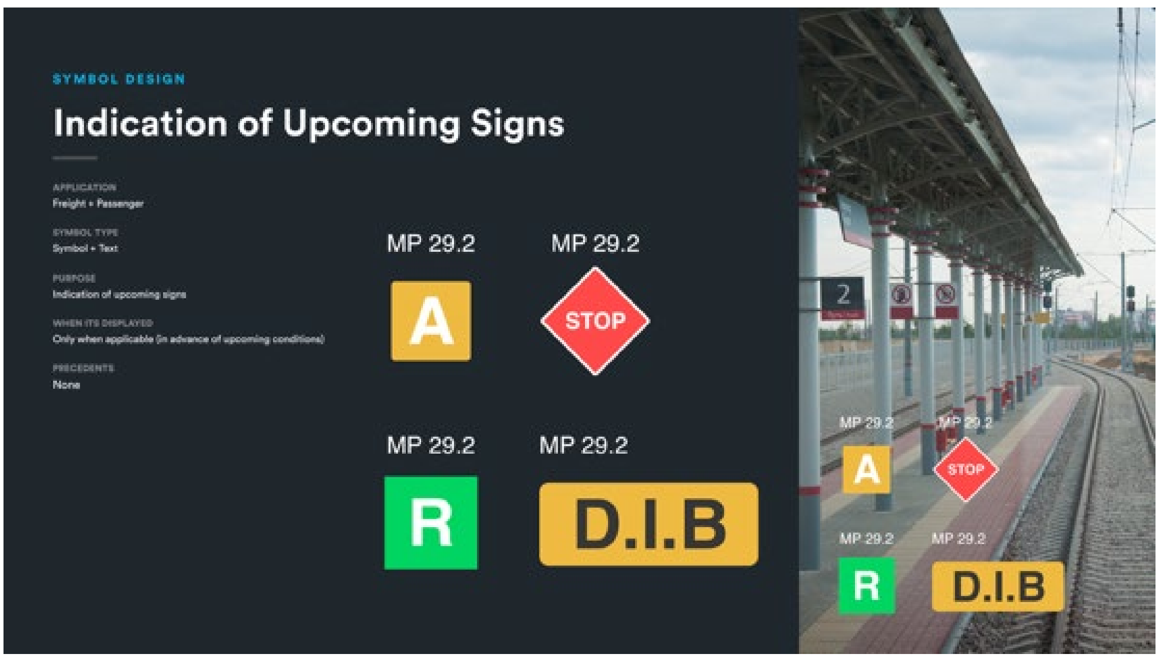


Figure 119: Task 5 Additional Symbol – Indication of Upcoming Signals

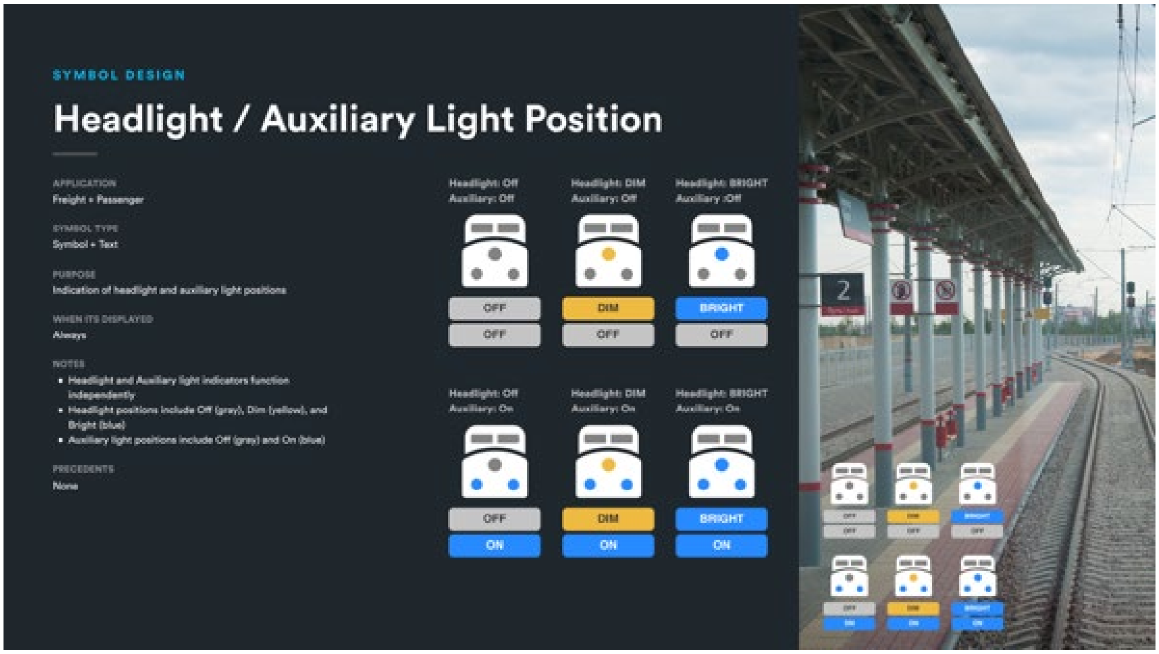


Figure 120: Task 5 Modified Symbol – Headlight/Auxiliary Light Position

6. Conclusion

In a project that was the first of its kind, researchers produced three symbology library subsets for HUD application for the rail industry: one with all the proposed symbols, a second with symbols relevant to passenger operations, and a third with symbols relevant to freight operations. The team collected extensive expert and end-user feedback to inform development of these libraries. Researchers conducted a literature review in Task 1 that examined symbology developed for past HUD studies in the rail industry as well as other transportation industries (e.g., the aviation and automotive sectors). Additionally, the team collected best practices for designing symbol aesthetics in Task 1's literature review and applied them when drafting the symbols in Task 3. The literature review conducted in Task 1 also allowed the research team to start rating each symbol for criticality to locomotive operations, especially when considering limited symbol space in HUD application.

The team developed two surveys to collect comprehensive feedback from industry stakeholders. The first was a demographic survey that captured the individual's current and past professional experience, years in each position, and years in the rail industry. Researchers placed particular focus on understanding whether the individual was a current locomotive engineer or had ever worked as a locomotive engineer in the past, as these individuals would have operating experience and would be the primary end user. The second survey included the library of proposed symbols and asked questions regarding the frequency of use, perceived meaning, criticality, and overall effectiveness of symbols. The team presented icons that had multiple options side-by-side and requested that subject matter experts report their preferences and the potential strengths and weaknesses of each example. The team also asked questions regarding the symbols' aesthetic properties, such as whether colors, font, and size of elements were appropriate

