Augmented Reality Airport Training System

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Design Challenge Addressed: Airport Operation and Maintenance Challenge E. Innovative applications including web-based solutions, for airport operations and maintenance

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Executive Summary

This report presents an innovative design solution for Airport Operation and Maintenance for the 2018-2019 ACRP University Design Challenge. We present a solution to Airport Operation and Maintenance Challenge E: “Innovative applications including web-based solutions, for airport operations and maintenance”. Airport operations training is facing a potential succession crisis as mid-level and senior operations personnel prepare to retire. Many airports do not have employees prepared to assume these positions, and institutional knowledge is in danger of being lost. This problem is especially severe in airport operations where most training is based on job shadowing, and institutional knowledge is often not written down but passed on during this training. Current training methods and training software have gaps in meeting the needs of airport managers. Insights gained from interactions with industry experts and literature review on potential improvements, helped us better understand the needs of the airport managers. These interactions provided us with information for multiple iterations during the conceptual design phase for this proposed training system. From our risk analysis and cost/benefit analysis, we show that Augmented and Virtual Reality (AR/VR) solutions have a large positive potential impact to improve airport operations training.

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Problem Statement

Airport operations personnel at airports struggle to maintain adequate training. This problem is typically compounded by a high turnover rate. This can lead to a low level of preparedness in emergency or non-standard airport operations. A majority of operations training focuses on job shadowing and takes a large amount of time, between 4 and 9 months depending on the airport.

Another challenge facing airports is a potential succession crisis within airport operations. Since line airport operations personnel typically stay in their position for about 2 years, and training is focused on shadowing, employees do not have much time to gain institutional expertise and can lose classroom specific knowledge related to procedures. Current high and mid-level airport operations personnel who have accrued a great deal of institutional expertise, are also preparing to retire. This continuous turnover cycle and low experience levels has generated a gap in operational safety and training.

Background

This project explores the idea of improving airport operations training through on-demand access. Through the innovative application of virtual and augmented reality (VR and AR) training devices, this training may be better suited to airport/airfield operations personnel needs than current training platforms allow. As airports face potential succession crisis and institutional knowledge may be lost, training becomes a particularly serious issue because airport operations have historically focused on job shadowing as the main form of training. This focus means that training materials and procedures are difficult to access or are informally passed from senior to junior employee through training interaction.

Our investigation has led us to believe that the integration of VR and AR technologies will improve the effectiveness of new hire training, recurrent training, and reduce the amount of knowledge lost when senior employees leave. According to *Tabletop and Full-Scale Emergency Exercises for General Aviation, Non-Hub, and Small Hub Airports,* many airports use tabletop or simulation-based training for Part 139 required recurrent training (Smith, 2016). These technologies will augment tabletop and current simulation-based training, allowing for more immersive and collaborative training. With the right digital infrastructure, airport operations teams can have access to a virtual training environment where events can be simulated reducing the cost of equipment procurement for the simulation. This platform could also allow combined training events with other airports or other agencies with similar digital capabilities anywhere in the world. Similar to the capability that already exists in gaming, the hardware for these airport training capabilities is readily available through many commercial vendors.

Literature Review

Airport Environment

Modern airports are facing a unique challenge to meet increasing throughput and staffing demands while maintaining safety and regulatory requirements. Current senior airport operations and airport management personnel are reaching retirement age, and many airports do not have adequate replacements available (Cronin, et al, 2016). Airports also have seen that employees do not stay in airport operations positions for very long, and the position has a large amount of upwards and sideways movement (Cronin, et al, 2016). These two problems combine to create a succession crisis in airport environments. Succession is usually planned well in advance and two or three levels deep (Cronin, et al, 2016). This approach is meant to ensure that the loss of one individual will not have a large effect on the organization, but currently employees are not staying in operations positions long enough to allow this (Cronin, et al, 2016).

Exacerbating a looming succession crisis are high turnover rates in airport operations. Airport operations is described by *Identifying and evaluating airport workforce requirements* as a mission critical occupation (Cronin, et al, 2016). Mission critical occupations are required to support the daily operations as well as the long-term strategic goals of the airport (Cronin, et al, 2016). The same report states that there is a lack of training and leadership development in these positions (Cronin, et al, 2016). The picture painted by this report is a job position that is critical to airport operations, with a high turnover rate, difficult training support, or leadership development opportunities.

Existing Software Solutions

At the time of writing, there are commercially available software solutions that have been developed for training for airport personnel. The existing VR training software is focused toward ground crew operations VR training with some also having basic training for mechanics and pilots. This leaves a gap in available software for airport operations personnel specifically, which this proposal intends to provide guidelines for filling. Five software solutions were found and are described below.

1. RampVR

   RampVR was created by International Air Transport Association (IATA) focuses on training and proper procedures for ramp procedures for commercial aircraft at airports. RampVR is only usable in VR and is in use by Qatar Airways for training ground personnel. RampVR is compliant with the Airport Handling Manual and the IATA Ground Operations Manual (International Air Transport Association, 2019).

2. EON Reality

   Eon reality has generated 4 AR/VR trainers that involve multiple aspects of the airport and airline. This includes Engine explorer which focuses on engineering students interactions with a turbine engine, Ground Crew VR training focused on Boeing 777 pre-flight checks with ground crew procedures, Aviation Maintenance Trainer where a student can perform an inspection regarding maintenance on an aircraft, and VR Airport

Security and Safety Training which focuses on an the need for practice regarding emergency situations. Airport security and safety training was selected by Avinor AS to conduct research on how VR training can be used prepare for real life disasters (EON Reality, 2019).

3. Tengo Interactive

   Tengo Interactive has developed a VR training software that acts as a course for ground handling of aircraft. Compared to the other software available Tengos model has the highest quality of 3D models for replication and freedom of movement/tasks. Tengo has received feedback about the quality of the training from IATA, Qatar Airways, and Heathrow airport (Tengo Interactive, 2019).

