

Incorporating NextGen Technology in Ground Vehicles to Decrease Runway
Incursions

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Design Challenge: Runway Safety/ Runway Incursions/ Runway Excursions

Team Members:

Graduate Students: Mason Edwards, Marc Suarez, Jiansen Wang,
Kenneth Zollars

Number of Undergraduates: 0

Number of Graduates: 4

Advisor's Name: Mary E. Johnson, PhD

Name of University: Purdue University



School of Aviation and
Transportation Technology
POLYTECHNIC INSTITUTE

Executive Summary

Runway incursions are a significant safety issue for commercial aviation. The Federal Aviation Agency (FAA) and other safety organizations have taken steps to promote mitigation strategies and help reduce the severity of incursions. Airports consider runway incursions a major issue as evidenced by the ACRP University Design Competition challenge category addressing runway incursions. A thorough literature review was performed to better understand the issue of runway incursions, their prevalence, and current mitigation technologies. One such technology is ASDE-X. However, in its current state it does not address one of the significant contributing factors: ground vehicle related runway incursions. This design team developed a solution to address this gap in technology for challenge topic F of “expanding the situational awareness of pilots and ground operators on the airfield” in the Competition Guidelines.

The design team identified three possible technologies that could mitigate ground vehicles as a contributing factor. The team ran through two iterations of comparison between currently used technologies, basing judgement criteria off published documents from the FAA and personal experiences. The team decided to implement ASDE-X into ground vehicles by way of a multifunction display. The team developed a technical description of how the units would function and then performed a sustainability analysis of the proposed solution.

This analysis was performed via the EONS framework. The operational, economic, environmental, and social impacts of the solution were theorized and discussed. Additionally, the team performed a risk-hazard assessment to determine possible issues with implementing the system. After reviewing the proposed design, the team believes that implementing ASDE-X into airport ground vehicles can prove a viable method to combating runway incursions with a cost-benefit ratio of 281:1.

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1. Problem Statement

According to the International Civil Aviation Organization (ICAO) definition that the Federal Aviation Administration (FAA) (2015c) began to use in 2007, “a runway incursion is any occurrence at an airport involving the incorrect presence of an aircraft, vehicle, or person on the protected area of a surface designated for the landing and take-off of aircraft” (para. 2). According to the FAA (2015c), in fiscal year 2013, towered airports reported a total of 1,241 runway incursions which is an increase of 91 from fiscal year 2012. These same airports reported a total of 1264 runway incursions in 2014, an increase of 23 from fiscal year 2013 (FAA, 2015c). There is solid evidence pointing towards an increasing trend in the occurrences of runway incursions.

According to the FAA (2014a), “Runway incursions are classified by the FAA into three categories by their types: Operational Incidents, Pilot Deviations, and Vehicle /Pedestrian Deviations.” Research reported in 2007 showed that 62% of runway incursions were caused by pilots and 35% due to air traffic controllers (Prinzel, 2007). More recently, in 2017 the FAA found that over 20% of all runway incursions annually are caused by ground vehicle deviations (FAA, 2017). Such statistics point to human factors as a significant role in the cause of runway incursions.

To decrease both the impact and frequency of runway incursions, the FAA has implemented a variety of techniques and technologies. One of these pieces of technology is the ASDE-X system. It uses multiple inputs from other navigation sources to allow ATC to create live feed maps of surface and near airport movements of aircraft (FAA, 2014a). However, this technology (and by extension many of the FAA efforts) focus mainly on the Air Traffic Control (ATC) side of the operation and not on the personnel working in the high traffic ground areas.

Many navigation systems for traffic management are primarily designed for the air traffic controllers' use. This information has inspired the team to incorporate aspects of ASDE-X into the ground vehicles of airport operations to provide increased situational awareness for personnel and help reduce the frequency of runway incursions due to Vehicle/Pedestrian Deviations.

2. Literature Review

2.1. Runway Incursions and Prevalence

Dating as far back as the early 2000s, runway incursions have been a significant factor affecting the safety of the aviation industry (FAA, 2005a). As the FAA stated, "Although they are not a new problem, with increasing air traffic, runway incursions have been on the rise" (FAA, 2012a, p. 2). Prior to 2011, the number of reported incidents had slightly fluctuated, but increased slowly. The number of FAA reported runway incursion related incidents had trended upwards quickly between the years of 2012 and 2016, going from nearly 50 cases to almost 80 cases between the respective years (Werfelman, 2017). According to this same report, the fiscal year of 2017 had nearly 1,341 FAA reported runway incursions, of which the FAA places eight in the most severe categories (FAA, 2014b).

2.2. Incursions and Ground Vehicles

According to the FAA's *2015-2017 National Runway Safety Plan*, the key metrics of runway safety are frequency, severity, and type (FAA, n.d.b). Frequency is measured by number of events, and type is broken down to the three aforementioned "causes". Severity is measured on a scale of categories, from A (most severe) to D (least severe) (FAA, 2015a). Through the combined implementation of incursion mitigating technologies, the number of category A and B incursions has dropped significantly from 67 in 2000 to only 8 in 2017 (of which only three

involved commercial aircraft) (FAA, 2018a). Yet, while the severity of incursions has been reduced, the overall frequency of incursions per operations continues to rise (FAA, 2020a). Integral to this issue is the recurrence of one specific type of incursion: Vehicle/Pedestrian Deviation (VPD).

VPD is defined as “any entry or movement on the movement area by a vehicle (including aircraft operated by nonpilots) or pedestrian that has not been authorized by air traffic control” (FAA, n.d.c., p. 1). When looking at national runway incursion statistics provided by the FAA, one begins to see VPD contributing significantly. Of the 1764 runway incursions in the fiscal year of 2019, VPD was accountable for 293 (FAA, 2020b). This was nearly 16% of national runway incursions and falls in line with the FAA’s claim that nearly 20% of annual runway incursions are caused by ground vehicles (FAA, 2017). The most current statistics show that of the 663 runway incursions reported, 117 were due to VPD (FAA, 2020b).

Linda Werfelman (2017) found the largest contributing factors to pilot related runway incursions were errors in communication, distractions and pilot inattention. While the least utilized prevention barrier was ASDE-X. Though the implementation of ASDE-X has been beneficial for ATC, its implementation does not address one of the most significant factors contributing to runway incursions: awareness (Prinzel & Jones, 2007). These findings may be extended to apply to VPD related runway incursions, specifically communication errors and inattention.

There is a disconnect in communication between ATC and ground crews that can influence the chances of runway incursions. Additionally, as ground personnel are not as aware of the airport surface traffic as ATC, the importance of proper communication between the two is stressed. When there are obstacles to effective communication, and information is not relayed

clearly, the barriers designed to prevent runway incursions break down. Due to the steady rise in runway incursions, there has been an increased focus on mitigating runway incursion via different technologies, allowing for multiple forms of barriers to runway incursions.

2.3. State-of-the-art Technology: ASDE-X, RWSL, RAAS

Though the commercial airport industry uses several technologies, there is one that remains at the forefront: the Airport Surface Detection Equipment, Model 3 (ASDE-3) (FAA, 2014b). Specifically, this system utilizes a software known as the Airport Movement Area Safety System (AMASS). Together, the ASDE-3 radar and AMASS software provide visual and auditory alerts to ATC personnel when the system detects potential runway collisions (FAA, 2014c). However, the ASEDE-3/AMASS is only operational at nine airports. The wider impact of this system can be seen when considering its most recent modification.