The team made suggested changes to the symbols based on stakeholder feedback collected in the surveys and finalized the libraries. Researchers provided PNG images for each symbol with recommendations of use and symbol grouping to the MIT Human System Lab to integrate with the prototype HUD that the team is developing. Future verification should be conducted to examine the exact overlay of symbology in the dedicated locations and ensure the icons in the library look the way they should for human interactions. Further testing of the symbols should be conducted with locomotive engineers in a high-fidelity environment, such as CTIL. While the stakeholder surveys showed which symbols may only be relevant for passenger and freight locomotive operations, researchers recommend considering the symbols as additional add-ons for each library or removing them after pilot testing in a realistic environment if it is confirmed they do not belong in the specific symbology library.

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Appendix A: Final Symbology Libraries

Final Library of All Symbols

The final library of all the symbols is shown in Figure 85: Task 5 Final Aggregated Symbology Library.

Final Freight Operations Library Ordered by Criticality

1. Task 5 Final Symbol for Speed Indicator
2. Task 5 Final Symbol for Main Reservoir
3. Task 5 Final Symbol for Rear
4. Task 5 Final Symbol for Flow
5. Task 5 Final Symbol for Cab Signal
6. Task 5 Final Symbol for Fault Message/Error Message
7. Task 5 Final Symbol for Brake Pipe (BP) Pressure
8. Task 5 Final Symbol for Current Train Location/Signal
9. Task 5 Final Symbol for Upcoming Temporary Speed Restriction
10. Task 5 Final Symbol for Equalizer Reservoir (ER)
11. Task 5 Final Symbol for Effort
12. Task 5 Final Symbol for Stop
13. Task 5 Final Symbol for Distance Counter
14. Task 5 Final Symbol for Throttle
15. Task 5 Final Symbol for Approach
16. Task 5 Final Symbol for Resume
17. Task 5 Final Symbol for Headlight/Auxiliary Light Position
18. Task 5 Final Symbol for Stopping Distance
19. Task 5 Final Symbol for Time and Date*
20. Task 5 Final Symbol for Delay in Block
21. Task 5 Final Symbol for Radio Communication Notification
22. Task 5 Final Symbol for Condition Brakes
23. Task 5 Final Symbol for Critical Curve Ahead
24. Task 5 Final Symbol for Bell
25. Task 5 Final Symbol for Upcoming Station*
26. Task 5 Final Symbol for Grade
27. Task 5 Final Symbol for Temperature and Weather Conditions
28. Task 5 Final Symbol for Quiet Zone

*Symbol may not be relevant for freight operations. Should consider making optional add-on or removing from this library.

