IDEA

Innovations Deserving
Exploratory Analysis Programs

Transit IDEA Program

Augmented Reality Dispatcher Interface

Final Report for
Transit IDEA Project 92

Prepared by:
Carl Stanton
Ross & Baruzzini | Macro

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TRB TRANSPORTATION RESEARCH BOARD
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IDEA Programs
Transportation Research Board
500 Fifth Street, NW
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Augmented Reality Dispatcher Interface

IDEA Program Final Report

For the period *January 2019* through *April 2021*

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Carl Stanton
Ross & Baruzzini | Macro
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Investigator Profiles

Carl Stanton, PMP, Lead Investigator

Carl has 5 years of experience as a Transportation Consultant, as well as a Master's Degree in Industrial Design. Carl has with experience in Design, Project Management, IT, and Education. Carl has worked on a range of Transit and ITS projects with both large and small agencies across North America, and with ITS clients abroad.

Mark Talbot, PE, Assistant Investigator

Mark has over 22 years of experience as an engineer and more than 17 years as a project manager for many transit communication systems including the design of several Operations Control Centers involving a broad range of Intelligent Transportation Systems. His experience includes consulting engineering for many transit clients in North America, Europe and Asia.

360 World

360 World is Hungarian company specialized in Augmented Reality research and development for various industries. Clairity is the company's Traffic Management platform which can display live or simulated data stream superimposed on the real world or in tabletop view. www.360.world

NDP systems

NDP Systems is a full-service software company based in France. The founder and CEO, Nicolas Pigneau, created the TS2 simulator as a hobby project, and Ross & Baruzzini | Macro contracted with NDP systems to modify the TS2 simulator.

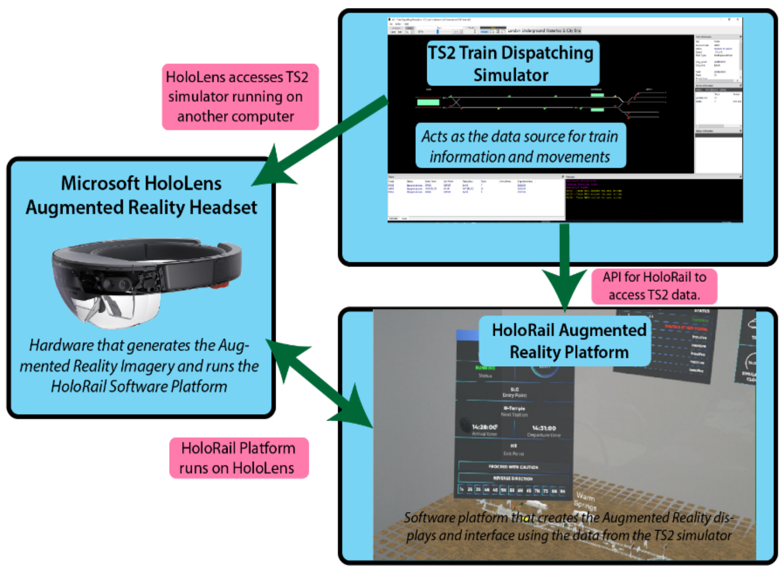
Executive Summary

This report summarizes the accomplishments and work performed by Ross & Baruzzini | Macro during the Transit IDEA project “Augmented Reality Train Dispatcher Interface.”

The purpose of this proof of concept project was to determine the viability of leveraging the emerging technology, Augmented Reality (AR) as a new user interface for train dispatching. The result was HoloRail, a train dispatcher user interface that uses AR to recreate the current displays in 3D. Dispatchers experience a track layout superimposed in their existing setting and can still see and hear what goes on around them. This new interface allows dispatchers to use hand and head movements, along with voice commands, to manage the same things that they do currently on their multi-monitor displays, such as; track diagrams, alarms, train and station information, and setting of train movements.

HoloRail was built by combining an off the shelf, open-source train dispatching simulator (NDP Systems’ TS2) as its back end, and 360 Worlds’ Clairity AR platform to create the AR displays. The Microsoft HoloLens Augmented Realty Headset was chosen to run the AR user displays.

Figure 1: Project Concept Diagram



Dispatchers and control center staff from Utah Transit Authority (UTA) and Metro Atlanta Rapid Transit Authority (MARTA), agreed to be partners on the project and provided staff time to determine the requirements, perform user testing, and provide feedback on the outcome of the pilot.

To derive user requirements, Ross & Baruzzini | Macro project staff met with Utah Transit Authority Frontrunner (UTA) in March of 2019, and Metro Atlanta Rapid Transit Authority (MARTA) in May of 2019. Meetings were held with two different groups of dispatchers and other operations staff. Each person present was given an opportunity to use the Augmented Reality environment. UTA and MARTA also provided functional information on their current train control systems to support requirements definition.

The completed HoloRail platform was tested by dispatchers from UTA in February 2020 and MARTA in September 2020. (The user testing with MARTA was conducted virtually due to COVID-19. More information in section 5.6.1)

A total of 11 dispatchers and two support staff members participated in the testing. The testing was conducted in a series of one-on-one sessions with each dispatcher. Each session consisted of a short tutorial on how to interact with the AR interface, followed by dispatchers testing the HoloRail platform using the agreed upon test procedures.

Feedback from each session was collected voluntarily from an online questionnaire. Ten of the 13 testers responded to the survey.

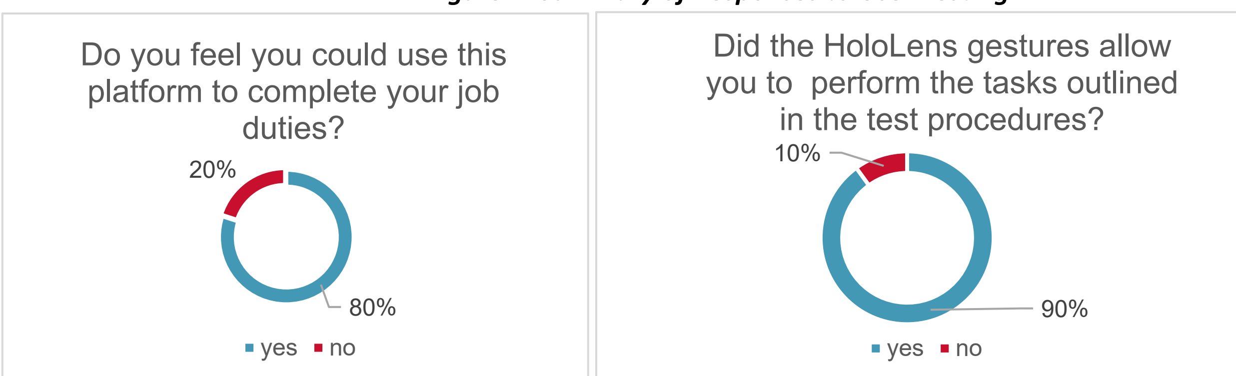
Summary of Findings:

HoloRail proved to be a viable solution for train dispatching and was positively received by the participants. Though the headset technology is not yet where it needs to be, too heavy, not comfortable, poor battery life; within the next few years, these limitations will no longer be a problem.