The most recent modification to ASDE-3 is known as the Airport Surface Detection Equipment, Model X (ASDE-X) and is in-use at 35 major airports in the United States (FAA, 2014a). ASDE-X provides a highly precise tracking of ground movements while providing a visual and audio alert to ATC if potential collisions are detected (FAA, 2014c). This is because the system is capable of multimodal data acquisition. To clarify, the system receives information from a myriad of sources including: local ATC surveillance radars, Automatic Dependent Surveillance Broadcast (ADS-B) sensors, terminal automation systems (flight plan data), multilateral data sensors, as well as many other airport specific systems. As the system compiles information from a multitude of other positioning systems, it allows ATC more accurate and precise location information for ground traffic.

While the importance of ASDE-X cannot be overstated, it is not the only mitigating technology in use. In fact, the system has a significant shortcoming; the information is available

only for use by ATC, and therefore lacks a key communication mode. A common mitigation tool that is more focused on ground personnel are Runway Status Lights (RWSL), which utilizes a combination of in-pavement Runway Entrance Lights (REL) and Takeoff Hold Lights (THL) that illuminate red when a runway is either unsafe for crossing or takeoff. The RWSL system processes information from surveillance systems, which then activates RELs and THLs in accordance with the motion and velocity of the detected traffic (FAA, 2015b, P. 1). Though the system is independent of ATC, they have limited indirect control of the system. As stated by the FAA (FAA, 2015b, p. 1), “Clearance to enter, cross, or takeoff from a runway must still be issued by Air Traffic Control”. Pilots and ground vehicle operators are still responsible to obtain a clearance but must not proceed if the red lights are illuminated.

Another common runway incursion mitigation tool, one that is more focused on pilots, is called the Runway Awareness and Advisory System (RAAS) developed by Honeywell (Honeywell, n.d.). The system is capable of providing visual and auditory annunciations to pilots on certain physical conditions or locations of the airport (SKYbrary Wiki, 2019). The system is primarily designed to provide more situational awareness to cockpit crews on their aircraft’s status in respect to their locations on ground areas. This is done by coupling the system with the native GPS and Enhanced Ground Proximity Warning (EGPWS) units of the aircraft (SKYbrary Wiki, 2019). However, the system does not provide a true visual indication of the airport, as only annunciator lights are utilized, leaving pilots without critical visual affirmation.

All three systems provide advantages, and all seek to provide more situational awareness to their users, though doing so in different ways. However, none of these systems target ground crew personnel, which are a significant factor in runway incursions.

2.4. NASA Runway Incursion Prevention System

In 2000, the NTSB recommended the FAA develop a valid tool capable of implementing various warning systems into the cockpit (NTSB, 2000). Despite this recommendation, as of the initial phase-in of ASDE-X in 2003, there has been no industry wide application of this technology to the cockpit of aircraft (FAA, 2018b). Simultaneously, there has not been industry wide support of warning systems in ground vehicles for ground crew. However, there has been some research and discussion of possible approaches, namely: NASA's Runway Incursion Prevention System (RIPS). The system was created and tested for performance at Dallas-Fort Worth International Airport in 2000 (Allen, 2008).

RIPS combined multiple technologies into a surface communication, navigation and surveillance system that could be utilized by flight crews and ground vehicles (Allen, 2008). Specifically, the system synthesized the use of commercially available equipment (such as ASDE-3 radars and ADS-B transponders) and proprietary NASA software. The two software packages were the Runway Safety Monitor (RSM) and the Runway Incursion Advisory and Alerting System (RIAAS). Each of these systems were designed to recognize potential incursion scenarios, alert the pilots, and offer maneuver guidance much like traditional Traffic Collision Avoidance Systems (TCAS).

This system incorporated an electronic moving map of the airport's runways and taxiways, as well as a heads-up display (HUD) that gave the aircrew real-time guidance on the position and movement of other equipped vehicles. Both visual and auditory alerts would be given by the system if a possible incursion scenario was detected (Allen, 2008).

A Boeing 757 and a ground vehicle were equipped with avionic equipment to test the reliability and validity of the system through scenario-based experimentation. The main

conclusion drawn from this test was that all the integrated systems were feasible for implementation, however the system is influenced heavily by the performance of “ownership” and traffic information (Allen, 2008). This means that the timing of the alerts given to pilots will suffer if the aircraft cannot accurately sense its own geographical location precisely, and if there are issues with transmitted data from onboard systems to airport surface equipment. Due to this, the study found several advantages of aircraft-to-aircraft based data links over ground-based data links. Primarily, these advantages were the shorter time delays between system recognition and alert annunciations, as well as the accuracy of ownership positions when close to violating hold short lines.

Unfortunately, little information was found as to the commercial implementation or current state of this system. However, it provides an excellent technical benchmark from which to derive new, state-of-the-art designs.

3. Problem Solving Approach

In order to implement a new runway incursion warning system (RIWS) for ground vehicles, several alternative solutions were compared through a Pugh matrix against a baseline. In nearly every airport there is signage throughout runways and taxiways to help navigate pilots and ground crew around the airport grounds. Therefore, this was taken to be the baseline from which all other solutions would be compared. These alternative solutions come from currently utilized mitigation strategies of airports. Runway status lights (RWSLs) that could be specific for ground vehicles and tied to a monitoring system only for ground vehicles was one of the alternatives. Next, the team discussed possibly including a runway alert and avoidance system (RAAS) for ground vehicle usage. Additionally, the concept for ASDE-X implementation in ground vehicles through some type of physical display was another alternative solution.

For the purposes of comparison, runway and taxiway signage and markings were taken as the baseline, meaning the score for each category was a zero. Each alternative solution was measured on a five-point scale against the baseline from -2 to +2. If a solution performed significantly worse, then it would receive -2, whereas a 0 would be given for equal performance, or a +2 for significantly better performance.

Each alternative was compared against the baseline strategy through a list of identified needs. In other words, each of the criteria represents a specification that must be met by the system, and how well each alternative solution meets these criteria versus the baseline determined the amount of awarded points. The criteria listed in Figure 1 were extrapolated from the FAA's Advisory Circular 150/5210-25 on performance specifications of airport vehicle RIWS (FAA, 2012b).

Each criterion was weighted in terms of priority to assist in assessing which alternatives would be worth investigating further. As the purpose of the systems are to mitigate runway incursions, the highest priority criteria are those most closely associated with this goal. Each criterion is important to consider, yet an order was established to create a usable tool for the decision-making process. Figure 1 depicts the initial Pugh matrix comparisons.

	Baseline	Alternative One	Alternative Two	Alternative Three
	Signage/Markings	Runway Status Lights	RAAS	ASDE-X on Ground Vehicles
Clear Alert Signals / Proximity Warnings	0	1	1	2
Precise Display of Ground Vehicle Position	0	0	0	2
Adaptability to Airport	0	1	2	1
Functional in various weather conditions	0	0	1	1
Indication of Alert / "Hot Spot" Areas	0	1	1	1
Raw Totals		3	5	7
Weighted totals		10	13	23
Point Scale: -2 to +2				
Weight Scale: 1 to 6				

Figure 1. Comparison of Alternative Modes for Runway Incursion Mitigation

The first criterion considered was how well the system could provide clear warnings to flight deck crews. These warnings would entail proximity warnings to aircraft, breaking hold short instructions, or even system malfunctions. Regardless of the form of warning, it must be clear and easily interpretable by crewmembers in most scenarios. Comparative to the baseline ASDE-X was the system most capable of providing clear and accurate feedback to users. Although both RWSL and RAAS are capable of alert signals, RWSL lacks the function to provide contextual messages, and RAAS cannot give alerts of proximity to other aircraft as it functions primarily based on runway data (such as length). Only ASDE-X can provide proximity alerts, in addition to runway data and contextual information.

