Case Report

Case Study of an Automated Mower to Support Airport Sustainability

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Abstract: This paper documents a case study of an automated mower to support sustainability at an airport. Mowing is an essential component of an airport's Wildlife Hazard Management Plan (WHMP), which reduces the risk of birds and other wildlife to aircraft operations. Many airports have large areas of land (hundreds or even thousands of acres), which requires significant resources to manage and mow; experience at the Purdue Airport (KLAF) suggests that automated mowing may support economic and environmental aspects of sustainability. Automated mowing supports economic efficiency by reducing personnel requirements, although personnel are still needed for inspections, maintenance, and "mower rescue" if there is a malfunction (technical or field issue). Automated mowing supports environmental impacts by reducing local emissions since the mower is powered by electricity rather than gasoline; this benefit would be increased with the use of solar-powered mowers. Automated mowing may not be viable everywhere, and factors such as terrain, access to available power, acreage, and location on the airfield (including proximity to protected areas) must be carefully considered. Although automated mowing will not completely replace traditional mowing in the near future, autonomous mowers in remote areas may be an appropriate practice to support airport sustainability.

Keywords: sustainability; automation; automated vehicle; mowing; airport efficiency; airport operations; emissions

1. Introduction

Sustainability is increasingly important at all facilities, including airports, which strive to provide a positive experience, meet the needs of passengers and aeronautical users, support their communities, and do so within the context of a sustainable framework that considers economic, environmental and social impacts. Airport operators of all sizes are focused on controlling costs and increasing efficiency, and they are also increasingly mindful of the environmental impact of their activities, especially given campaigns such as Sweden's Flagskam, an anti-flying movement that supports train travel and flight shaming in an effort to reduce carbon emissions and harm to the environment.

There are a number of sustainability metrics that have been used at airports, including CEEQUAL (Civil Engineering Environmental Assessment and Award Scheme, part of the Building Research Establishment in the U.K.), LEED (Leadership in Energy and Environmental Design, developed by the U.S. Green Building Council), Envision (often used for infrastructure in the U.S.), GRI (Global Reporting Initiative, formed with support for the United Nations and used internationally), ISO 14001 (an environmental management system by the International Organization for Standardization), and the Airport Carbon Accreditation program (developed by the Airports Council International, ACI) [1]. Many of these sustainability metrics focus on infrastructure (e.g., CEEQUAL, LEED, and Envision). ISO 14001 and other environmental management systems (including the one outlined in

the Federal Aviation Administration's (FAA's) Advisory Circular 150/5050-8 [2]) provide a framework that can be tailored to specific goals, which may include protecting the environment and preventing pollution, conserving energy and other national resources, and protecting the health of people and resources [3,4]. The Airport Carbon Accreditation Program provides an internationally recognized program to support the assessment and reduction of carbon dioxide emissions and includes multiple levels from Level 1 (mapping) through Level 3+ (Neutrality) up to Level 4+ (Transition) [5]. The framework is inclusive, with the scope expanding at higher levels. For example, Level 1 measures emissions that are under airport control (called Scope 1) as well as emissions from electricity, heating and cooling generated off-site (called Scope 2); Levels 4 and 4+ also consider emissions from aircraft (while landing and taking off, called Scope 3) and implement offsets for emissions that are not eliminated through other means [6]. At many airports, emissions from mowing would be considered a mobile source in Scope 1 since they are under the control of the airport; emissions from mowers are not explicitly mentioned in the ACI technical manuals, whereas emissions from airside automobiles, trucks, employee buses, construction vehicles, and ground service equipment (GSE) for aircraft trucks are all mentioned as mobile sources [7].

Scholarly research has examined emissions for mowing and turf management at golf courses [8,9] and for urban turfgrass areas [10]; however, no scholarly research was found that quantified the specific impact of mowing at airports. The impact of emissions due to mowing is significant, and it is appropriate to evaluate ways to reduce emissions from mowing. In the U.S., mowing equipment is often gasoline-powered, consuming 800 million gallons of gasoline each year [11], and resulting in 5% of the air pollution [12].

New technologies are one way to support sustainability and are one alternative to consider for airport mowing. Many new technologies at airports have been focused on "passenger facing" activities, such as automated airline check-in kiosks and smartphone apps. Less attention has been focused on using new technologies to support sustainability in the airside environment, where airport operations and maintenance activities are conducted to ensure safe operations for aircraft.