Of most importance, 90% of the dispatchers were able to complete the test procedures without assistance only after a 10-minute training tutorial on using the equipment and software. 80% of the respondents said they felt they could use the platform to complete their job duties.

A WIFI hotspot tethered to a laptop provided enough bandwidth to transmit both the live video stream from the wearer and the communication between the server and AR platform, proving that standard WIFI networks would be sufficient for this technology and major upgrades would not be needed.

Figure 2: Summary of Responses to User Testing



The limitations described by study participants are generally related to the current state of the AR glasses technology and the limitations of the TS2 train dispatching simulator.

The next generation of AR glasses currently in development will significantly improve the user experience by expanding the field of view and a reduction in the size and weight. The study participants agreed that the HoloLens is too bulky and heavy making it impossible to wear for an 8-hour shift, so the next generation will need to look and feel like regular glasses. It is speculated that Apple plans its first AR headset in 2022, while Facebook has partnered with Ray-Ban's parent company Luxottica to develop AR glasses that look and feel like regular eyeglasses scheduled to launch between 2023 and 2025.

A follow-up study should be undertaken, that includes an interface between the AR glasses and a train dispatch system currently in use by dispatchers. In the case of MARTA, the Alstom TMS system could be upgraded to support an interface to the AR glasses so that the control system displays and data are familiar to the users allowing a direct comparison between the user of current display technology and the AR experience.

Idea Product

Overview

The HoloRail Augmented Reality Platform is a proof-of-concept Augmented Reality Transit Dispatcher Interface. The purpose of this proof of concept is to explore the potential of Augmented Reality as a dispatching platform. This proof of concept contains a limited number of dispatcher functions while still allowing users to have a relatable dispatching experience while keeping the proof of concept within the limited budget.

The Holorail platform consists of the following components:

Key Components

TS2 Open Source Train Dispatching Simulator: the TS2 Train dispatching simulator is a free and open-source train dispatch simulator that simulates the essential functions of train dispatching, including setting and clearing routes, managing crew and consist information, ensuring adherence to schedule, and alarm display. The TS2 simulator functions as the data back-end for the Augmented Reality Interface.

HoloLens Augmented Reality Headset: Although there are several different Augmented Reality headsets on the market today, the HoloLens is the most sophisticated, and is the platform that the Clairity AR software is built to work on. The headset runs on windows, making it the most consumer and developer friendly option for this project.

Clairity Augmented Reality Platform: This platform includes floating monitor displays for reference information, as well as a 3D map. For this proof of concept, the floating monitor displays enable dispatchers to view information such as alarms, schedules, train info, and other relevant information, and the track diagram that dispatchers use to route trains will be a 3D interactive map.(More info on this platform can be found here: http://360.world/clairity/)

Historically, Operations Control Center (OCC) visualization technology has been provided by using large, overhead display walls. The placement of user consoles based on sightlines needed to ensure optimal viewing of specific rail territory defined the amount of infrastructure as well as the overall layout of a control room. Augmented Reality (AR) can transform the way control rooms deliver visual information to operators, as well as the way they interact with that information.

Moving to an AR headset, like the Microsoft HoloLens, is a significant change to the current ways in which operators in a control room perform their functions. It has the potential to provide each operator with greater situational awareness yet would require an operator to learn a whole new way of working.

Background

Augmented vs Virtual Reality

Augmented Reality (AR) is an interactive experience of a real-world environment where the objects that reside in the real world are enhanced by computer-generated perceptual information, sometimes across multiple sensory modalities, including visual, auditory, haptic, somatosensory and olfactory (as defined by Wikipedia).

Virtual reality (VR) refers to a computer-generated simulation in which a person can interact within an artificial three-dimensional environment using electronic devices, such as special goggles with a screen or gloves fitted with sensors.

AR was chosen for this pilot, due to its ability to give the wearer situational awareness to what is happening in the control room and not immerse them in a private world. The ability to interact and understand what is happening around the wearer was deemed essential for this undertaking.

Microsoft HoloLens

Ross & Baruzzini | Macro chose the Microsoft HoloLens as the Augmented Reality headset for this project because it has the best-developed user interface and software development platform. The Hololens is a full-featured Windows 10 computer and uses the Microsoft Kinect technology to detect objects and hand movements.

Known hardware limitations

There were two hardware limitations that Ross & Baruzzini | Macro identified at the beginning of this project that could have affected the project's success. They are as follows:

Field of view

The field of view on an Augmented Reality headset is how much of the total area of the wearers' vision the Augmented Reality imagery can be generated on. Human eyes can see around 160 degrees, and the Microsoft HoloLens field of view is about 45 degrees, which means that the AR imagery only appears on the center third of the user's vision. The field of view restriction means that users have to move their head in order to see items not directly in front of them. If a train dispatcher is working with a large track model much of it would be outside the field of view at any given time.

Headset bulkiness

Because of the hardware and batteries necessary to make the HoloLens a full-featured computer, the headset is noticeably bulky, and the weight of the headset caused discomfort for many users with less than hour of use.

Concept Innovation

Overview of Innovation

The use of Augmented Reality instead of a traditional computer screen is the primary innovation in this project. Control centers today are constructed around, and constrained by, the 2D displays. The multi-monitor setups for dispatchers and the viewing of overview displays severely limit how control centers can be laid out. As Augmented Reality can dynamically generate imagery within the user's field of view, display sizes are not limited by the size of a screen. The Augmented Reality headset can also connect to server backends wirelessly, which means dispatchers are no longer constrained to a specific location in a control theater.

Technical basis and Uniqueness

Dynamic Generation of Imagery

Augmented Reality is fundamentally different than traditional 2D screens because of how it generates the imagery. 2D screens generate imagery within a static space: a screen that is fixed to a single location. This means that the user must focus at that location in order to see the information displays. Augmented Reality Headsets, such as the HoloLens, dynamically generate imagery into the users' field of view and are able to detect and track when the user moves their gaze. This allows an Augmented Reality display to be any size that is desired by the user and anywhere the user moves their head.