The second criterion was how well the system could provide indications of aircraft ground positions along the airport vicinity. This is vital to any active monitoring system, and

without capability to visualize ground traffic then one of the top driving factors in runway incursions continues to go unchecked. Due to its nature, RWSL lack any means to show aircraft positions. Similarly, RAAS functions through auditory messages, and alerts users when a possible collision is detected, thus, it does not offer visual confirmation. This means both systems perform comparatively equal to the baseline. ASDE-X, however, can provide visual depictions of aircraft locations.

Next, the system must be customizable to airports, meaning there must be capabilities for the system to adapt to current airport layout, traffic conditions, prevailing weather, and any other idiosyncrasies of a specific airport. At this high level of comparison, the main consideration is that the system has the capability to change dynamically. Ideally, the system would be capable of effectively reflecting current conditions at the airport to all users. Runway status lights, upon initial implementation, can be designed in such a way that suits the state of the airport. The issue arises should any changes to the airport occur as RWSL are generally stationary and placed into the ground. However, the system does have the capability to be altered, albeit at some cost. Additionally, the system will be slow to adapt, and thus not capable of changing in accordance with traffic or weather conditions. Therefore, the system is only slightly better than traditional airport signage. ASDE-X also suffers from the same delays, as it is a system that utilizes many inputs, changing the software to reflect current airport states (concerning permanent layout changes) would take significant time. Although, changes due to weather or traffic may be represented somewhat quicker than RWSL. RAAS is the most adaptable system, as it is only a software that pulls from an informational database, and this information could be changed easily. However, it is important to note that there are limits to this system. RAAS is incapable of updating to weather or traffic conditions, as it is primarily concerned with physical runway data.

Functionality in a variety of weather conditions was the next criterion to be considered. The system must perform near optimally in standard weather conditions found within the United States. Using specific criteria from AC 150/5210-25, the system must perform in certain extremes as well: in temperatures ranges of -4 degrees Fahrenheit to 140 degrees Fahrenheit, operate at 95% relative humidity at 140 degrees Fahrenheit, and be resistant to vibrations and dripping water (FAA, 2012b). As runway status lights are physical systems located outside, they are the most susceptible to weather conditions. Heavy rain or snow can obscure their signals, thus reducing visibility (thereby reducing effectiveness). Thus, RSL are just as dependent on weather as traditional signage. RAAS and ASDE-X, however, remain inside vehicles, and thus are not as physically sensitive to prevailing weather. On the other hand, they are more susceptible to vibrations than traditional airport markings, as well as water spills. However, their insensitivity to weather conditions offset this weakness.

The final criterion that was considered in this comparison was the systems capability to indicate local airport “hot spots”. Areas of intense traffic or significantly elevated chances of runway incursions should be clearly marked to all crew. The system must be capable of showing these areas as temporary or permanent. Traditional markings can easily denote which areas of an airport are permanently considered hot spots, and temporary markings can be used to denote temporary areas of concern. As all the alternative systems can provide some manner of physical indication of the airport, they all rank equally. The only significant difference is that RWSL can notify crew quicker, while RAAS and ASDE-X can be more accurate. Therefore, each system ranks only slightly higher than the baseline.

Using this initial comparison, ASDE-X was determined to satisfy these criteria the most successfully over the baseline. The team then decided to look at both RAAS and ASDE-X

through a second comparative analysis with more detailed criteria to determine if ASDE-X on ground vehicles would still be a viable mitigation strategy.

3.1. Comparison between implementation of RAAS versus ASDE-X

A second Pugh matrix tool was used to compare the possibility of implementing RAAS over ASDE-X, as the team felt there were several other criteria to consider regarding these systems. As with the previous matrix, many of these considerations were extrapolated from Advisory Circular 150/5210-25 (FAA, 2012b). Figure 2 depicts the second assessment.

	Alternative One	Alternative Two	
Criteria	RAAS	Ground Vehicles with ASDE-X	Weight of Criteria
Provide ownership position of vehicle in AOA	0	1	7
Provide moving map of airport	0	1	3
Update map information to current airport status	1	1	2
Vehicle position accurate to <10 feet	1	1	6
Vehicle position data updated > once per second	1	1	4
Synchronicity with ATC information	0	1	5
Functional in various weather conditions	1	1	1
Raw Totals:	5	7	
Weighted Totals:	13	28	
Point Scale: 0-1			
Weight Scale: 1-10			

Figure 2. Comparison of RAAS versus ASDE-X

The first criterion was that of the system's capability to provide “ownership” position (specifically in the air operations area). Ownership position means the vehicles geographical position in relation to the surrounding area and other vehicles reporting through the same system. It is vital that any RIWS be capable of self-location, otherwise the information given through the

airport's navigation equipment would be difficult to interpret. Any GPS-like system must be capable of displaying traffic centered around the user. Due to the criticality of this need, the criterion was ranked with the highest priority. ASDE-X is the only of the two alternatives capable of visual ownship. ASDE-X is capable of contextualizing location relative to other aircraft and can display this information visibly. RAAS does have a form of self-location, but it lacks the key factor of contextualizing this information with other vehicle locations and a visual representation.

The second criterion considered, was the ability of the system to provide a moving map of the airport. A moving map is one that is centered on the vehicle using the system and moves the map orientation (and traffic orientation) in relation with the movements of the vehicle. This need was considered fairly important, but not critically so. This capability would increase the ease of use and system clarity, but not one that is absolutely vital to operation. So long as a visual representation is given, stationary or moving, the system could perform successfully. Again, as RAAS does not provide visual representations, it could not satisfy this criterion in its current state. In addition to this criterion, the systems capability to provide updated information based on the status of the airport was considered again. As with the initial assessment, RAAS would be as capable of these updates more readily than ASDE-X but also lacks certain aspects of information, whereas ASDE-X is more encompassing yet slower to change.

The fourth and fifth criteria were assessed simultaneously and were related to system performance. The chosen RIWS must be able to provide accurate position data, while providing real-time data. As per AC 150/5210-25, positions must be accurate within less than ten feet, and provide updated data no more than one second old. Both considerations are vital to the success of the system, as an inaccurate and slow RIWS could lead to an increase in incursion rates.

Therefore, they were each weighted highly. RAAS and ASDE-X both provide accurate and reliable data, as they each utilize current navigation technologies such as ADS-B. It is important to note though that the system only performs as well as the supporting navigational equipment of a specific airport.

Through using the second iteration of this Pugh matrix, the team determined that implementing ASDE-X through ground vehicles would be able to meet key needs of the FAA for runway incursion warning systems, while still targeting one of the significant leading factors in runway incursions for commercial aviation.

3.2 Comparison of Different Implementations for ASDE-X

After the team verified that ASDE-X integration with ground vehicles would be the focus of the design, the team utilized another comparative analysis to determine the form of this integration. Three modes of integration were compared: tablet application, self-contained multifunctional display, or synthetic vision. These modes were based on current aviation industry standards for navigation equipment and software. The tablet application would be a newly designed software for use with tablets that could be handed out to ground crews (or mounted in ground vehicles) that would be linked to the airports pre-existing ADS-B and ASDE-X towers. The multifunction display would be a smaller screen variation on the computers in use by ATC and would utilize the same software and infrastructure. The synthetic vision would couple the use of a smaller variation on ATC computers with a digital heads-up display overlaying the ground vehicles window (as opposed to a digital monitor mounted in the dashboard).