Previous research has investigated the potential for automated vehicle (AV) technologies (aka advanced ground vehicle technologies or AGVT) for airside operations, including activities such as mowing, snow and ice control, and perimeter inspection [13]. This article focuses on the deployment of automated mowing on the airside at the Purdue University Airport (KLAF), a general aviation (GA) airport in West Lafayette, Indiana.

The U.S. Department of Transportation (US DOT) has made AV technologies a priority and published a comprehensive plan for deployment in January 2021 [14]. This plan builds on previous documents that outline the role of automated driving systems (ADS) to support safety [15] and provide a multimodal approach to deployment [16]. Although generally focused on AV technologies on the roadways, much of the information is relevant to ground vehicles in the airport environment. There are many AV technologies that may support safety at airports, ranging from driver support features (Levels 0, 1, and 2) to conditional automation, in which the driver is responsible for monitoring the system and the environment (Level 3) to full vehicle automation (Level 5), in which the vehicle can perform all functions in all conditions. The levels of automation are shown in Figure 1. These levels were published in May 2021 by SAE and augment previous definitions to include remote support functions (both remote assistance and remote driving) such as the remote support used for this automated mowing case study. AV technologies may include obstacle warnings enabled by sonar, light detection and ranging (LIDAR) or other sensors, location alerts based on vehicle position and protected areas of the runway (enabled by GPS in the vehicle and a robust electronic map of the airport), and proximity alerts to nearby aircraft based on ADS-B data.

Figure 1. Automation Levels as Defined by the SAE in 2021 (Image: SAE International, 2021 [17]).

Airports are an interesting use case for AV technologies since airports have a limited and well-defined geographic area, all users have licenses and/or have received training through their employer, and activities are regulated and well documented.

Benefits

There are a number of potential benefits to automated mowing, including economic and environmental benefits. Automated mowing has the potential to increase the efficiency of mowing activities, reduce labor costs, support wildlife management efforts, remove people from a potentially hazardous job, reduce emissions, and provide a better understanding of issues related to automation in the airside environment in a low-risk context. During the spring and summer seasons, mowing activities may require dedicated personnel and significant resources, especially at airports with large areas of grass. Adequate maintenance of grass areas is important to prevent erosion, to ensure compliance with the Airport Wildlife Hazard Management Plan (WHMP) and reduce the likelihood of wildlife strikes, and to reduce the risk of foreign object debris (FOD) such as sand or dirt caused by jet blast [18].

2. Materials and Methods

There are a variety of possibilities when it comes to automated mowers. Automated mowers range in size from about 0.5 m (20 inches) to the size of a conventional riding mower. Although the agriculture sector has developed and demonstrated automated full-size tractors, these are not currently available "off the shelf" for purchase and use.

The most appropriate mower varies depending on the application. Small mowers could be deployed as a fleet and may be suitable for use in protected areas of the airfield since it would presumably be easier to demonstrate that small mowers are frangible; frangible objects are designed to yield on impact to help ensure aircraft safety. Some remote-control mowers can handle steep slopes (up to 40 degrees) and, theoretically, these remote-control mowers could be programmed to operate for functionality that is similar to automated mowers (the programmable operation would be analogous to the programmed operation of an unmanned aircraft system or UAS). Some airports already use remote mowers on steep slopes, which provides significant benefits by removing people from a potentially dangerous situation. Stavager Airport Sola in Norway uses automated mowers to cut about 28 hectares (70 acres) of airfield turf [13], but there is little published information about their use and operation.

The mower used at KLAF is approximately 1.2 m by 1.2 m (4 ft by 4 ft), with a 1 m (approximately 40-inch) cutting path. It has five floating disks; each disc has three replaceable blades, as shown in Figure 2. Smaller mowers may have fewer disks (one or three, depending on the size of the mower). The mower used at KLAF was originally designed for a two-hectare (five-acre) plot; since the aesthetic standards airside at the airport are not as stringent as applications in other sectors (e.g., sports fields), it may be possible for a single mower to manage two two-hectare (five-acre) plots or more. The mower cuts a random path, although zones can be defined and the mower can be programmed to mow within one or more designated zones. The mower can also be programmed to avoid a zone, which may be useful if there is a low spot where ponding may occur after a heavy rain, or if there is steep terrain that the mower cannot accommodate.