4. KPASS AIRPORT Virtual Experience (KAVE)

   KAVE focuses on Checking F.O.D, marshalling aircraft, aircraft walk around, tow bar connections, and pushback. KAVE contains an AR and VR components with the VR focused on a full immersive training with gesture recognition and real world like environments for training. In addition to the VR aspect they also offer a standalone AR which gives user the options to replay marshalling gestures in a rendered scene or place real world objects like a tow bar in a real-world space (KPASS Airport, 2019).

5. Prepar3D

   Prepar3D by Lockheed Martin focuses on VR training of all aviation aspects allowing for coordination between pilots and airport traffic control. This allows for all aspects of an airport to interact with each other in training focused on the interactions with each other (Lockheed Martin, 2019).

Augmented and Virtual Reality Hardware

For AR applications there have been prior prototypes in development for headsets such as Google Glass and Microsoft HoloLens. These products were never fully offered through the commercial market and were only available to a select few people for use in addition to the educational market for research and use. Most of the current AR products that have been adopted widely, primarily involve cellular devices, such as the Google Pixel, Samsung Galaxy S, and Apple iPhone. These devices have been primarily used as handhelds where the user will hold the phone to some object or in a designated environment and recognize the area. However, with the attachment of goggles the phone can be used as an AR/VR headset. This lowers the cost of the AR systems from a hardware perspective as most smartphones that would be capable of running AR software are under 1,000 USD with many people using a smartphone for work or personal purposes.

VR applications can use the phones mentioned earlier as they are much cheaper and more portable then current VR technology. With VR phones Google Cardboard and Samsung GearVR wearables have been used (Samsung, 2019). There are currently two major, stand-alone VR headsets available to the market. These are the Oculus Rift and HTC Vive. Both headsets use very similar technology however, the HTC Vive is supported by Steam, which is the largest video game seller in the world compared to the Rift which is only accessible through the Facebook game store (Oculus, 2019). Drawbacks for both headsets are a requirement of a separate computer to display the information that the viewer would see on the headset. These computers are often high-end gaming computers worth around 1,500USD (HTC, 2019). In addition to requiring a computer to drive the device they also require separate trackers to monitor the head movement of the user during use usually an area of approximately 3 meters by 3 meters. With these requirements most VR headsets typically require a large dedicated area and are considered immobile during use.

Description of Ideas

Proposed Solution

Our proposed solution to the problem is creating AR and VR training methods for airport operations personnel. The proposed solution can be created with existing software development platforms such as Unity combined with Vuforia. Unity is an existing software development tool primarily used for video game development. Vuforia is an add-on to Unity that enables AR applications to be developed. The AR side of the design would serve as a digital assistant to operations personnel capable of providing assistance with an airport operations task. The VR aspect of the design would be focused on creating an immersive training environment for airport operations. This would allow a safe and immersive environment prior to performing the task in the real-world.

This design would have a real-world impact that would decrease the amount of training time that would be required. It can allow for a decrease in training time through increasing the familiarity of existing airport solutions and reducing the need for shadowing airport operations on the airfield.

Prior to the design being implemented there would need to be some additional construction with the software prior to implementation. To assist with the initial design of the software a prototype was created using Unity and Vuforia to help visualize how the application would be used. The image shown displays the prototype which the team used. To use the software the team had a paper print-out of Purdue University Airport (KLAF) diagram, which once shown to the camera the AR application would pull up a 3D model of the airport as shown in *Figure 1*. For development of the design, due to each airport's uniqueness. This will be a time-consuming process because each airport will have different signage, frequencies, and layouts that will need to be implemented into the application.

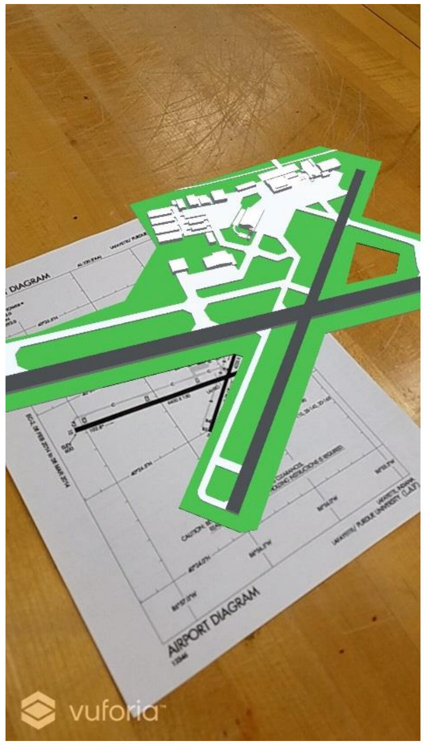

Figure 1: Screenshot of the prototype AR application

Sustainability

This project will use the EONS (Economic, Operations, Natural resources, and Social) model of sustainability as the framework from the Sustainability Aviation Guidance Association (SAGA). Our framework will only involve the Economic, Operations, and Social aspect of EONS due to the lack of ingest materials being used. The definition of sustainability being used is as defined by the Brundtland Commission "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland Commission, 1987). Below we discuss how our project affects each aspect of the EONS model. Natural Resources has been left out of this explanation because we do not believe our design will have an appreciable positive or negative effect on this aspect.

Sustainability Assessment

- Economic

    - Lowers the hours requirement/costs required to train an employee by reducing the amount of traditional training methods
- Operations
    - Can help get people up and running faster reducing on the job training
        - With the turnover time of many employees can raise the effectiveness by increasing the available independent work time
    - Ease of integration, will be easy to use and allow for an increase in the productivity of employees
    - Increased safety through familiarity with the aircraft/process prior to working with the real-world situation
- Social
    - Increased safety of aircraft operations and airport

Descriptions of Airport Operational Applications

Problem Solving Approach

Pugh Matrix 1

Our design decisions were influenced by our interactions with industry experts, and the experiences of individual team members. This combination of input and experience formed our comparison criteria, described in table 1. We began our design session by determining the training mediums that should be used, and the designs used in the initial Pugh matrix are described in table 2. The initial Pugh matrix can be seen in figure 2.