3D: A Whole New World

Another unique aspect of Augmented Reality is its ability to create 3D imagery. 3D removes important constraints that 2D train dispatching systems have. For example, a 3D display can show informational panels above trains without blocking the dispatcher's view of train movements. Another advantage of 3D is it allows for more viewing angles of the track layout. For example, a 2D track layout can only be rotated along a single plane (the screen), and since both display screens and track layouts tend to be much longer than they are wide, track layouts are generally oriented horizontally for maximum visibility. In a 3D display environment, there are 3 planes of movement for a track display (up-down, left-right, and side-to-side), and because the display size is not constrained by hardware the entire track layout can be visible in a much wider range of orientations.

Customization & Collaboration

Customization

In an Augmented Reality control center environment, both the Dispatcher's area of responsibility (Territory) and the overview display common in control centers, are entirely created by software. Since each user in an Augmented Reality control center has their own headset displaying imagery to them, their overview display can be customized without affecting other user's overview displays.

Each user having their own headset also allows each dispatcher to customize the layout of their overview display without affecting the layout of the dispatcher that they hand off that territory to. For example, at a large rail control center, Dispatchers may only want to put the adjacent territories or lines to their area of responsibility on their OVD (Overview Display) instead of all territories. Some dispatchers may also want their OVD to be zoomed in more than other dispatchers. Dispatchers could also have multiple OVD configurations that they would toggle between depending on what they are doing.

Collaboration

One of the tradeoffs of Augmented Reality in the control center is that unlike physical screens, where anyone nearby can see what is on them, only the wearer can directly see what is being displayed on an Augmented Reality Headset. This means that other people are not able to walk over to a user's console and see what that user sees, as they can today.

Augmented Reality software platforms are still capable of allowing collaboration in a variety of ways, which range from something akin to "screen sharing" on a desktop computer to a more immersive "telepresence" type experience. Users are placed into a common virtual space where information can be viewed by everyone in that space. Although these collaboration methods require control center managers to also have headsets, they also enable dispatchers and managers to collaborate with each other at a distance. Overview displays are most important and useful to control center managers, and an AR dispatching platform gives managers more options for OVD views, layouts, and customization then they are currently able to have today.

Investigation

Preliminary User Research:

To derive user requirements, Mark Talbot and Carl Stanton, of Ross & Baruzzini | Macro, met with Utah Transit Authority at their FrontRunner division office in Salt Lake City on March 29th and 30th, 2019. Subsequently, Carl Stanton met with Metro Atlanta Rapid Transit Authority at their Control Center in Atlanta on May 21st and 22nd, 2019.

Meetings were with two different groups of dispatchers and other operations staff, and each person present was given an opportunity to use the AR environment. A list of several useful observations, requirements and questions was compiled from this user research.

UTA and MARTA also provided functional information on their current train control systems to support requirements definition, as well as track layouts, schedule, and consist information, that was used to build simulations of their service.

Requirements Document:

The requirements for the Augmented Reality interface were developed based on the discussions with, and feedback from, the on-site user research. The requirements were reviewed and updated based on feedback from UTA and MARTA, as well as 360 World. The requirements document was signed off by both agencies in June of 2019.

The success of the proof-of-concept product was evaluated based on the following criteria:

The ability to:

Display Track layout and trains in 3D

View information about trains, services, equipment, and stations

Monitor on-time performance

Route trains

Leverage gesture and voice inputs

Test Plan and Test Scenarios:

A Test plan and a list of test scenarios were developed by Ross & Baruzzini | Macro after the requirements were complete. These scenarios created the structure for the test scripts that were developed at the completion of the Augmented Reality Interface build. The scenarios and success criteria were also signed off by the agencies in October of 2019.

Train Simulator Updates:

The NDP Systems simulator was re-engineered to have an API that allows the AR interface to access simulator information. The simulator functions as the back-end "server" for the AR interface. NDP systems completed the train simulator API in May 2019.

Augmented Reality Interface:

The Augmented Reality interface development was completed in December 2019. The interface was developed iteratively, with each version of the software incorporating more and more features. Each version of the software was tested and reviewed by Ross & Baruzzini | Macro. Internal testing occurred through January 2020, with system signoff occurring in February 2020.

User Research:

A structured simulation of UTA's and MARTA's current operations was completed using the developed AR interface. Operators were trained on the interface for the first part of the simulation, to the point that they felt comfortable with using it.

Onsite user testing with UTA was conducted on February 24th and 25th, 2020, at UTA Frontrunner offices in Salt Lake City, UT. Ross & Baruzzini | Macro led six one-on-one testing sessions with dispatchers and managers from UTA.

Onsite User testing with MARTA was scheduled for March 24th and 25th, 2020 at MARTA's control center; however, this testing was postponed due to the coronavirus pandemic.

Virtual User testing with MARTA was completed on September 8th, 2020. Ross & Baruzzini | Macro led five one-on-one testing sessions with dispatchers from MARTA.

Data was gathered from observing operator input through the livestreaming feature of the HoloLens during and after the simulation, as well as by having the operators complete an online survey.

Virtual testing plan

A plan to conduct this user testing virtually, was created by Ross & Baruzzini | Macro, and agreed upon by MARTA. Ross & Baruzzini | Macro provided all equipment necessary for completing the virtual testing, which consisted of the HoloLens AR headset, a laptop to control the simulation and provide remote access to the HoloLens (already part of the onsite testing procedure), and external speakers to ensure that testers could hear instructions from Ross & Baruzzini | Macro.

This equipment was shipped to MARTA, and MARTA provided staff support to set up the equipment, clean the headset in between testers, and troubleshoot any technical issues that arose during the testing. Ross & Baruzzini | Macro was able to communicate with the testers using Microsoft Teams, and through the livestreaming feature of the HoloLens, was able to see what the testers were seeing in real time.

Research Findings

Typically, railroaders are slow to change, especially when it comes to technology adoption. Based on that experience, it was uncertain how this pilot and the Augmented Reality interface would be received. However, the overall results of the user testing were surprisingly positive.

Augmented Reality Technology

The AR hardware is the largest limitation in implementing HoloRail. Headset bulkiness and battery life are both serious limitations.

In user testing, the headset battery lasted between 2 and 2.5 hours. Since dispatcher shifts are generally eight or more hours long, significant improvements in battery life are required for the headset to be usable in a production environment.

Additionally, the headset became uncomfortable to wear after about an hour. There were more issues when it came to those wearing glasses and/or head coverings.