The comparative analysis was based on a list of criteria generated by the teams' previous research into RIWS needs, as well as thoughts on general needs of a system from an EONS framework. EONS being a sustainability concept that considers the economic viability,

operational efficiency, natural resource conservation, and social responsibility of a program (FAA, 2019b). It is important to note that natural resource conservation was not a significant factor in this iteration of assessment.

The criteria were weighted by overall priority, and scores were awarded on a zero to two scale. A zero meaning that the integration mode would not adequately satisfy the criteria (or would perform relatively poorly), whereas a two meant that the integration mode more than adequately satisfies the criteria or would perform relatively excellently. Figure 3 shows the design comparison utilized by the team.

Both the clarity of the display and the size of the unit were lower on the priority scaling of criteria. It is still worth ensuring that the system is clear to operators, while not so large it hampers the limited space of a ground vehicle. Both the MFD and tablet were considered to only minimally impact the space available in the ground vehicle. The MFD was also considered to have the clearest display of the alternatives. Notably, the MFD and synthetic vision equipment would likely be the only two alternatives not susceptible to glare from sunlight and modifying the tablets for non-glare screening could increase the cost of implementation.

The cost of installation and maintenance of the unit were the next criterion considered. In order to remain an economically viable mode, the cost to install software and the unit itself must remain relatively low. Additionally, the cost of maintenance must be equally low. The tablet ranked highest in both cases, as commercially available tablets are significantly less costly than the implementation of MFD's or synthetic vision equipment. However, MFDs are comparatively cheaper than synthetic vision.

	Alternative 1	Alternative 2	Alternative 3	
Criteria	Tablet	MFD	Synthetic Vision	Weight
Clear Clarity of Display	1	2	1	5
Small Size of Unit	1	1	0	1
Low Cost of Installation	2	1	0	11
Low Cost of Maintenance	2	1	0	10
High Longevity of Unit	0	2	1	7
High Resistance to Physical Damage	1	0	0	6
High Environmental Resistance	1	2	1	4
Powerful Technical Performance	0	1	2	12
Low Complexity of Unit Operation	2	1	0	3
Low Required Training Time	2	1	1	2
Low Cost of Personnel Training	2	1	0	9
Minor "Heads-Down" Time	0	0	2	8
Raw Totals:	14	13	8	
Weighted Totals:	111	138	119	
Point Scale: 0-2				
Weight Scale: 1-15				

Figure 3. Comparison of Possible ASDE-X and Ground Vehicle Integration Modes

The next three criteria were all similar and considered together. The longevity of the unit, its resistance to physical damage, and the resistance to environments take into consideration the ruggedness of the unit, and how long it could potentially remain in operation. Primarily, the longevity of the unit is a consideration of the general lifespan of the unit hardware, and the need for complete overhaul (or replacement). When considering constant use of commercial aviation, the team believed the tablet would need the most replacements of hardware (if not the entire unit itself). The MFD would need the least amount of corrective maintenance and would be able to withstand the constant use. However, the sensitivity of the unit and its display is much higher

than the tablet (and on par with synthetic vision equipment). Therefore, their resistance to outside damage, such as impact damage, mishandling issues, or scratching is lower than that of a tablet. Environmental resistance applies to the unit's performance in and acceptance of adverse temperature or moisture. Both the tablet and synthetic vision equipment could perform adequately in a wide variety of temperatures and with a low presence of moisture, but the MFD would be most resistant to moisture. Since the MFD would be mounted into the ground vehicle, the entrance of moisture into the unit would be highly unlikely. The operation in temperature was considered equal across all platforms.

Each mode was then assessed on the potential technical performance of the unit. How well the integration mode would meet the previous criterion of ASDE-X, such as accuracy of position and data update rate, is absolutely critical. If a unit is not powerful enough to handle the software demands, and operate smoothly, then the unit would be virtually useless. The tablet was not considered to be a competitive platform, the hardware would be significantly limited in power, and the software would need to be designed around these limitations. This is opposed to an MFD or synthetic vision unit which are comparatively more powerful and could be customized in hardware to meet the specific needs of the RIWS.

The complexity of the user interface and the required training time of personnel for each integration mode were more considerations by the team. These criteria were associated with how easily an operator could use the system with limited training, and how long it would take for personnel to achieve competency with the unit. Since tablets are widely utilized in commercial and personal use, the team felt that this mode would be the most understood. Additionally, the use of touch screens eliminates the need for buttons, dials, or line select keys, further reducing the confusion of an operator. A tablet-based application would be the simplest in terms of user

complexity and require the shortest training. Synthetic vision was believed to be the most complex mode, which negatively impacted its intuitive use, as well the required training time. In turn, these criteria influenced the estimated cost associated with training personnel on that specific mode.

The last criterion taken into consideration was the potential “heads-down” time created by the mode. In other words, how often personnel would be more focused on the screen of the RIWS, rather than on the surrounding environment. In this category, only synthetic vision, which overlays the personnel’s sight outside the vehicle, was deemed to pose no significant “heads-down” time while in normal operation. The other modes could cause personnel to potentially over-focus on the equipment rather than their situation during operation.

Using this last comparative method, the team was able to determine that the mode with most potential for success would be through a unique MFD, utilizing the ASDE-X monitoring technology.

4. Technical Description of System

Our solution to the runway incursion problem is to incorporate elements of the ASDE-X system, which is already present at many of the larger airports in the United States, into airport ground vehicles that are operated within the Aircraft Operation Area (AOA). This will be accomplished via utilizing the receivers for ASDE-X and ADS-B that currently exist at and around airports. A multi-function display will be used to communicate the necessary positional information within the vehicle itself. These displays will be similar in size and construction to those utilized at various ATCs.

Regarding the function of the system, the initial design is to implement a multi-functional screen on airport vehicles that has a color map of the terminal through which the movement of

both aircraft and other ground vehicles are shown dynamically. Data from ASDE-X and ADS-B is primarily processed through computers utilized at the tower control, but it is then uplinked to ground vehicle monitors. In further derivations it may be possible to include these processing computers onboard vehicles to provide more tailored systems.

The team identified a list of features the system must provide to the ground personnel in order to increase safety of airport ground surface movements:

1. Visualized and dynamic terminal map
2. Aircraft location: assigned runway, taxiway, or apron and movement information
3. Flight number, call sign, and aircraft model.
4. Ground vehicle locations, movement, and identifiers
5. Detection to avoid collisions and accidents
6. Visual and auditory warning to drivers and controllers in the cases of incursions with runway and ground conditions displayed dynamically
7. Simplified information layout and operation system
8. Navigation system for the drivers to specific, customizable airport locations

The information update rates would be held identical throughout the system to ensure information is accurate for all users. In order to differentiate between aircraft and ground vehicles, the units would provide their own specific identifier code that is dissimilar to those in use by aircraft. The identifier codes would have a prefix to depict the unit as a ground vehicle, with serialized numbers to indicate which vehicle it is.

Since the ground vehicles using the system are constantly moving, the map takes the ownership position of the vehicle to be the central point. In figure 4, this is represented by an arrow icon. All aircraft around the vehicle are shown by icons of planes, with identifiers readily

available. Users can choose aircraft through a button panel and after confirmation, the information of the targeted aircraft such as flight number, assigned runways or taxiways, and rate of movement (speed and direction) will be given by the information panel on the left side. In cases of impending incursions, the system will automatically give a warning sign on the upper right corner of the screen and audio warning will be given to the driver until the crisis is dismissed. These warnings will simultaneously alert ATC. Due to the differences in detail of information available between ground personnel and ATC, the layout of the system may be altered to preferences or by necessity.