Design Criteria	
Ease of integration	This is the amount of time and specialized knowledge required to implement the training system in question
Depth of training	How comprehensive can the training be, and how flexible is the training platform
Training development costs	How expensive will it be to change the training material
Other operations people required	Will the training system require multiple operations/management personnel to train new hires

Space requirements	Will the training system require a large amount of dedicated space
Ease of onboarding	Will the training system allow new hires to easily integrate to the airport environment
Development time	How long will it take to modify the training system
Safety	How safe will this training system be during training

Table 1: Design Criteria

Training System Concepts	
Current Training	New hires shadow an experienced employee, and receive on the job training
AR only	New hires receive almost all training from an AR device, but receive direction from management
VR only	New hires receive in depth VR simulation training similar to pilot simulation environments
Hybrid current/AR	New hires shadow an experienced employee and use AR devices to receive supplemental training
Computer Based Training	New hires receive computer based training on all aspects of their job

Table 2: Training System Concepts

CRITERIA			CONCEPTS				
			Current Training	AR only	VR only	Hybrid current/ AR	Computer Based Training
CRITERIA	econ	Development time	Baseline	-	-	-	-
	econ	Training development costs		-	-	-	-
	ops	Other ops people required		+	S	-	+
	ops	Depth of training		+	+	+	-
	ops	Space requirements		+	-	S	S
	ops	Ease of onboarding		+	-	S	-
	ops	Ease of integration		-	-	S	+
	soc	Safety		-	+	S	+
		Sum of positives	0	4	2	1	3
		Sum of same	0	0	1	4	1
		Sum of negatives	0	4	5	3	4

Figure 2: First step Pugh Matrix

We began our original Pugh matrix using the current training methods as our baseline. “Development time” and “Training development costs” are seen as negative for all concepts when compared with current training. Each requires a training program to be developed and purchased instead of being performed “ad hoc” by current personnel. We assessed each concept, but for the sake of brevity we have only included our assessments for the top two designs.

AR Only

- Does not require an additional operations employee to lead new hires through training
- Provides the capability to provide a near unlimited amount of information to new hires to deepen their understanding of the processes they are completing
- Does not require dedicated space
- Will allow new hires to use the platform for navigation around the airport and their job requirements
- Will be more difficult to integrate than the current system, because it will have to be tailored to the airport

- Will be less safe than the current system because it will require new hires to be more focused on the AR device during their training time

Hybrid current/AR

- Will require another operations person for shadowing
    - Rated worse instead of same because the new hire might focus on their AR device instead of shadowing
- Will provide the same level of training as current system and the benefits of AR
- Will require no more space than the current system
- Will be similar to current system for onboarding
- Will allow current employees to assist with learning the AR platform
    - Rated same because this is similar to the other processes being taught
- Will be no more dangerous than current system, because of the shadowing process
    - May increase safety slightly

Pugh Matrix 2

The second design iteration uses AR only as our baseline, because it was design in that had the most positives in figure 2. We then combined the concepts from figure 1 into hybrid designs, and assessed them against AR only. We have included our assessments for the first two designs underneath of Pugh matrix 2, figure 3, and for the sake of brevity have only included the top two designs. For our purposes the top designs are those with the most positives and fewest negatives.

Training System Concepts	
AR/VR hybrid	New hires are given VR simulation training, and then provided with AR for on the job assistance
Shadow/CBT	New hires will be provided CBT for hazardous parts of their job, and job shadowing for familiarization with the airport
Shadow/VR	New hires will use VR to train on emergency and crew based tasks while using job shadowing for their main tasks
CBT/VR	New hires will use CBT to train on the majority of their job tasks and VR to train on emergency and crew based tasks
CBT/AR	New hires will use CBT to train on the majority of their job tasks and use AR for on the job assistance

Table 3: Second Step Concepts

		Concepts					
		AR only	AR/VR hybrid	Shadow/ CBT	Shadow/ VR	CBT/ VR	CBT/ AR
CRITERIA	Ease of integration	Baseline	-	+	-	-	-
	Depth of training		+	s	+	+	s
	Training development costs		-	+	-	-	-
	Other ops people required		-	-	-	-	s
	Space requirements		-	s	-	-	s
	Ease of onboarding		-	s	s	-	s
	Development time		-	+	-	-	-
	Safety		+	+	+	+	s
	Sum of positives	0	2	4	2	2	0
	Sum of same	0	0	3	1	0	5
	Sum of negatives	0	6	1	5	6	3

Figure 3: Second Step Pugh Matrix

Shadow/CBT
- CBT will be easier to integrate than AR
  - Computers assumed to already be available on site
  - Operations employees also already present on site
- Will provide the same depth of training as AR only
  - CBT can describe training not available through shadowing, but CBT can be unengaging
  - Shadowing can only provide training on operations that are currently taking place
- CBT will likely be cheaper to purchase than AR software
  - Cost of second employee not taken into account here
- An operations employee will be required for job shadowing
- Will require no additional space
- A veteran employee will be introducing new hires to the site
  - Rated same because people cannot show things like 3D maps for navigation, but can provide very useful "tours"
- CBT will be quicker to develop than AR software
- CBT will allow hazardous jobs to be trained on in a safe environment
  - Veteran employee should also keep new hire out of danger

Shadow/VR
- VR training will need to be created

        - Job shadowing should be easy to integrate
- Combination of simulation and personal experience should provide very in depth training
- VR software and hardware will need to be purchased
- A veteran employee will need to operate the simulation and be used for shadowing
- Will require dedicated space for the VR environment
- New hires will have to acclimate to the simulated environment
    - The team believes that having an employee control that environment could ease the process
        - For example they could show the new hire a location in real space and then go to virtual space or vice versa
- VR software will take time to develop
- Hazardous jobs can be trained on in VR
    - Veteran employee will keep new hire out of trouble on airfield

<u>Weighted Objectives</u>

After completing two rounds of Pugh matrices our team completed a weighted objectives matrix. We chose to use the same criteria from the Pugh matrix as well as the designs that showed the most promise. We used a -3 to 3 scale to show importance and direction of impact. A -3 shows that an item has a strong negative influence, a 3 shows a strong positive influence, and a 0 shows a neutral influence. We included all of the hybrid concepts, along with the AR only concept. For the sake of brevity, we only discuss the top two items in the matrix.