User testing

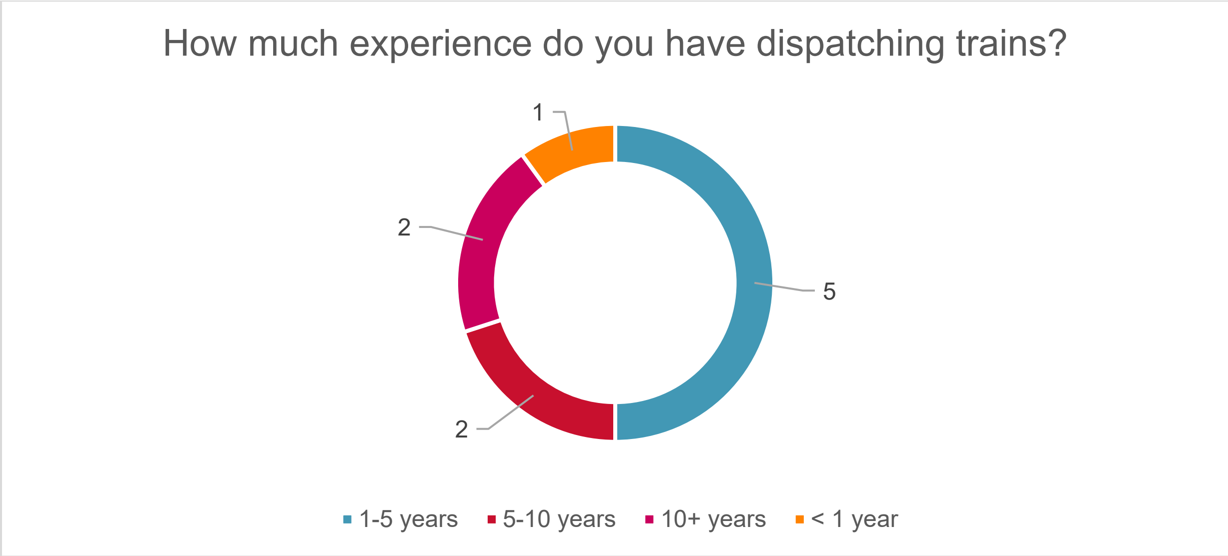
The below table summarizes the findings from the feedback questionnaire completed by the agency personnel who tested the HoloRail Interface.

Table 1: Summary of findings

Responses to user feedback survey	**Total respondents from UTA: 5** **Total respondents from MARTA: 5** **Total Respondents: 10**			
Survey questions	Responses			
	<1 year	1-5 years	5-10 years	10+ years
How much experience do you have dispatching trains?	1	5	2	2
	Yes	No		
Did you feel you were trained enough to use the AR interface?	9	1		
Was the headset comfortable to wear for the duration of the test?	6	4		
Do you currently dispatch trains?	9	1		
Do you feel you could use this platform to complete your job duties?	8	2		
Did the HoloLens gestures allow you to perform the tasks outlined in the test procedures?	9	1		
Were you able to clearly see all objects and read all text?	7	3		
	Yes	No	Maybe	
do you think this has a future as a train dispatching platform?	4	1	5	
	Yes	No	If the tech improves	
Would you use the AR platform again?	4	1	5	

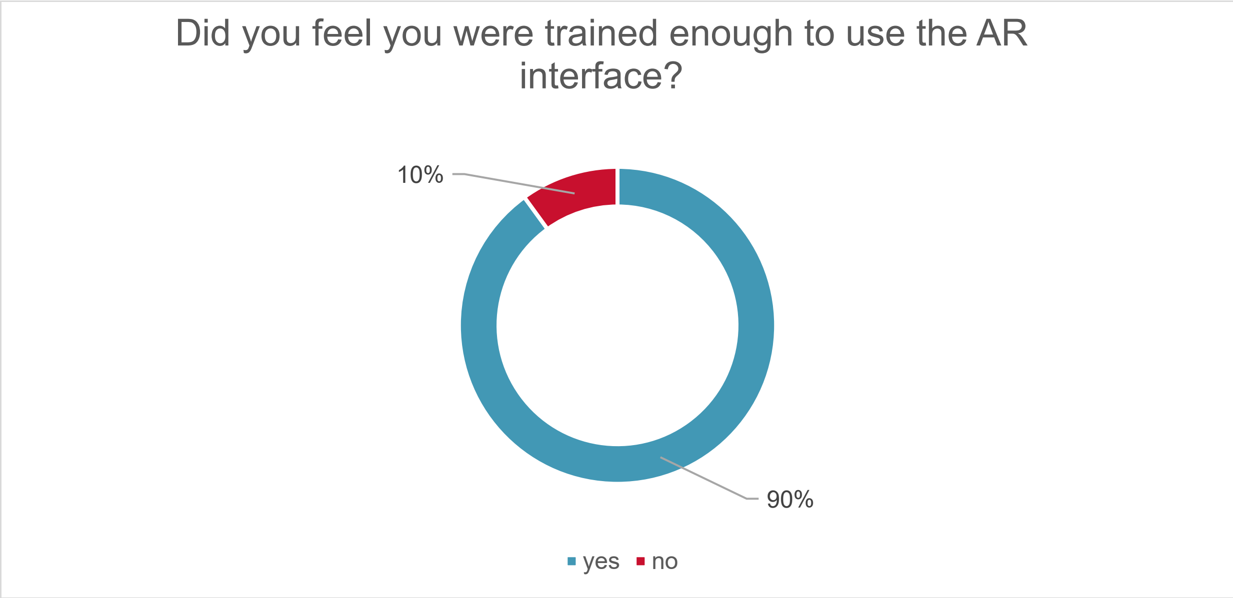
The charts on the following pages contain more detailed breakdowns of the data shown in the above table.

Figure 3: experience dispatching trains



As shown above, the testers had a range of experience with dispatching trains. Having this range of experience was important to see how the experience of a dispatcher affected their use of and opinion on the AR platform.