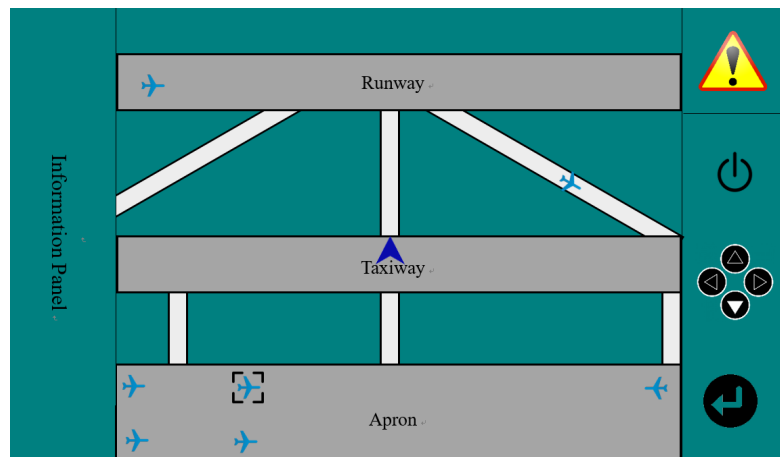


Figure 4. *Concept of ASDE-X Digital Display in Airport Vehicles*

One major alteration from ASDE-X available to ATC is that vehicle-based units would be equipped with navigational guidance to reinforce ground vehicle operational efficiency. Much like traditional GPS the system will assign optimal routes to user defined destinations. However, rather than considering only time to determine optimization, the system would also assess traffic into or out of the area, and any relevant advisories or cautions. However, ground crew must still be in contact with ATC if movement across taxiways or runways is needed. Training must emphasize the supplemental value of the system, as it is not a replacement for ATC.

As proposed, the system is flexible, remaining viable in taxiway management, runway incursion prevention, and as a training tool assisting unfamiliar ground personnel. As each airport is unique and utilizes its own variation of ASDE-X, there may be display differences between various airports. This would largely apply to the layout of the airport on the display, and may extend to certain features available to users, depending on the airport, but all users must be able to access the same functions in terms of monitoring the airport movements.

Despite minor differences in software between airports, the physical design of these units should be identical. Touchscreen LED monitors, with various line select keys and buttons to navigate pages, would be the primary interface for the users. The units will be mounted into the dashboard of ground vehicles, similar to the methods of mounting MFDs into flight decks. Shock absorption mounting would be employed to keep the unit stable inside the vehicle.

5. Safety Risk Assessment

A safety risk assessment was conducted on the proposed solution utilizing the foundational safety risk management phases outlined in AC 150/5200-37 (FAA, 2007). The system was described in previous sections, and this section will go through the phases of identifying hazards, determining risks, analyzing those risks, and creating mitigation strategies.

AC 150/5200-37 provides a general guideline on defining levels of risks (FAA, 2007). High risk events were those that are single-point failures in the system, or commonly occurring failures. As well, they are undetected latent events which could be a combination of the previously mentioned failures. For our design, high risk was not acceptable, as critical system failure would result, leading to significant monetary loss or system down-time.

Medium risk events were those that could potentially impact the operation and success of the system but were acceptable if mitigation strategies were in place. These events may be more

likely to occur on a common cause, but the impacts were much less severe. Oppositely, more impactful events that have a significantly lower chance of occurring are also placed in this level.

Low risk events were acceptable while not necessarily implementing a mitigation strategy, as these either have negligible impact or have a minor chance of occurrence. These events pose no significant risk to daily operation of the system.

To determine the level of risk that a given scenario was operating within, the likelihood of the event occurring and the severity of the event if it occurs must be determined. In terms of likelihood, the table is broken down into four levels from “improbable” to “occasional”. For the severity portion of the table, the scale is broken down from “negligible” to “critical”.

Table 1 provides the risk assessment matrix used to categorize several key risks identified. The table was based on examples provided by the FAA (2005b) and the FAA (2019a). Red colored areas were identified as high risk, yellow colored areas as medium risk, and green colored areas as low risk. Each square within the table is also identified using a number and letter combination.

Several different hazard scenarios involving the proposed solution were analyzed to determine their associated risk level. These ranged from potential events during normal operations to more abnormal scenarios. Each line in Table 2 represents one of these hazard scenarios along with the mitigation strategy for each. The lines are also color coded according to the risk level that was identified with each hazard scenario.

Table 1
Risk Assessment Template

Probability	Severity				
	Negligible (A)	Minor (B)	Moderate (C)	Serious (D)	Critical (E)
Probable (4)	4A	4B	4C	4D	4E
Occasional (3)	3A	3B	3C	3D	3E
Remote (2)	2A	2B	2C	2D	2E
Improbable (1)	1A	1B	1C	1D	1E

Table 2
Examples of Identified Hazards for Implementation of Ground Vehicle ASDE-X

Risk Scenario	Likelihood	Severity	ID	Risk Level	Potential Mitigation Strategies
MFD Temperature Failure	Improbable	Moderate	1C	Low	Identify hazardous temperature ranges,
Long MFD Boot-up Time	Probable	Negligible	4A	Low	Assess methods for downsizing data caches to increase boot-up time, perform preventive maintenance
MFD Power Failure	Remote	Moderate	2C	Medium	Routine maintenance of MFD and power source from ground vehicles. Instill training program to ensure systems are properly powered on/off
ASDE-X Tower Failure	Remote	Critical	2E	Medium	Routine maintenance of towers, with strict inspection programs to ensure the health of digital systems and datalinks from tower
Inaccurate Data	Improbable	Serious	1D	Medium	Install an alerting system to identify when the data from the system is interrupted. Install subprograms to process invalid data due to time update issues.
Datalink Interruption	Occasional	Critical	3E	High	Implement "reversionary mode" for the system to take data input from secondary sources, while shedding potential load from the system. Implement programs to prioritize re-establishing secure transmission from ASDE-X

6. Industry Interaction

Each of the industry experts the team spoke to offered a large amount of information.

Their expertise included different perspectives and knowledge we were unable to obtain from

previous research. This allowed for a review of incorporating NextGen technology into ground vehicles.

Dr. Stewart Schreckengast

Having many years as a specialist in airport safety, Dr. Stewart Schreckengast was able to provide the team with information about runway incursions and current solutions. Dr. Schreckengast's aviation background is extensive, having roles as a Naval Aviator (Commander), a Consultant with MITRE, a Senior Aviation and System Safety Analyst for FAA, a Technical Consultant with ICAO, and a Researcher and Educator at Purdue University. He is also a Certified Member of the American Association of Airport Executives, a Member of the International Society of Air Safety Investigators (ISASI), an FAA Certified Flight Instructor, and an FAA Commercial Pilot.

Adam Baxmeyer

The team spoke with Adam Baxmeyer, who has held different key operational roles at airports. After graduating Purdue University, Mr. Baxmeyer became the Operations Supervisor at Cherry Capital Airport, followed by the Director of Operations at Central Illinois Regional Airport. He currently serves as the Airport Director at Purdue University Airport and is also a Certified Member of the American Association of Airport Executives (AAAE). Mr. Baxmeyer was influential in helping the group better understand the thoughts of airport operations regarding runway incursions, runway incursion prevention systems, and safety.

Tom Rainey

As the FAA Technical Operations Manager at Louisville International Airport (KSDL), Tom Rainey was able to explain the importance of ASDE-X. Tom has been working with

aviation and airport NAV-Surveillance-Communication-Weather technology repair and engineering for 32 years.