Final Passenger Operations Library Ordered by Criticality

1. Task 5 Final Symbol for Current Train Location/Signal
2. Task 5 Final Symbol for Speed Indicator
3. Task 5 Final Symbol for Stop
4. Task 5 Final Symbol for Approach
5. Task 5 Final Symbol for Upcoming Temporary Speed Restriction

6. Task 5 Final Symbol for Resume
7. Task 5 Final Symbol for Fault Message/Error Message
8. Task 5 Final Symbol for Cab Signal
9. Task 5 Final Symbol for Equalizer Reservoir (ER)
10. Task 5 Final Symbol for Main Reservoir
11. Task 5 Final Symbol for Brake Pipe (BP) Pressure
12. Task 5 Final Symbol for Headlight/Auxiliary Light Position
13. Task 5 Final Symbol for Time and Date
14. Task 5 Final Symbol for Effort
15. Task 5 Final Symbol for Rear*
16. Task 5 Final Symbol for Delay in Block
17. Task 5 Final Symbol for Critical Curve Ahead*
18. Task 5 Final Symbol for Grade*
19. Task 5 Final Symbol for Radio Communication Notification
20. Task 5 Final Symbol for Throttle*
21. Task 5 Final Symbol for Bell
22. Task 5 Final Symbol for Flow*
23. Task 5 Final Symbol for Upcoming Station
24. Task 5 Final Symbol for Distance Counter*
25. Task 5 Final Symbol for Condition Brakes*
26. Task 5 Final Symbol for Quiet Zone*
27. Task 5 Final Symbol for Stopping Distance*
28. Task 5 Final Symbol for Temperature and Weather Conditions

*Symbol may not be relevant for passenger operations. Should consider making optional add-on or removing from this library.

Abbreviations and Acronyms

ACRONYM	DEFINITION
AAR	Association of American Railroads
ACSES	Advanced Civil Speed Enforcement System
ASRS	Aviation Safety Reporting System
BC	Brake Cylinder (Pressure)
BP	Brake Pipe (Pressure)
CA	Control Area
CCA	Consolidated Control Architecture
CIO	Consolidated Input/Output
CS	Continuous Service
CTIL	Cab Technology Integration Laboratory
DAD	Dynamic Active Display
DB	Dynamic Braking
DP	Distributive Power
DPR	Distributed Power Radio Module
EAB	Electronic Air Brake
EBV	Electronic Brake Valve
EC	Engine Control
EOT	End Of Train
EPCU	Electro–Pneumatic Control Unit
ER	Equalizing Reservoir (Pressure)
ER	Event Recorder
ETMS	Electronic Train Management System
FAA	Federal Aviation Administration
FRA	Federal Railroad Administration
Fx	Function Key Number
HDD	Head-Down Display
HMD	Helmet Mounted Display

ACRONYM	DEFINITION
HMI	Human Machine Interface
HOTD	Head of Train Device
HSL	Human Systems Lab
HUD	Head-Up Display
IPM	Integrated Processor Module
ISO	International Standards Organization
KLBS	Kilo Pounds (Tractive Effort)
LCD	Liquid Crystal Display
LOD	Locomotive Operating Display
LSI	Locomotive System Integration
MIT	Massachusetts Institute of Technology
MPH	Miles Per Hour
OMB	Operator Message Box
PCS	Power Cutout Switch
PFD	Primary Flight Display
PSI	Pounders per Square Inch
PTC	Positive Train Control
PTD	Protocol Translator Device
RPG	Rocket Propelled Grenade
SAE	Society of Automotive Engineers
SDIS	Smart Display
SPAD	Signals Passed at Danger
TAM	Technology Acceptance Model
TO	Trip Optimizer