		Weights	AR only	AR/VR hybrid	Shadow/ CBT	Shadow/ VR	Shadow/ AR	CBT/ VR
CRITERIA	Ease of integration	5	-1	-2	1	-1	1	-1
	Depth of training	6	1	2	0	2	2	2
	Training development costs	4	-1	-2	-1	-2	-1	-2
	Other ops people required	3	3	-2	-1	-2	-1	-1
	Space requirements	1	0	-1	0	-1	0	-1
	Ease of onboarding	5	2	2	-2	1	2	-3
	Development time	4	-1	-2	-1	-2	-1	-2
	Safety	12	-2	3	2	2	0	1
	Weighted sum		-13	23	8	12	16	-15
	Design ranking		5	1	4	3	2	6

Figure 4: Weighted Objectives

Explanation of weighting

- Safety was rated the highest by the group
  - If a training device is unsafe or leads to unsafe operations it is unacceptable
- Depth of training was rated second
  - How in depth the training is will be the largest driving force behind the purchase of any training device
- Ease of integration
  - Easy integration is appealing when providing technology solutions
- Ease of onboarding
  - Reducing the onboarding time of new employees will reduce their training time
    - This will be nice, but we do not think this will make or break a decision
- Development time
  - The amount of time needed to change the program will affect how rapidly the training material can be changed
    - This will likely be noticed during operation but will likely not be examined when choosing the system
- Training development costs
  - Costs are important when determining new processes, but not as important as safety. These costs can also sometimes be mitigated through airport improvement plan funds
- Other ops people required
  - Airports are already willing to use another employee for shadowing
- Space requirements

    - If a training device performs well in the previous categories dedicated space will be found

AR/VR Hybrid

- Fairly easy to integrate
    - An experienced employee can help new hires learn the software and it's capabilities
- Can provide in depth training through simulation and on the job assistance
- Software will take a while to develop, and must be standardized between platforms
- Will require an experienced employee to run the simulation
- Will require dedicated space for the VR hardware
    - VR hardware needs to be integrated into a room and should not be moved once integrated
- New hires can be introduced to the airport through a simulated environment
    - This will allow for familiarization in non-ideal situations like heavy snow/rain/fog
- VR simulations will require time to be developed/changed and must have a similar interface with the AR platform
- Introduction through a virtual environment can reinforce the safety concerns at an airfield by presenting the repercussions of actions, and train employees on dangerous operations in a safe environment

Shadow/AR

- Slightly difficult to implement
    - Software must be learned but platform can be a cell phone
- Will amplify the effect of information provided through job shadowing
    - AR device can provide additional visual information to augment shadowing procedures
- Software will cost a little bit to develop
- Platform require an experienced employee to perform the shadowing
    - AR should augment the shadowing process, and reduce the reliance on the employee providing shadowing
- Will neither require additional space or save space
- New hires can explore the airport through their AR devices
    - Can get an aerial perspective of the airfield
- AR software will require development time, but this can be mitigated through shadowing
- This was listed as neutral because airports are already comfortable with the safety considerations with shadowing

Effect of Industry Experts on Design Process

Our interactions with industry experts had a large effect on our design process. During our initial meetings we discussed the gaps that currently exist in airport operations training. These discussions provided us with our criteria for the Pugh matrices, and weighted objectives activities. After performing these design activities we were left with the two ideas of VR/AR hybrid and shadow/AR hybrid. We met with industry experts after these activities. These meetings allowed us to reassess the gaps in airport operations training, and to provide our initial concepts as a potential solution to the gap. These discussions led us to focus on the AR platform development, and challenges with training to drive on the airfield. This was particularly interesting because if we look at our weighted objectives table, figure 3, we can see that shadow/AR was rated below VR/AR. These conversations led to an expansion of potential AR uses for airport operations, such as: quickly finding tower frequencies, terminal management, and vendor management. While the idea space was expanded the idea of using AR to assist in airfield driving was seen as having much positive potential.

After incorporating the feedback we received we had a final round of interactions with industry experts. In this round we revisited one of our original interactions and brought in a new expert. During the discussion with the original expert we were provided with some features that we had not discussed. There were some concerns over usability and accessibility, specifically on the usability for those with colorblindness. There were also some concerns with user experience. These concerns will need to be addressed if this design is implemented, but were not discussed in depth in this paper as to avoid scope creep. The interaction with the new expert expressed interest in the capabilities of VR simulations. The expert believed that these simulations would be very useful in training for winter operations, or any other event does not occur daily but has a large effect on the airport as a whole. There was some interest in the AR platform showing the concrete loading information so operations personnel know which aircraft can go where on the airfield.

Projected Impacts

Cost Benefit Analysis

In order to assess all impacts of a project, a cost/benefit analysis must be included. The analysis takes a deeper look at the economic impacts of a project. For this report, the cost/benefit analysis has been broken into two critical parts: tangible benefits and intangible benefits. It is common for tangible benefits to be assessed because those benefits easily show the costs and savings of a project. However, some criterion cannot be easily measured but can have a large impact on the project. This criterion falls within the intangible benefits.

Tangible benefits of projects can include increased revenue, cost savings, increases in productivity, and increases in environmental efficiencies. The intangible benefits include increased safety risk mitigation. An assessment of the cost of development to implementation is explored first and then a cost/benefit analysis is conducted to explore the value of safety risk mitigation. Both the cost analysis as well as the cost/benefit analysis are conducted in accordance with the framework suggested by the ACRP contest guidelines.

First development costs were considered. For product development there is usually an alpha and beta development stage with alpha being the first stage of development and beta being the second stage. It is important to note that as the training program is being developed, the time that the visual/graphic expert and the coding/game development expert needed to develop the training module could significantly decrease. This is because most of the codes and visualizations could be copied.