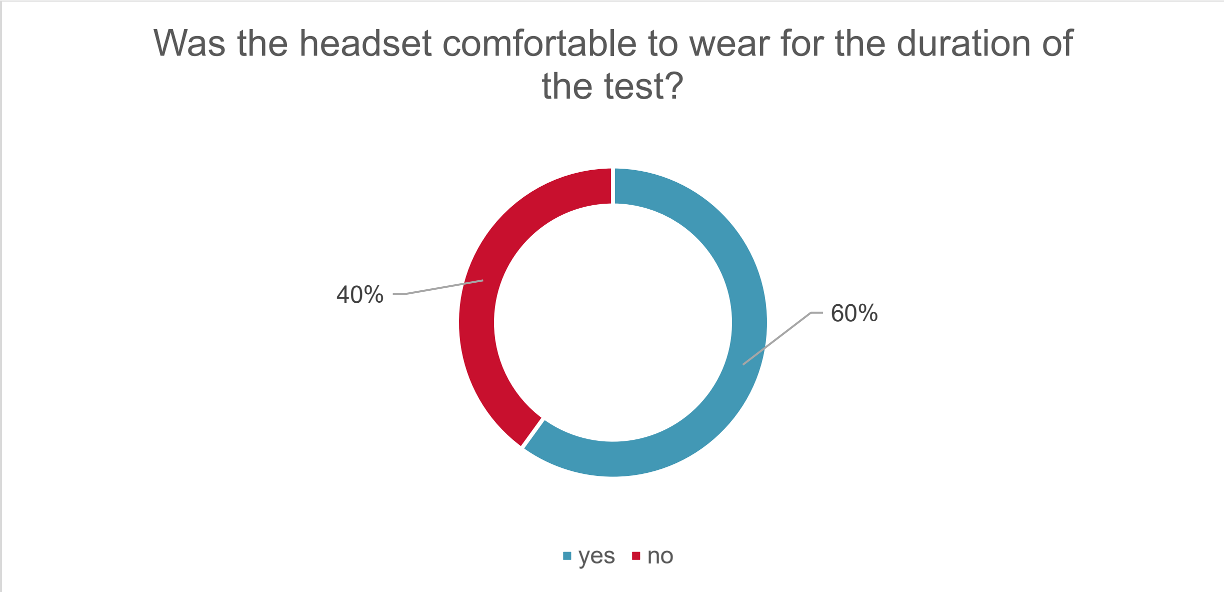
Figure 4: AR Interface Training



This result was the most surprising of all the feedback received and could have the most impact to leveraging this technology in the future.

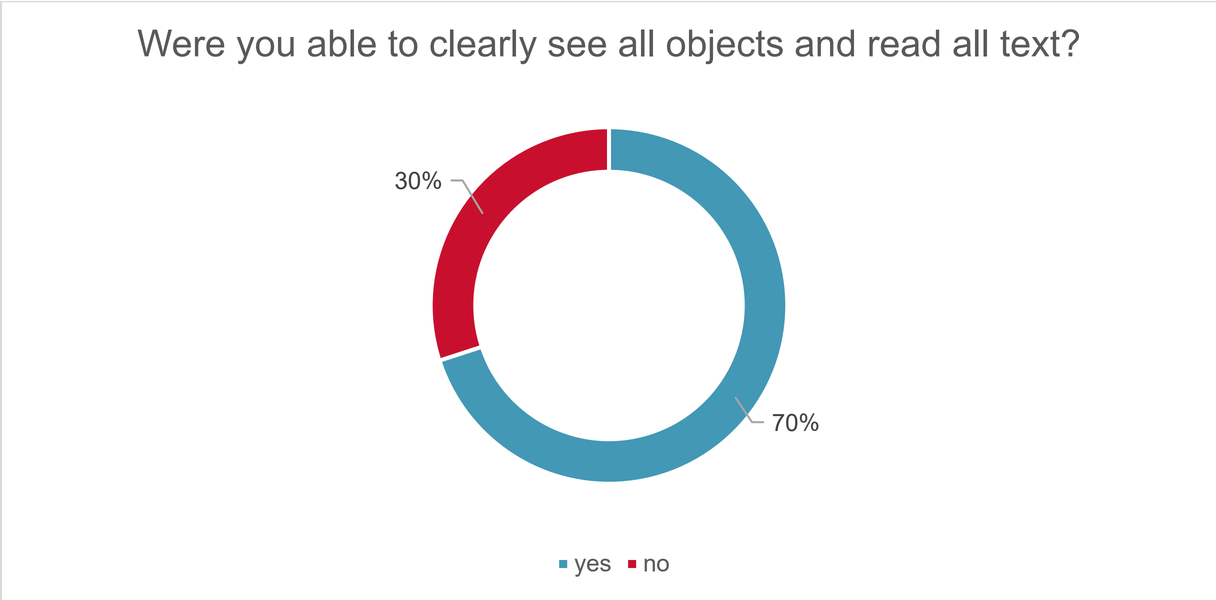
Each dispatcher received just ten minutes of training on how to use the Augmented Reality Interface. As it turns out this was sufficient 90% of the time. The finding also aligns with the experience of Ross & Baruzzini | Macro personnel who conducted internal testing.

Figure 5: Headset Comfort



As discussed in Section 2.3.2, headset comfortability was discovered early in the project as a limitation of current Augmented Reality Technology. Additionally, the testing was usually around an hour for most participants. Had the dispatchers worn the headset longer, the results likely would have been worse.

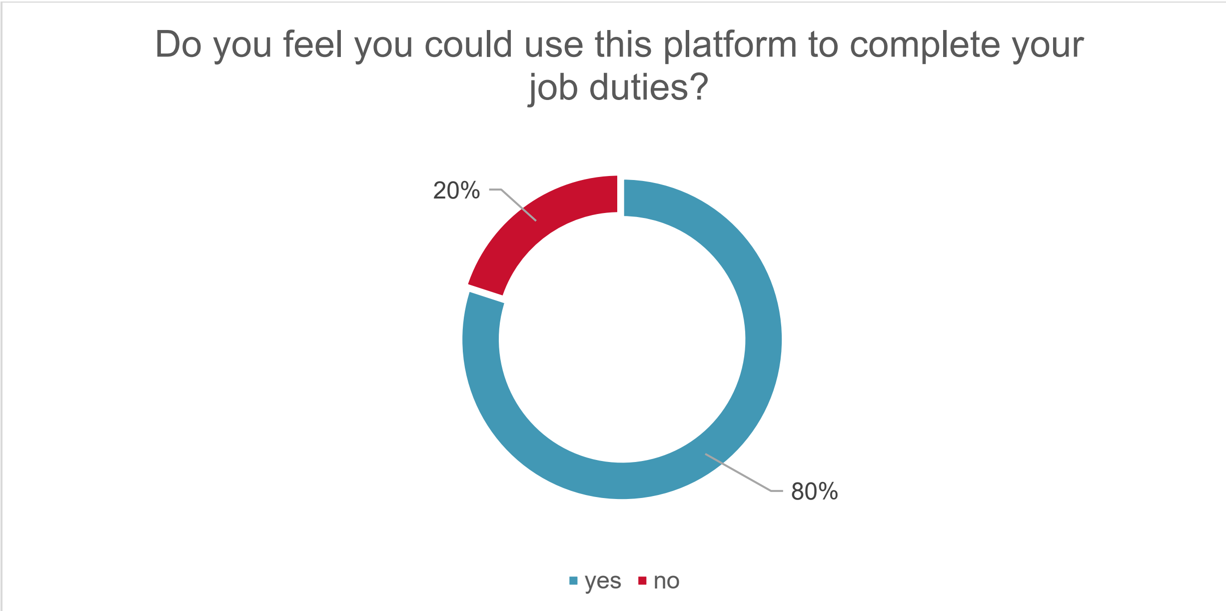
Figure 6: Object and Text Visibility



The visibility of objects and text in the AR environment can be improved either through further software enhancements or by changing the physical space that the headset is being used in.