The responses we received from our industry experts had a constant theme:

- Effectiveness of the ASDE-X system
- Costs of the ASDE-X system
- Safety impacts incorporating a digital display into ground vehicles has on airport operations
- Situational awareness impacts on ground vehicle operators that had access to a digital display

Overall, the industry experts agreed that incorporating a digital display into ground vehicles would increase the situational awareness of their operators. Most of the feedback showed that there were many positives with the ASDE-X system, and it has become very essential to ATC operations. Our experts concluded that the main prevention of runway incursions is dependent on the situational awareness of the controllers, pilots, and operators of ground vehicles. When this fails, there are not many other systems available to prevent potential runway incursions. Also, many of the current runway incursion prevention systems are impacted by overall costs and weather limitations (i.e. snow or reduced visibility). This clearly presents a concern for safety.

Although this system has been very effective, the costs were the main concern of our experts. The team was unable to determine the exact cost, but it was believed to be in the millions. This would vary for different airports due to multiple factors. Ultimately, the experts were not sure if the costs outweigh the benefits in some cases. However, our experts questioned what our team thought safety should cost. The team, as well as our industry experts, were unable

to justify an exact answer. They said there is always that possibility of something bad occurring, but that does not always mean it will. With this in mind, it was determined by the team that it is better to be safe than sorry, especially in the aviation industry. Ultimately, the team decided to continue with our original design.

7. Projected Impacts of Design

7.1. Cost-Benefit Analysis

Table 3 depicts the R&D cost breakdown. The initial R&D costs for the alpha stage are assuming a pay rate equal to that of a teaching assistant at Purdue university, with the same timeframe of work provided for the ACRP design competition. The beta stage changes this pay rate to be more equal to that of a research assistant and assumes a 16-week academic period. Faculty labor is also incorporated at this stage. The beta stage is when the prototype design is created, and therefore has some significant costs associated with it. The major assumption is that the team would acquire a Garmin GTN-625 MFD to work as the prototype unit. It was chosen as Garmin is a common avionics manufacturer, and the unit fits the technical demands from the system. The price is based on aftermarket units listed on Elliott Aviation (Elliott Aviation, 2020). The prototype must be retrofitted with ASDE-X software for testing (as would the eventual production units). The team was unable to find an exact estimate of the cost for the software and potential support equipment for reprogramming. Therefore, these values were based on the cost of the entire system, \$21.22 million (United States Congress et al., 2009). The team felt the software itself should account for ten percent of the entire system, and therefore the license would equate to \$2.12 million. From there, support equipment would be another ten percent fraction, equating to 212 thousand dollars. It is important to note that the initial year of stages of research would include the cost of this license, but it may not be a recurrent expense dependent

on the timeframe for licensing renewal. Therefore, when assuming a ten-year timeframe for this analysis, the team added in this licensing cost for only the initial year of development.

Table 4 details the costs associated with an airport acquiring the system from the developers (in this case the research team) for 100 units over a one-year period. A technician provided by the developer would be contracted by the airport to retrofit aftermarket Garmin GTN-625 MFDs with the ASDE-X software the airport uses (again, assuming only airports with pre-existing equipment). It should be noted that the units would be acquired by the developer, but the airport would be charged the units cost to cover the expense. The wages used in these calculations assumed the average salary of avionics technicians according to the U.S. Bureau of Labor Statistics (2019). The airport would also be charged for the installation of the reprogrammed units into their ground vehicles. This cost was estimated to be roughly 50% of the cost of the unit itself, as the team could not reference a specific benchmark for avionics installation. Finally, the unit shipments would also be at the cost of the airport, and this information was based on UPS ground services for small simple rate shipments.

On top of the acquisition costs, the team identified recurring costs to the airport for the technical and maintenance support of the units over the one-year period. The system developers would provide these personnel at the average salary of avionics technicians as identified previously. Another recurrent cost to airports would be the user training for ground crews. The team benchmarked this cost against the average cost of an airframe and powerplant certification test for Purdue students, roughly two thousand dollars. The training would provide ground personnel with the required knowledge and skills to operate the proposed system. For simplicity, the team opted to account for this training as an annual three-day program, capable of supporting a 30-person team.

As a final total, the team calculated that an airport would spend approximately 2.1 million dollars to acquire and support the system over ten years. This cost comes from the one-time system acquisition costs, the recurrent cost of maintenance and technical support, and a surcharge for R&D. For the developers to cover their own costs for creating the system, the R&D total found in table 3 would be divided among airports acquiring the system. The team operated under the assumption that 15 airports would utilize the system, so each airport would be charged just over 6% of the total R&D costs. Of course, this surcharge would change dependent on the adoption by airports, and realistically could be extended over a period of time rather than an upfront cost.

A risk summary was performed using Chicago O'Hare (ORD) as a benchmark due to its volume and current usage of ASDE-X systems (Table 7). From 2009 to 2019 ORD had 9.638 million operations and had 63 VPD incursions during the same timeframe (FAA, n.d.a.; FAA, n.d.d.). This equates to 6.5 VPD incursions per million operations and would be used as the risk potential for the benefit versus system cost analysis found on Table 8. Prevention benefits depicted on table 6 were also used in this analysis to create a model for the projected economic benefit of the system. The cost of one accident per million operations resulting in three moderate injuries, major aircraft damage, a destroyed ground vehicle, and an accident investigation within a ten-year time frame is approximately \$607 billion. Compared to the ten-year cost of system support, \$2.1 million, the system has a benefit to cost ratio of nearly 281.

Table 3
Development Cost

	Item	Rate	Qty.	Subtotal	Remarks
Stage					
R & D (Alpha)	Labor- University Design Competition to Develop Concept				
	Student Research	\$20/hr	100	\$2,000	4 students - 25 hours each
R & D (Beta)	Labor- Academic R&D to Develop Test Unit				
	Student Research	\$32/hr	2,688	\$86,016	Assuming GRA work over 16-week period
	Faculty Advisor	\$100/hr	1,000	\$100,000+	Assuming Faculty Advisory work over 16-week period
	Marketing & Sales		Est.	\$4,000	Advertising
	Expenses				
	Travel	\$20/trip	14	\$280	Assuming gas prices for travel to ORD for field testing, based on average mpg and gas prices
	Hardware	\$4,250	1	\$4,250	Based on aftermarket GTN-625 MFD
	ASDE-X Software license	\$2,120,000	1	\$2,120,000	Estimate of acquiring software license from pre-existing ASDE-X system / based on 10 percent of ASDE-X system cost
	Support Equipment for ASDE-X Retrofit	\$212,000	Est.	\$212,000	Cost of tools used in retrofitting MFDs / based on 10 percent of Software costs
Total				\$2,528,546	Final total for all R&D stages

Table 4.
Costs to Airport for System Acquisition

	Item	Rate	Quantity	Subtotal	Remarks
Stage					
Airport Acquisition Cost	Labor - Installation of 100 units at Airport with Pre-existing ASDE-X towers				
	Technician Labor for ASDE-X Retrofit	\$31.41/hr	800 hrs	\$25,128	Average technician salary multiplied by 1 unit per 8 work hours
	Ground Vehicle Installation	\$2,125	100	\$212,500	Cost for installation of MFD into vehicle based on 50 percent cost of unit acquisition
	Expenses				
	MFD Procurement	\$4,250	100	\$425,000	Cost of developer acquiring aftermarket GTN-625 MFDs for reprogramming
	Unit Shipping	\$10.95	100	\$1,905	Shipping based on UPS ground services for small simple rate size
Subtotal				\$664,533	Subtotal for unit acquisition over 1 year period
Operations & Maintenance Services	Labor - Maintenance and Technical Support Contracting, Recurring Costs				
	Maintenance Support	\$31.41/hr	2,080 hrs	\$65,300	Onsite maintenance support, average technician salary over work year
	Technical Support	\$31.41/hr	2,080 hrs	\$65,300	Remote technical support, average technician salary over work year
	Ground Crew User Training	\$2,000	Est.	\$2,000	Training program of 3 days for 30 ground crew personnel
Subtotal				\$132,600	Support subtotal for 100 units over 1 year period