Research and Development (Alpha)

Item	Rate	Quantity	Subtotal
Labor - University Design Competition			
Student Efforts	$25/hr	100	$ 2,500
Expenses			
Travel	$ 100	1	$ 100
Training Material Expert	$ 100	40 hrs	$ 4,000
Visual/Graphic Expert	$ 100	40 hrs	$ 4,000
Coding/Game Development Expert	$ 100	40 hrs	$ 4,000
Miscellaneous	$ 300	*Lump Sum (LS)*	$ 300
Subtotal			$ 14,900

Research and Development (Beta)

Item	Rate	Quantity	Subtotal
Labor - Academic R&D			
Student Efforts	$25/hr	100	$ 2,500
Expenses			
Training Material Expert	$100	20 hrs	$2,000
Visual/Graphic Expert	$100	20 hrs	$2,000
Coding/Game Development Expert	$100	20 hrs	$2,000
Hardware/Travel	$ 5,000	1	$ 5,000
Subtotal			$ 13,500

Figure 5: Development of Training Product

After the development and implementation of the system, operating costs were assessed. These costs are shown in figure 5. These costs are detailed through assumptions gathered based on labor rates and hardware rates from Microsoft, Vuforia, and Apple.

Operations and Maintenance

Item	Rate	Quantity	Subtotal	Remarks
Labor - Operators' Personnel + Technical Support Representative				
Operators' Personnel	$25/hr	10	$ 250	Initial Training of Personnel
Technical Support	$25/hr	10	$ 250	Initial Training Trip with 2 employees
Expenses				
Travel & Per Diem	$500/person	2	$ 1,000	Airfare, Lodging, Per Diem for 1 day
Subtotal			$ 1,500	

Figure 6:Operations and Maintenance Costs

Cost Summary (1 unit for 10 years)

Item	Unit	Qty	Subtotal	Remarks
Costs				
Development	$ 28,400	1	$ 28,400	
Sale, Operation and Maintenance	$ 9,500	1	$ 9,500	
Total Cost			$ 37,900	

Figure 7: Total Cost for Development and Operations

A thorough understanding of risk is required for a cost/benefit analysis. The risk assessment was conducted based on the figures provided by the ACRP within the cost/benefit analysis video. The likelihood of an aircraft to vehicle collision was assessed since it was more likely to occur than an aircraft to aircraft risk assessment. This risk is present when driving on the airfield. Using the AR training tool, this accident frequency can be mitigated. As shown in the figure, the total cost of an accident substantially outweighs the cost the system the total cost of the system includes development and implementation of the system as well as the cost of maintenance and operation.

Benefit vs Cost (A/C - Vehicle Collision)

Item	Unit	Qty	Subtotal	Risk	Total	Remarks
Cost						
Value of Fatality (VSL)	9.1 million	1	$ 9,100,000	0.0625	$ 568,750	*Tables E & F*
Value of Injury (VSI)	955,000	2	$ 955,000	0.0625	$ 59,688	*Tables E & F*
A/C Destroyed (AVD)	1.5 million	1	$ 1,500,000	0.0625	$ 93,750	*Tables E & F*
Vehicles Destroyed (VVD)	250,000	1	$ 250,000	0.0625	$ 15,625	*Tables E & F*
Total Accident Cost Prevented (Benefit					$ 737,813	
Less Cost (Development/Deployment)					$ 37,900	*Table G*
Benefit to Cost Ratio					19.5	***Benefit outweighs cost***

Figure 8: Cost vs Benefit Analysis

Vehicular accidents on an airport airfield are not common but do happen and can have catastrophic results. In March of this year, a Bombardier Challenger 300 collided with a ground's vehicle at SZB airport in Malaysia (Chuanren II & Dennis, 2019). The authors went on to report that the aircraft sustained significant damage to its wing and the airport vehicle was destroyed. Unfortunately, the driver was killed in the accident.

While the likelihood of an aircraft and vehicle collision is small, it still could happen. Through using a blended AR/VR training system, the risk could be further mitigated. As seen in the figure, the cost of an accident would be about $738,000. The total cost of the training system is roughly $38,000. The benefit to cost ratio is 19.5. This means that the cost of the training system is vastly outweighed by the benefit of increased mitigation of accidents.

<u>Safety Risk Assessment</u>

This framework was developed in compliance with the FAA Advisory Circular 150/5200-37 Within this document, the FAA identifies mandatory safety risk management (SRM) steps. The five steps that were used during the design process include:

Phase 1. Describe the system

Phase 2. Identify the hazards

Phase 3. Determine the risk

Phase 4. Assess and analyze the risk

Phase 5. Treat the risk (i.e., mitigate, monitor and track).

As discussed above, the complete training system is comprised of a hybrid blend of AR/VR technology. This technology will initially be used for onboarding training, therefore, the initial safety risk assessment (SRA) only extends to the initial model. However, the SRA can be expanded to cover other areas if needed. One targeted training for the system is driving on the airfield.

The hazards identified with the training on driving on the airfield include vehicle/personnel accidents and vehicle/aircraft accidents. Each hazard is addressed, analyzed, and treated individually below.

Safety risk assessment:

- Vehicle/Personnel Accident
- Vehicle/Aircraft Accident

Vehicle/personnel accident:

A vehicle/personnel accident could occur when a driver is driving into an area where there are people operating. This training system could mitigate this risk by showing through the AR system that certain areas have frequent foot traffic and require extra caution.