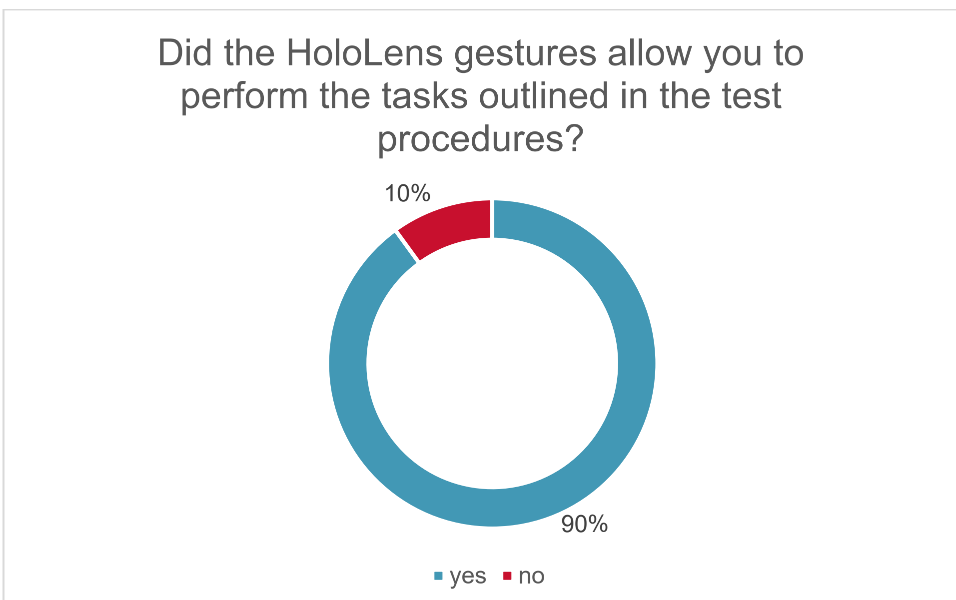
The results show that most participants had no issues with legibility.

Figure 7: Completion of Job Duties



At the beginning of this project we were uncertain if dispatchers would find the AR platform useable. This feedback in encouraging for the viability of this technology in a future control room.

Figure 8: Completing Test Procedures



The results matched the responses to the question regarding training, meaning that the same person who did not feel that they had sufficient training to use the interface also felt that they were not able to use it to complete the test procedures.

Figure 9: Using AR Platform Again

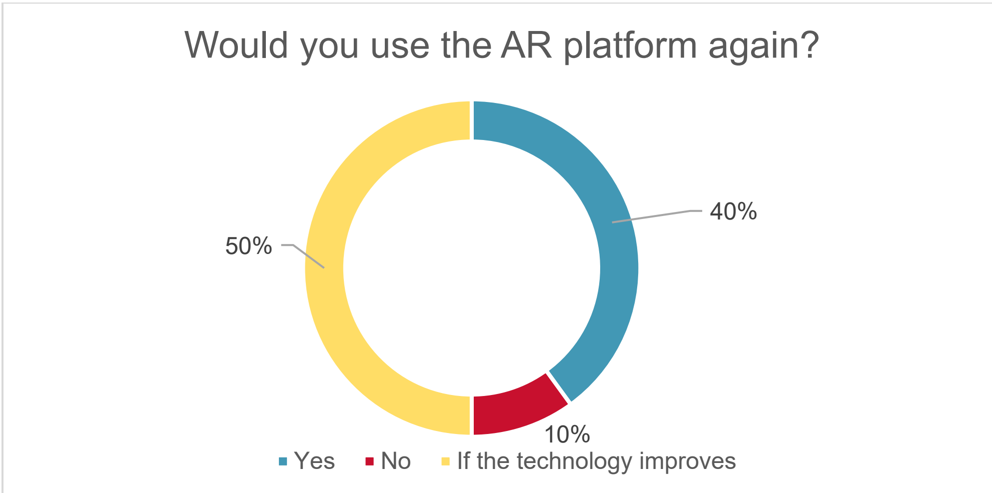
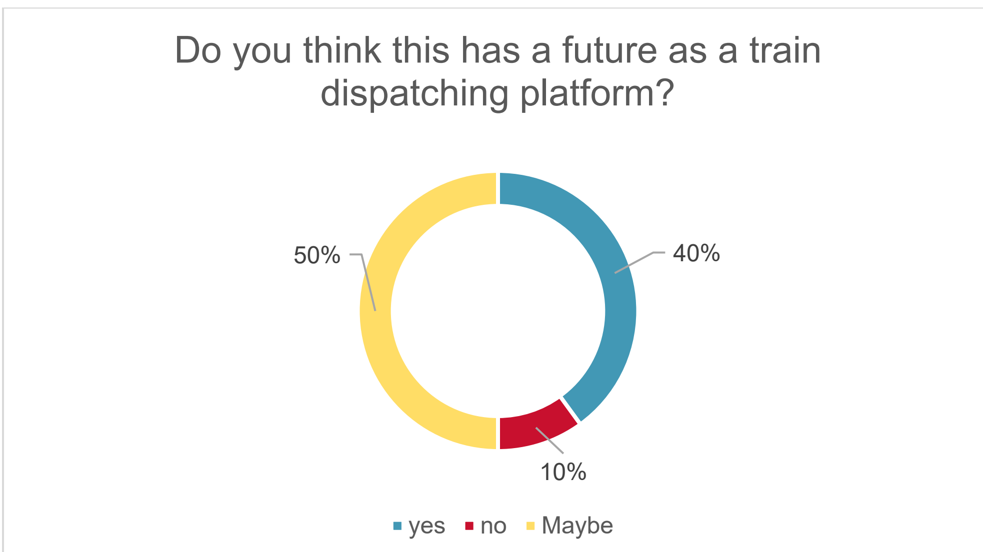


Figure 10: Future as a Dispatching Platform



The results are encouraging for the viability of AR as a future dispatching platform in a control room. Although as shown in these findings the Augmented Reality technology will have to improve before it can be implemented in a production setting. Section 8 details the conclusions and lessoned learn from the user testing.

Plans for Implementation

There are no current plans to further the implementation of the concept. The development of AR technology is progressing rapidly, so options for implementation will dramatically increase in the next 5-10 years. There are also other possible use cases to be explored for AR and VR in transit that were outside the scope of this project.