Table 5
Airport Cost Summary for System Support

Cost Summary for Airport Acquiring & Supporting ASDE-X Ground Vehicle MFDs Over 10 Years					
Item	Charge	Timeframe	Subtotal	Remarks	
Costs					
Appropriated R&D Costs	\$168,569	1 year	\$168,569	6% charge to airport based off R&D costs	
Airport Acquisition Costs	\$664,533	1 year	\$664,533	Table 4	
Operations & Maintenance Service Costs	\$132,600	10 years	\$1,326,000	Table 4	
Total Cost			\$2,159,102	Total Cost to Airport over 10 years	

Note: R&D charge is assuming 15 airports are acquiring system and R&D cost is split evenly among them

Table 6.
Risk Avoidance Benefits Provided by System

Prevention Benefits		
Item	Rate	Remarks
Value of Life	\$9.6 million	Based on values provided by FAA (2016) for fatalities
Value of Moderate Injury	\$451,200	Based on values provided by FAA (2016) for injuries
A/C Destroyed	\$114.7 million	Based on average price of 737 variants from Boeing (n.d.) and loss scaling from Čavka and Čokorilo (2012)
A/C Major Damage	\$91.77 million	Based on average price of 737 variants from Boeing (n.d.) and loss scaling from Čavka and Čokorilo (2012)
Ground Vehicle Destroyed	\$250,000	Based on estimate provided by Virginia Space Grant Consortium (2016)
Ground Vehicle Major Damage	\$25,000	Based on estimate provided by Virginia Space Grant Consortium (2016)
Accident Investigation	\$1 million	Composite estimate of indirect costs associated with accident investigation based on Čavka and Čokorilo (2012)

Table 7
Risk Summary

Risk Summary for Vehicle/Pedestrian Deviation (Based on Statistics from ORD)				
Item	Number of VPD Incursions over 10 years	Number of Operations over 10 years	Risk multiplier	Remarks
Operational Risk				
Risk of VPD	63	9.638 million	6.5 / 1mil	Risk potential for 10 years

Table 8. Benefit vs Cost for System Implementation

Benefit vs Cost (A/C to Ground Vehicle Incursion)						
Item	Unit	Qty.	Subtotal	Risk	Total	Remarks
Cost						
Value of Moderate Injury	\$451,200	3	\$1,353,600	6.5	\$8,798,400	Tables 6 & 7
A/C Major Damage	\$91,770,000	1	91,770,000	6.5	\$596,505,000	Tables 6 & 7
Ground Vehicle Destroyed	\$250,000	1	250,000	6.5	\$1,625,000	Tables 6 & 7
Accident Investigation	\$1,000,000	1	\$1,000,000	N/A	\$1,000,000	Tables 6 & 7
Total Accident Cost Prevented (Benefit)					\$607,928,400	
Cost (System Deployment)					\$2,159,102	
Benefit to Cost Ratio					281.56	Benefit outweighs cost

7.2. Sustainability Assessment

Sustainability has several interpretations, but one definition would be “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (FAA, 2019a). In order to better assess the impacts of the system for both this generation and future generations, the team utilized the EONS model. As mentioned previously, EONS is a sustainability framework that encompasses more than concepts of environmental impacts. The framework assesses a system based on economics, operations, environmentalism, and social responsibility. This sustainability model was chosen to evaluate the proposed system due its encompassing perspective. The FAA has encouraged the use of this model for airport sustainability planning (FAA, 2019a). The solution proposed in this project has been designed to aid in airport sustainability and safety, and the impacts of this solution are discussed through the viewpoint of the EONS model.

7.2.1. Economic Impact

The new solution has a significant economic impact on airports. Runway incursions are considered as one of the most frequent accidents in airports and can be costly (Eekeren et al., 2017). Due to damages to equipment and assets, the losses from an incursion can be high. Not only do losses arise from equipment, but there are associated costs due to diversions, delays, and operational impacts from incursions. As described by Čavka and Čokorilo (2012) insurance premiums, wreckage searches, and accident investigations comprise indirect safety costs of an accident, which prove a heavy financial burden on airports.

The losses are significantly worse when considering the potential for human injuries or fatalities. Since the implementation of ASDE-X category A and B incursions have been reduced significantly, but lower categories are still frequent. Though the chances of a runway incursion related fatality are reduced with the current ASDE-X status, even injuries have significant associated costs. It has been estimated by the FAA that a moderate injury would have an associated cost of \$451,200 (FAA, 2016). The FAA suggests a fatality could cost 9.6 million dollars, with reasonable assumption that this could increase to 13.4 million dollars (FAA, 2016).

Between the period of 2015 to 2018, there was an estimated cost of 20 billion dollars due to runway accidents and incursions (Eekeren, Wright, & Čokorilo, 2018). Nearly 500 million dollars per month was lost by the commercial aviation industry due to runway related incidents. Eekeren et. al (2018) also denoted an increasing trend with associated costs on runway related issues, growing throughout the years.

Though implementing new ASDE-X systems is incredibly costly, the proposed design is predicated on utilizing pre-established equipment and expanding its control. The costs of implementing more ASDE-X monitors into ground vehicles is greatly offset by the potential

losses from these incursions. The system has already been a proven tool at reducing the severity of incursions, and with new implementation, it can further reduce the frequency. Thereby, airports can reduce their losses from these financially straining events.

7.2.2. Operational Impact

The proposed solution intends to have a significant impact on the operational efficiency in airports. It is difficult to provide an accurate description of operational benefits due to absence of historical data concerning ASDE-X and ground vehicles, but it is undeniable that implementation of ASDE-X into the aviation system has had an impact on operations. During the initial phase-in of ASDE-X Mark Runnels (2009) stated, “One of the greatest untapped benefits of ASDE-X today is the analysis of real-time and recorded data to assist in understanding airport operations.”

ASDE-X capabilities are commonly discussed when considering total airport management (TAM) systems. The concept behind TAMs is to create a performance-based system that employs system wide information management to increase airport efficiency (Eurocontrol, 2016). As discussed in previous sections, the highest categories of runway incursions have been significantly reduced by ASDE-X. Coupled with the sheer magnitude of data made available from the system, ASDE-X has proved to be a valuable tool in increasing the efficiency of ground operations at airports. The value of ASDE-X can only be improved by allowing the system to integrate into more operations.

By implementing this tool into ground vehicles, and targeting the high frequency of vehicle related incursions, operational efficiency of airports is sure to rise. Coinciding with the concept of TAM, runways and taxiways will be occupied more frequently and operations will be safer due to lower chances of vehicle incursions. In turn the rate of normal operations will be

promoted, as will their relative safety. Additionally, the time wasted on recovering from runway incursions, and all their associated operational impacts will be reduced. In this regard, operational efficiency in airports can be advanced through the proposed implementation of ASDE-X.