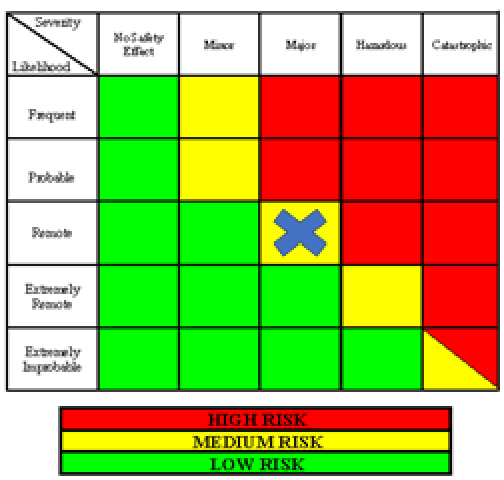

Figure 9: Safety Risk Assessment of Vehicle/Personnel Accident

The collision of an operator's vehicle with another airport vehicle could be a hazardous occurrence even as remote as it is. The operator's vehicle as well as other vehicles should have high visibility paint and reflective components in order to make all vehicles easily noticeable.

Additionally, drivers should have procedures in place for operating within high risk areas or around blind corners in order to mitigate this risk.

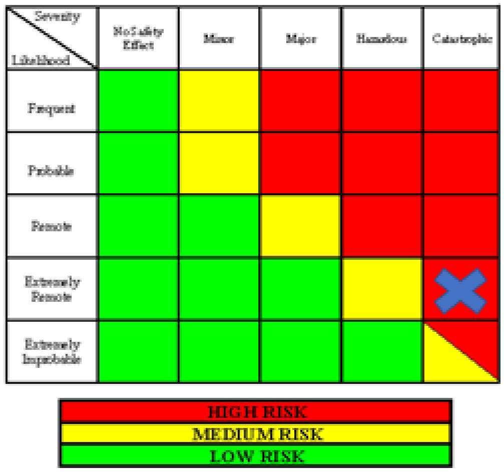

Figure 10: Safety Risk Assessment of Vehicle/Aircraft Accident

While an occurrence between a vehicle and an aircraft is extremely remote, the outcome would be catastrophic and requires appropriate safety measures. While the system should aid in operator awareness assisting in the prevention of this type of accident, additional safety measures are required. High visibility and reflective equipment should be installed on the system-equipped vehicle enabling pilots to see the vehicle. Additionally, annual training should occur in order to ensure that operators are aware of all procedures and safety precautions necessary. Analysis of issues during the previous year should be brought up and addressed during annual training.

Health Risks

While there are substantial benefits associated with AR/VR training, there can be negative health ramifications associated with usage of both types of training. Motion sickness can be present in some users while using AR/VR applications. This condition is more typical with VR training because it is more immersive than AR training. Before implementing VR training technology, user experience testing should be explored.

Many professionals have even grown concerned that this motion sickness that can sometimes be present during simulation training might prevent these applications from realizing full potential (Fernandes, 2016). Symptoms of VR sickness can include headaches, nausea, vomiting, sweating, fatigue, drowsiness, and disorientation (Oculus, 2019). These symptoms are problematic and can cause users to shy away from using the devices for VR training.

These concerns and symptoms were addressed by Robert Kennedy, Kay Stanney, and William Dunlap in a study conducted to explore sickness curves during sessions of simulation training. This study found that there longer exposures to simulation training produced more symptoms (Kennedy, 2000). Additionally, the study found that the total sickness the users were experiencing tended to subside over repeated exposures. The study determined the positive relationship between sickness and session duration and the negative, linear relationship between sickness and exposure time by analyzing flight simulator data from military agencies. The simulator flights were divided into categories based on duration of exposure (Kennedy, 2000). Then complete records of sicknesses during the simulator training were analyzed. The understanding of these relationships between sickness, duration time, and exposure time can be used to make training simulations that will allow short enough exposure times to prevent sickness from occurring.

Sometimes training sessions might not be well-suited to accommodate short exposures for users. Ajoy Fernandes and Steven Feiner explored ways that could be implemented in order to mitigate and prevent symptoms without shortening exposure in a study conducted regarding the relationship between Field of View (FOV) and sickness. Through reducing the FOV subtly during times that users were prone to experience sickness, users can experience a decrease in VR sickness as well as an increase in comfort (Fernandes, 2016). Historically, it has been accepted that decreasing FOV can significantly reduce user sickness (Witmer, 1998). But Fernandes explores whether a dynamic approach of managing FOV during the simulation affirms that through the dynamic management of FOV can help users stay in the simulation longer and feel more comfortable during the sessions. One important note is that Fernandes conducted all research with users sitting down while wearing the VR gear.

Other research has been conducted to analyze VR sickness and walking. Suggestions to mitigate VR sickness in users included using a gamepad, interfaces that users use their hands in, and detecting user movements and modeling them closely in the system accurately to match the character (Lee, 2017). Lee verified that immersion in user simulation could be increased and sickness could be decreased. These conclusions should be considered when developing any simulation training.

Industry Experts

The team met with airport operations industry experts from and AR/VR technologies. The team met with the following industry experts. Most of the meetings were approximately 30-45 minutes in length with some meetings running up to two hours and contained follow-up meetings.

- Adam Baxmeyer, Airport Manager at Purdue University (KLAF)
- Christopher Morris, Airport Operations Supervisor at Purdue University (KLAF)
- Allison Hopkins, Data Visualization Specialist at Envision Center at Purdue University
- Dr. Maria Muia, Senior Aviation Planner at Woolpert Inc.
- Tyler Miller, Operations Manager at South Bend International Airport (KSBN)
- Nick Keller, Assistant Airport Director at Yeager Airport: Charleston, West Virginia (KCRW)
- Travis Ryan, Operations Manager at Yeager Airport: Charleston, West Virginia (KCRW)

Industry Background Information

The information that we gathered from our industry experts aligned with the *ACRP Document 28* (Cronin, et al, 2016) regarding the succession crisis in airport management and workforce. When hiring for airport operations, one of the items that was mentioned is that airport operations is the back-up plan for many pilots, ATC, or mechanics; however, the skillset for airport operations is not the same as the other careers. For pilots, ATC, and mechanics all have a certification process through the FAA, but airport operations do not have FAA certificates; they may be certified through third party such as the American Association of Airport Executives (AAAE).