Possible benefits of AR Control centers

Layout flexibility

In an AR control center, many of the layout constraints that exist in current control centers disappear. Dispatcher's consoles and OVD video walls are both replaced by wearable headsets In an AR control center, resulting in dispatchers no longer being anchored to a specific location in the control room. This removal of constraints creates opportunity for large scale re-envisioning of what a control room could be in the future. Additionally, it opens possibility for other work environment options, like co-location or work from home.

Cost savings

AR headsets replacing dispatcher consoles and OVD video walls will likely result in significant cost savings in building out a control center. This cost savings is even more pronounced for backup control centers, since a full replication of consoles and OVD's is not required. The exact amount of the cost savings is currently difficult to predict, but because of the rapid development of AR technology happening right now, the cost savings is likely to grow as the hardware becomes less expensive.

Remote collaboration

Augmented Reality software allows for users to virtually collaborate with each other without leaving the dispatching environment. (This collaboration works similar to how people can collaborate virtually today using screen share on a video conferencing platform.) This remote collaboration could allow control center staff to collaborate with each other without being physically in the same room/building.

Virtual co-location

The remote collaboration discussed above opens up the possibility of virtual co-location of control centers instead of physical co-location. As the cost of physically co-locating different control centers can be quite significant, virtual co-location allows for new options for agencies who currently cannot afford it.

Disaster/pandemic responsiveness

This technology could enable transitioning to an alternative backup or remote control center setup more seamlessly in a disaster or pandemic scenario. Given that AR headsets are portable, and only require power outlets for charging and wireless connectivity to the control system servers, it would be relatively inexpensive to create spaces where dispatchers could come with their headsets and set up a control center during an evacuation, or when physical distancing is required as a result of a covid-like pandemic.

Barriers to implementation

Headset weight

Based on both internal and user testing feedback, the current AR headset is too bulky and uncomfortable to be used in a full production setting. Some level of technological advancement in AR hardware is necessary to decrease the size and weight, but the exact level of advancement varies depending on how much an agency is willing to spend on custom hardware.

Battery life

Under continuous use the headset's battery lasted around 2.5 hours, which is far below the 8-10 hours required in an implemented system. A significant increase in battery life, potentially combined with hot swappable batteries, would be required to make a headset usable for the full dispatcher shift.

Train Dispatching System API

In order to implement an Augmented Reality Display system, API's are required between the train control system and the Augmented Reality Display System. Current train control systems are sometimes stand-alone, closed loop systems, so significant, often costly, modifications would be required to support existing control systems to support an Augmented Reality Display interface.

Change management/culture shift

Change within transit agencies, particularly around operations, has traditionally been a slow process. In many of the control center upgrade projects that Ross & Baruzzini | Macro has been a part of, managing changes to operations and how personnel do their job has been challenging. As an Augmented Reality control center would likely result in larger changes to processes and adoption of new technology, than previous control center upgrades, the change management challenges could be significant.

Other use cases

During the preliminary research conducted by Ross & Baruzzini | Macro, and during the user research several other use cases for Augmented Reality in transit surfaced. These additional use cases were outside the scope of this project, but some are already being explored by others. These use cases include:

Training

There have already been explorations in using both AR and VR for training in a variety of industries, including transit. Uses cases for AR in training include field maintainers, dispatchers, and operators/engineers.

Remote maintenance

Remote maintenance is one of the most explored use cases for AR in transit to date. An AR solution for remote maintenance involves a field technician wearing an AR headset collaborating in real-time with one or more people in a remote location. The remote collaborators can see what the wearer is seeing and can highlight items in the wearers field of view. Technicians can also pull up detail technical information and specifications, and potentially have that information overlaid onto their field of view. Several agencies have participated in pilots and proof of concepts.

Bus dispatching

An Augmented Reality Train Dispatching platform could be adapted for bus dispatching. An AR bus dispatching platform could display map views of bus locations, along with information panels. The 3D display environment allows information panels to be open without interfering with other important views, which could improve situational awareness. AR in bus dispatching could leverage the 3D environment to convey important information, such as changing the size and color of buses based on on-time performance or bunching. An AR bus dispatching system could also allow dispatchers to seamless integrate camera feeds.

Future Testing

If the testing of AR in the control center was taken further, the next step would be to build an AR dispatching platform that interfaced with an existing train dispatching system. This would require a partnership with a train dispatching software vendor, as well as, one or more transit agencies who are customers of that vendor.

Conclusions

This report summarizes the work performed toward the objectives of the Transit IDEA project "Augmented Reality Dispatcher Interface." The purpose of this program was to determine the feasibility of using an AR platform in an OCC environment.

Project Objectives

The project objectives have been accomplished. This interface is functional, and dispatchers can complete basic train dispatching.

The overall reception from our agency partners was more positive than expected. As discussed in section 6.2.4, transit operations staff are sometimes reticent to change, and going into this project Ross & Baruzzini | Macro was uncertain how this new technology would be received by our agency partners. Throughout this project we received overwhelmingly positive reactions from the agency personnel we interacted with, and as shown in the feedback collected, most of the testers felt the technology would be viable in the future.

As shown by the results of user testing, 80% of the dispatchers felt that they could use this platform to complete their job duties, such as dispatching trains, viewing schedules, and managing on-time performance. As this proof of concept did not include all the features typically found in a train dispatching system, and not all the testers felt they could use the platform to complete their job duties, more development and testing is required in the future, however the potential is clearly there.

Viability of Technology

Based on user research and user testing, we have concluded that Augmented Reality is a viable technology for a future control room. As shown in the results of the user testing, large majorities of the testers said that they could use this technology to complete their job duties, and that AR could be used in a control room in the future (Provided the technology improves). User testing also showed at the interface is intuitive enough that it does not require significant training, as 90% of testers were able to complete the test procedures with 10 minutes of training. Although there are some limitations with the hardware (which will be discussed in detail in the next section), the current hardware worked well enough to prove the concept.

Current Limitations

The biggest limitation was the AR hardware. Significant improvements to battery life, field of view, and headset size/weight are required before any transfer to practice can happen.

Battery Life

As discussed in section 5.7, the current battery life of the HoloLens headset is around 2.5 hours when in continuous use, far below the 8-9 hours required for use in a production environment.

The HoloLens is an off-the-shelf product that was designed to be "affordable" to the general public, and as a result, tradeoffs were made on hardware performance to keep the price down. If a custom headset was built, it is possible that the battery life could be extended to eight hours with current technology. Battery technology is also advancing rapidly, so even if it is not possible with current tech it will be possible in the next few years.