7.2.3. Environmental Impact

The new solution will have minimal impacts on the surrounding environment because it will be utilizing systems that have already been put into place by the airport. Airports without the ASDE-X system will require additional materials, which should also have minimal impacts. The new solutions main environmental impact would be an increase in materials needed to implement a MFD within the ground vehicle. This would only result in a negative outcome if these devices are not properly recycled when and if needed to be replaced.

7.2.4. Social Impact

The new solution will have very minor impacts on the social aspect of the airport. There will be some social changes required for those that operate the ground vehicles on the airport surface. This required change will manifest itself in an adjustment of the social norms that the operators were used to prior to the new solution. Proper change management starting with ramp and ground operations supervisors will need to be implemented. This will come in the form of strong training of these supervisory groups, who will then train the regular line employees on the operation of the new system. Proper training procedures for new employees will also need to be developed. Once the operators understand how the system works and how to properly use it, they will likely not have any issues with it.

7.3. Fulfillment of ACRP Goals

For many years, the aviation industry has focused on reinforcing its safety assurance system. Airports are a vital component of the aviation industry, and as such it is the

responsibility of these components to operate flights in a safe and efficient environment. The implementation of ASDE-X into ground vehicles promotes both operational efficiency in airports and, more importantly, safety. Through providing ground crew personnel with a detailed, accurate, and dynamic diagram incorporating navigation functions, the proposed system aims at reducing the probability of runway incursions. Thus, safety and overall sustainability of airports is promoted, which in turn benefits the industry. Furthermore, both economic effectiveness and operational efficiency are increased, which are also parts of ACRP goals. Additionally, through this project, the team acquired substantial and thorough comprehension about ASDE-X and the operational regulations at airports, especially where it concerns RIWS. Interaction with industry experts in multiple subjects brought the team insightful and professional opinions in the field of aviation.

8. Conclusion

Runway incursions are a serious issue at airports throughout the United States.

Implementing ASDE-X into airport ground vehicles will address the Runway Safety/Runway Incursions/Runway Excursions category of the ACRP Airport Design Challenge.

Ground vehicles may interface with the existing ASDE-X data already present at larger airports within the United States. This data will then be transmitted into airport ground vehicles and displayed to the operator via a multi-function display (MFD) which will allow the operator to see other aircraft and ground vehicles operating on the airport surface as well as the location of all nearby runways and taxiways. Based on our team's safety risk assessment and cost-benefit analysis, we can conclude that our innovative solution of implementing ASDE-X into airport ground vehicles will provide airports with a safe, cost-effective way to help mitigate the risk of runway incursions caused by these vehicles. This will reduce the cost that airports incur due to these occurrences and provide for a safer aviation industry for all involved in it.

Appendix A: List of Complete Contact Information

Student Information:

Mason Edwards

Email: edwar178@purdue.edu

Marc Suarez

Email: masuarez@purdue.edu

Jiansen Wang

Email: wang4410@purdue.edu

Kenneth Zollars

Email: kzollars@purdue.edu

Advisor Information:

Dr. Mary E. Johnson

School of Aviation and Transportation Technology, Purdue University

Email: mejohanson@purdue.edu

Appendix B: Description of the University

Purdue University is a state-funded university in Indiana. It was named after John Purdue who donated \$15,000 to begin construction of the university. With the help of Tippecanoe County, the university was officially founded in 1869 and started classes on September 16, 1874 (Purdue University, n.d.-a). Currently, Purdue University has an enrollment of over 41,000 undergraduate and graduate students (Purdue University, n.d.-a). It is estimated that about 2,000 full-time faculty teach and conduct research in Purdue's 157 principal buildings with 377 total buildings on 2,307 acres (Purdue University, n.d.-a).

The School of Aviation and Transportation Technology is one of seven schools within the Purdue Polytechnic Institute. The Purdue Polytechnic Institute is one of the 13 colleges that make up Purdue University (Purdue University, n.d.-b). It is recognized worldwide as a leader in aviation education with ownership of 24 aircraft based in Purdue University Airport, the second busiest airport in Indiana (Purdue University, n.d.-b).

Appendix C-Description of non-university partners involved in the project

There were no non-university partners involved in this project.

**Appendix E: Evaluation of the educational experience provided by the project.
Students****1. Did the Airport Cooperative Research Program (ACRP) University Design Competition for Addressing Airport Needs provide a meaningful learning experience for you? Why or why not?**

Our team thinks that the ACRP University Design competition provided a very meaningful learning experience for our team. It allowed the team to develop a greater understanding of the process for formulating, designing, and preparing for the implementation of an innovation in the aviation industry. It also allowed us to interact with industry professionals who were able to provide a new perspective of our design problem and the aviation industry as a whole. The real-world applications of safety risk assessments and Pugh matrices in this competition also helped the group understand how these tools, which we have learned about at Purdue, are important to the design process. Overall, it was a tremendous experience which provided immense learning benefits to the team.

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

There were many challenges that occurred during the completion of this project. After deciding on a project idea, it had to be adapted to meet the sustainability needs of an airport. The COVID-19 pandemic played a major role in the completion of our project. The pandemic greatly influenced our ability to work as a group, interact with industry

experts, and our daily lives. This created many difficulties that we as a group were able to overcome by working diligently and prioritizing tasks to stay on track.

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

To develop our hypothesis, we first identified the problem that needed to be corrected. Our group then came up with several possible solutions to the problem. To identify which solution would prove the most feasible, we utilized a Pugh matrix. Different parameters were inputted into the Pugh matrix and given values. Then each option for our solution was run through the matrix and received based on the parameters within the Pugh matrix. Based on these results, our team was able to identify which solution to our problem was the most feasible and which would be pursued within our project.

4. Was participation by industry in the project appropriate, meaningful, and useful?

Why or why not?

With the current pandemic, it made it difficult for our industry interaction to occur. Some of our industry experts notified us that they would not be able to help or at least not to their full potential. Fortunately, those who did help offered valuable information. Their viewpoints and knowledge of the topic covered allowed our group to better understand aspects we were not familiar with.

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 has allowed our group to increase our overall knowledge of project management, and being able to adapt when presented with a challenge. From these experiences, we believe that we can utilize the lessons learned to better our future works. This project has also provided our group with real world experience about developing a solution to an industry problem and also provided insight about the mitigation of risks during its implementation.

Faculty

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

This project has been a true challenge for the students this semester with all of the changes at Purdue, and the increased levels of concern for friends and family across the globe. I am happy to say that they completed this report. Resilience! That may be the biggest educational experience in this competition. For students in my aviation sustainability course, this competition has great value 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 that mirror a request for proposals. This competition encourages the 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. The students have had much fewer interactions due to the stresses placed on the air transportation system beginning in late January. When the industry interactions did occur, this energized the team as they

realized that these airport challenges are truly important and that with some tweaking or changes, their proposed solution may become a better solution.

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

Yes. This is a graduate level applied aviation sustainability course where the airport improvement projects are also evaluated on the sustainability analysis. The required literature review encouraged the team to not rely solely on what they had already learned about runway safety, but to extend their knowledge by reading academic and trade publications. Their interactions with airport managers and other experts encouraged them to delve into regulations to understand what is under the purview of each component of the ATS.

3. What challenges did the students face and overcome?

Targeting the problem and solution to the airport and not solely the aircraft was the first challenge for this team. It took a while to better understand what the airport's capabilities were versus aircraft, ATC and ground control. The corona virus also changed the way the team communicated with each other, myself, and the industry experts. The students overcame the challenges and produced a high quality project. I am very proud of them.

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.

Appendix F: References

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