In addition to the skillset, the pay is also much different when compared to the other aspects of industry. Usually moving up to a larger airport will mean an increase in pay and responsibility; however, for airport operations there can be a lot of movement from large airports to small airports and small to large. Part of the reason for the large amount of movement is due to there being around 500 US airports that are 14 CFR Part 139. For one of industry experts contacted, we understood that in the 4 years he worked at an airport, he progressed from the least experienced to the most senior official in the airport. In addition to quick rise to seniority, one item that was mentioned was how quickly the training is from newly hired to running an airport of around 3-4 months to be left alone to take care of the airport from an operations stand point.

Once on the airfield there have been some tasks that were brought up repeatedly that every operations manager should know how to perform. These include:

- **Driving on the airfield**
- Understanding of CFR 14 Part 139 standards
- Airfield inspection of signs, runway conditions, and F.O.D.
- Changing high voltage lighting

- Issuing a NOTAM
- Terminal maintenance and repair.

The team focused on **driving on the airfield** for the initial design process after numerous interactions mentioning that as a topic of interest.

Design Feedback

The initial design concept used an AR application for driving around the airport that would remind the driver of the needed frequency when entering certain runways and taxiways. The initial device that was targeted for this application was any Android and iOS devices. One interaction mentioned that using a head-up display in an operations vehicle instead of needing to pull out a cellular device would be more beneficial. All the contacts mentioned that by having a cellular device would allow for other ground vehicles to use the application for driving on the airfield. When discussing the VR design of emulating a flight simulator that would allow for interactions between different airport operations, pilots, and ground personnel was not looked at as fondly as the AR aspect. One of the interactions, however, was interested in the possibilities of using VR for winter operations training as an assistant to existing training.

Conclusion

Airport operations is facing challenges in employee retention and potential loss of institutional knowledge. The current training practices for these positions heavily relies on job shadowing, which is time intensive and the quality will be heavily affected as senior employees retire. Augmented and Virtual Reality (AR/VR) training solutions have the potential to improve upon current training practices. Current AR/VR training programs exist for airports, but are not designed specifically for airport operations. Through our contacts with industry experts our team has presented two conceptual design solutions for AR/VR training environments for airport operations. We have presented two designs due to the vast differences in airport requirements and operations. For some airports augmenting job shadowing with AR technologies will be sufficient, but other airports may require crew-based simulation training for their employees. These training solutions will need to be tailored to each airport employing them, but have the potential to provide training more rapidly and effectively.

Appendix A: Contact Information

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Appendix B: Description of the University (from purdue.edu)

Purdue University is committed to developing and preparing students for a competitive job market by empowering students with research and exploration. The university is known for its prestigious math, technology, and science programs as well as for innovation, discovery, and advancements.

The university was founded in 1869 in West Lafayette, Indiana through the Morrill Land Grant Act and donations of money and land from John Purdue, Tippecanoe County, and local community members. At its founding and presently, Purdue is a research institution committed to advancing research and discoveries. Presently, more than 39,000 students are enrolled at Purdue University. Purdue has a diverse demographic of students which represent all 50 states and 130 countries.

Currently, Purdue University is comprised of 10 academic colleges including the Purdue Polytechnic Institute. There are multiple academic schools, departments, and divisions that make up this academic college including the School of Aviation and Transportation Technology.

The School of Aviation and Transportation Technology provides its students with a learning curriculum that is based on industry trends. The School of Aviation and Transportation Technology offers several bachelor's degree programs in Professional Flight, Aeronautical Engineering Technology, and Aviation Management. Additionally, the school offers advanced degrees through MS and PhD programs in Technology with a concentration in Aviation and Aerospace Management.

Appendix C: Non-university partners

Currently, there are no non-university partners nor are there plans to include non-university partners.

Appendix D: Sign-off form for faculty advisor and department chair

Airport Cooperative Research Program
University Design Competition for Addressing Airport Needs
Design Submission Form (Appendix D)

Note: This form should be included as Appendix D in the submitted PDF of the design package. The original with signatures must be sent along with the required print copy of the design.

University PURDUE UNIVERSITY

List other partnering universities if appropriate: —

Design Developed by: ☐ Individual Student ☒ Student Team

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Name —

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Permanent Phone Number Email

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Competition Design Challenge Addressed:

AIRPORT OPERATION AND MAINTENANCE

I certify that I served as the Faculty Advisor for the work presented in this Design submission and that the work was done by the student participant(s).

Signed [signature] | [signature] Date 26 APR 2019

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Appendix E: Evaluation of Educational Experience Provided by the Project
Students

1. Did the Airport Cooperative Research Program (ACRP) University Design Competition for Addressing Airports Needs provide a meaningful learning experience for you? Why or why not?

The ACRP University Design Competition provided our team with a tremendous opportunity for deep thinking and educational growth. The Competition challenged our team to identify a real-world problem that airports face. Through research and interaction with industry professionals, the team was able to develop a framework that was applicable to addressing the identified problem. This experience is valuable because sometimes traditional classroom learning is not as heavily based in application and does not empower students to make meaningful connections outside of the university.

2. What challenges did you and/or your team encounter in undertaking the competition? How did you overcome them?

The biggest challenges that we encountered during the design challenge were time management and managing our own biases. Completing this challenge during a one semester time frame is very challenging. We were able to overcome this challenge through bi-weekly meetings, and clear task designation within Gantt charts. The second challenge, managing our biases during the design process, was more difficult to assess. In order to prevent biases from dictating the design we worked collaboratively through the Pugh matrices, and took an average of individual scores for the weighted objectives. We also met with a variety of industry experts throughout the process as a way to ensure that the design was always on the correct track.

3. Describe the process you or your team used for developing your hypothesis.

When creating our hypothesis for the ACRP design competition our team investigated common problems facing airport operations. These investigations began with personal experiences and relevant literature. These investigations led to brainstorming and an initial problem statement. Once we had an idea of the hypothesis we wished to investigate, we began communicating with nearby industry experts. These early discussions helped us determine exactly what problem we wished to investigate.