Field of View

The field of view limitation discussed in section 2.3.1 turned out to be less of a problem than anticipated. Because users turn their head to move the cursor, what they wanted to look at, generally, remained within the limited field of view. Improving the field of view is important for a future implementation that supports overview displays, since improving the field of view makes the Overview displays easier to see.

The part of the HoloLens headset that generates the AR imagery (And therefore defines the field of view), is the most expensive component of the headset. As discussed above, a custom hardware solution where cost is less of the concern, would significantly increase the field of view.

Headset bulkiness

The Microsoft HoloLens headset is currently quite bulky and weighs enough that 40% of the testers found it uncomfortable to wear. During internal testing, Ross & Baruzzini | Macro found that after an hour of continuous use the weight of the headset caused discomfort in the neck and on the bridge of the nose. Much like the battery limitations discussed above, building a headset with custom hardware would likely reduce the bulkiness of it.

Another way the headset could be made less bulky would be to tether it to a computer in order to operate instead of using WIFI. Most current headsets are built as stand-alone, wireless devices. Tethering is typically not a desired feature for most current users (gamers). However, this might not be the same in a real-world control room environment.

Cost analysis

An AR interface could have several advantages over current DMS (Display Management System) technology from a cost perspective. For the purposes of this cost analysis, the focus is on what would change in an upgrade from a traditional control center to an AR control center. Since there are no existing AR interfaces for operators in a control room to use, a full quantitative analysis is not entirely possible, so several assumptions had to be made. The assumptions are detailed in sections 4.1 through 4.7 below. This cost analysis focuses on hardware upgrade costs for a 20-person control room by comparing the cost of hardware components needs in an AR control room with the cost savings from hardware components no longer needed in an AR control room.

Table 2: 20 Person Control Center Upgrade Cost Comparison

20 person control center upgrade comparison			
AR Specific components	Units	Unit Cost	Total Cost
Headset	110	4,000	440,000
Wireless connectivity	10	1000	10,000
Network switch	1	7000	7,000
Wireless network setup	1	15,000	15,000
AR hardware total:			472,000
Dispatching system API	1	200,000	200,000
AR Display platform	1	175,000	175,000
AR software total:			375,000
AR total:			847,000
Systems not needed	Units	Unit Cost	
Video wall	36	25,000	900,000
Console monitors	60	150	9,000
Back up Video wall	24	25,000	600,000
Backup Console monitors	40	150	6,000
Total Systems not needed:			1,509,000
Total Cost savings:			662,000

Explanation of Cost Analysis

AR headset

In an AR control room, each person would need their Augmented Reality headset. When they are not on duty the AR headset will have to be stored and charged safely. The estimated cost of 4,000 per headset is the high end of the range of the current prices of AR headsets. The estimation of 110 headsets assumes that all personnel on all shifts have their own headsets that only they use, as well as a 10% spare ratio.

Wireless connectivity and setup

The Augmented Reality headsets connect to the train control system using WIFI, so that dispatchers are not required to be tethered to a specific location in the room. All hardware prices listed are typical for commercial installations.

The wireless installation and setup costs include installing the access points, running the cables, and the necessary network design work.

Dispatching System API

This API is necessary to allow the AR Display Platform to work with the train dispatching software. Building this API one-time cost that is only necessary the first time a control center is upgraded to AR, so all future upgrades after the first one will not include this cost.

The estimate of $200,000 for this interface is set at ten times the cost of building the API into the TS2 simulator for the Augmented Reality Dispatcher Interface because of the complexity of the train control software on the market today.

The maintenance costs of this API would be included in the overall maintenance contract for the dispatching system, however communication between the maintenance teams for this API and the AR Display platform is required.

AR Display Platform

The AR display platform is an entirely new GUI that is built to display the information from the dispatching software to the user. The estimate of $175,000 is set at 5 times the cost of building the AR platform from the AR Dispatcher Interface Proof of Concept because many additional features and integrations are necessary for a production AR platform than were needed for the proof of concept, and this cost is lower than the cost for the API because similar platforms already exist that can be built upon, and some of the mentioned integrations might be done on the back-end. Like the Dispatching System API this platform only had to be built once, and then can be adapted as needed for all future AR control center upgrades.

This AR Display platform will also require ongoing maintenance, which is assumed to be 20% of the overall cost each year, or $35,000.

Console Monitors

While AR is capable of entirely replacing workstations and LCD monitors, for the purposes of this analysis it is assumed that a workstation will remain for functions that are not integrated into the AR environment. As these are not dispatching tasks, fewer monitors are required for each workstation. The savings on monitors listed in table 1 assumed that workstations would change from having 4 monitors to having 1 monitor.

Spare headsets

To minimize downtime each dispatching center would need to have spare headsets ready to use if any problems arose with a dispatcher' headset. The costs detailed in table 1 above assume a 10% spare ratio. Spare headsets could also be used for guests and control center visitors.

Backup Control Center

The video wall and console monitor savings for a backup control center are included in this analysis because the AR headsets are portable and can be moved with the personnel from the primary to the backup control center.

Other possible Cost Savings

In addition to the items described above, there are other ways that AR could provide more cost savings in the control room. These include:

- Requires less costs to expand a control center.
- Less space and infrastructure required compared to a traditional control center.
- Ability to relocate equipment more easily (Headsets are portable).
- Maintenance and replacement of headsets could reduce long-term maintenance and upgrade costs.

Lessons Learned

Augmented Reality is a viable technology for a future control room. 90% of the dispatchers were able to complete the test procedures, and 80% said that they felt Augmented Reality Technology was viable.

Augmented Reality Hardware is the largest barrier to implementation of Augmented Reality in the control room. As previously discussed, custom hardware could potentially solve the current hardware limitations.

The gesture interface was easier for dispatchers to learn, and use, than anticipated. Due to how different the gesture interface is from traditional computer interfaces, we anticipated that using the gesture interface would be challenging for many users. As it turned out, only one of the ten dispatchers surveyed, had significant struggles using the gesture interface.

How certain functions are handled and executed by the back-end server affect how things are displayed in Augmented Reality. For example, the simulations that were loaded into the TS2 server were programmed to display the trains size, relative to the length of the track circuit, as opposed to showing the entire circuit as occupied.

This method makes the movement of trains smoother on the track model, however it also causes the displayed length of the train to fluctuate, as there is no consistent relationship between how long the real length of a track circuit is and how large it is drawn on the track layout. When the trains were rendered in 3D on the HoloRail platform, this fluctuation in size became more noticeable, and some adjustments were required to maintain a minimum train size so that trains were still easily visible.

In future implementations of an Augmented Reality train dispatcher interface, more consideration should be taken into how trains and trains movements are displayed to ensure they are easily visible and move in intuitive and logical ways.