4. Was participation by industry in the project appropriate, meaningful and useful? Why or why not?

Our contact with industry experts was very meaningful and useful. These contacts influenced our design decision processes throughout the design process, and provided a very useful perspective. We had a prior understanding that every airport is different, but through these contacts we got an understanding of just how different every airport is. We were able to talk to a variety of experts experienced in many areas of operations, and this provided a variety of important feedback on the design. We also had one contact familiar with the development processes of AR and VR technologies. This person proved invaluable as they had also worked in airport operations in their past. The design process undertaken during this project was based very heavily upon communication with industry experts, and we believe this has strengthened our design.

5. What did you learn? Did this project help you with skills and knowledge you need to be successful for entry in the workforce or to pursue further study? Why or why not?

This project helped us develop design skills, and more deeply understand airport training. These design skills will be useful in any future career because they help us more deeply understand problems, and develop robust solutions. This project also helped us immensely in the technical writing capabilities required to create this report. Technical writing is a skill that can only be improved through practice, and competitions are a good motivator to practice. The final skill that was improved was time management and communications. Our accelerated timeline meant that we were forced to streamline the writing process as much as possible, and effectively delegate tasks within the group.

Faculty

1. **Describe the value of the educational experience for your student(s) participating in this competition submission.**

   This competition is valuable for students in my aviation sustainability course primarily due to the challenges and topics coming from real airports, the interactions with industry experts, and the structure of the project report being a proposal in response to the competition guidelines (a request for proposals). This competition encourages my students to do deep dives into not only what to do to improve airports, but also to quantify the risks, costs, and for my students, to describe the impact that these projects may have on airport sustainability. One key to the educational value of the experience is the interactions with industry experts from airports, airlines, and consultants. While the written portion in the report may be brief, what is doesn't say is the overwhelmingly positive response these experts provide the students. Every one of these experts took at least 30 minutes from their day, most of them took an hour or so. Some experts also interacted with the team via email and follow-up phone calls. These interactions energized the team as they realized that these airport challenges are truly very important and that with some tweaking or changes, their proposed solution may become to a better solution.

2. **Was the learning experience appropriate to the course level or context in which the competition was undertake?**

   Yes. This is a graduate level applied aviation sustainability course where the airport improvement projects are also evaluated in a sustainability analysis. The required literature review was enlightening for this team as they found information on the topics of AR/VR and airport personnel required training that is not found in textbooks that I have seen.

3. **What challenges did the students face and overcome?**

   The biggest challenge for this team was narrowing down applications of AR/VR so that it would provide direct benefits to airports and also be scalable to other airports. There are so many choices in AR/VR technologies that had to be sorted through by the team before they found a low cost and effective solution for airport operations personnel training and recurrent training. They found that a one-size-fits-all technology approach would not work as well as they would like it to. They also learned more about the specific roles of the airport, the airlines, and the support services and concessionaires, and how these entities interact to serve the public. This team enjoyed talking with industry experts, once they had spoken with the first one. After that, they were not only contacting people that I know, but also people that they started reaching out to on their own.

4. **Would you use this competition as an educational vehicle in the future? Why or why not?**

   Yes. This competition inspires students to learn more deeply, to seek out regulations and guidance, to read the available literature, and to learn how to learn - skills needed for the rest of their careers

5. **Are there changes to the competition that you would suggest for future years?**
   Yes, consider including a sustainability analysis as a required section of the report

1. **Describe the value of the educational experience for your student(s) participating in this competition submission.**

   Learners often fall into passive learning when all you do is lecture. Even on writing assignments they can sometimes just go through the motions and are not able to scale their learning to solve real world problems. This competition represents an active learning opportunity that spurs self-directed research and problem solving, forcing the learner to go beyond the textbook and engage the industry directly. Because it combines technologies and problem solving in the context of real-world operations, the result I've observed first hand is deep learning transfer of skills and practice of critical professional competencies which are what our global workforce is in need of. Their ideas and products have real applicability and broad reaching impact for the industry.

2. **Was the learning experience appropriate to the course level or context in which the competition was undertaken?**

   The learning experience was most definitely at a challenging and appropriate level for the mixed student group involved. As noted previously in item #1, I observed the competencies of problem-solving, collaboration, data gathering, experimentation and innovation being explicitly practiced by the problems posed for the competition. These are the same high level skills and competencies sought in our university level course learning outcomes, and the competition is an excellent leveraging tool to accomplish those.

3. **What challenges did the students face and overcome?**

Each student brought a level of technical expertise and academic background to the design challenge. They also brought their own visions and assumptions about project approach and development paths. All of these had to be collectively discussed and harmonized as a team. The biggest challenge initially was the process of getting to consensus efficiently and setting a vision that the team could grab hold of and begin to contribute – something all teams face. They accomplished this with excellent maturity and negotiation skills which as an educator was thrilling to watch and mentor. The other significant challenge was engaging industry experts and shaping the team's design path based on the SME's professional experiences and opinions. This forced the student team to describe their ideas and solutions succinctly, receive constructive feedback and rethink initial assumptions. They had to continually dissect and refocus the core problem. This was an extremely valuable part of the design process.

4. **Would you use this competition as an educational vehicle in the future? Why or why not?**

Yes, I will most definitely use this as an ongoing learning vehicle. It is especially helpful by enabling students to practice many of the higher level competencies sought by our aviation industry: innovation, team work, problem solving, communication (written, presentation and face to face). All of these and more are naturally exercised and demonstrated explicitly during the competition. Even better, they engage these in the context of the actual industry setting and the NextGen challenges we face. As such, they were able to grapple with incorporating human friendly design, ethical decision making, cost balance and other challenges that go along with innovative solutions. This type of experiential learning is highly valued in education as well as industry and is superbly exercised through this competition.

5. **Are there changes to the competition that you would suggest for future years?**

   I’m pleased to see a continuous improvement in scope of the competition reaching into additional topical areas pertinent to aviation. Additionally, it is exciting to see the competition continually embrace areas of disruptive technologies (mobile computing, Internet of Things etc.). I would continue this type of evolving competition framework as it keeps the competition relevant and is a vital investment in the young, up and coming technical workforce.

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