(**a**)   (**b**)

(**c**)
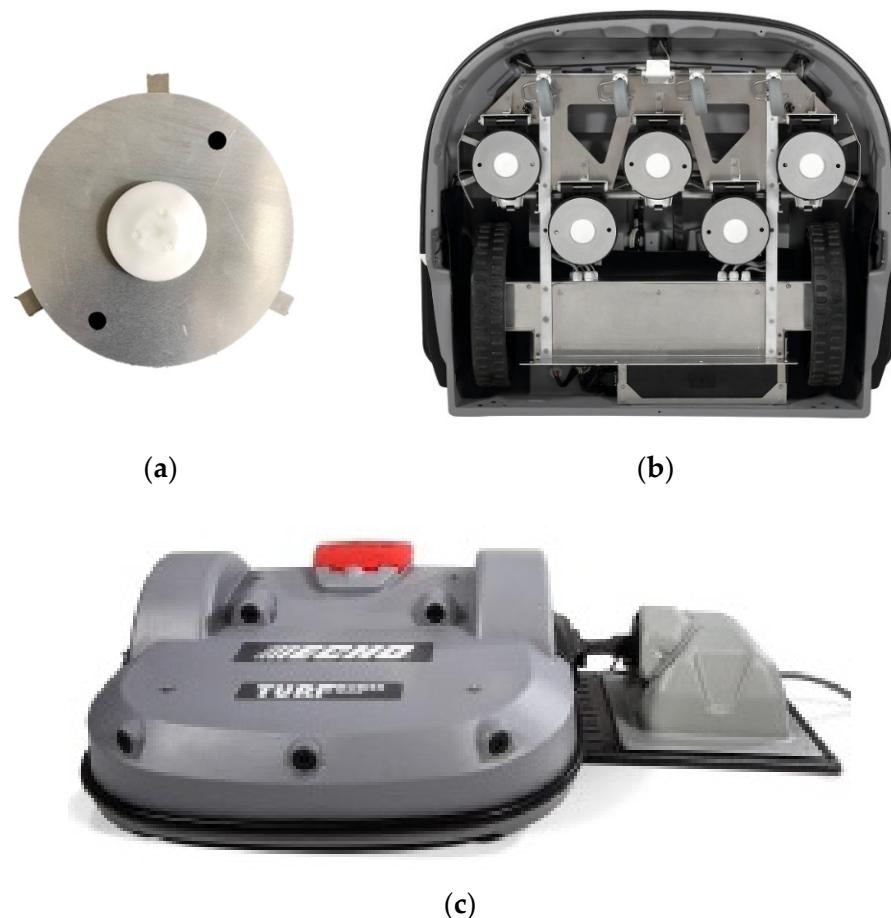
Figure 2. Automated Mower Used at KLAF (Images: Echo Robotics). (**a**) A single disc with three blades; (**b**) Mower has five discs with blades; (**c**) Mower at charging station.

Location Considerations

There were a number of considerations when identifying the most appropriate location for the trial at KLAF. These considerations include proximity of mowing area to aeronautical activities and protected surfaces, terrain, a suitable plot size, availability of power, and relative location on the airfield, including ease of access for inspections and natural barriers between the mowing site and protected surfaces. Purdue University Airport management consulted with, and received concurrent approval from, the FAA before commencing testing.

In terms of terrain, different automated mowers have different characteristics with respect to the grade and terrain that can be accommodated. The mower used at KLAF was originally designed for sports fields, so it is better suited to a relatively flat area. There would be additional safety benefits realized if deploying automated mowers that can handle steeper grades. Another consideration with respect to terrain includes the drainage characteristics of the site, including the likelihood of ponding, since automated mowers may not be able to manage standing water or swampy areas.

At KLAF, a relatively level two-hectare (five-acre) area with good drainage was selected for the initial deployment. The area is fenced on three sides and is shown in Figure 3. The fourth side does not have a fence; however, the area is far removed from the movement, safety, and object-free areas. A second site closer to the airfield has also been identified for future deployment of an automated mower powered with solar power. The KLAF mowing sites are shown in Figure 3.

Figure 3. *Cont.*

Figure 3. Automated Mowing Sites at KLAF (Images: Google). (**a**) Initial site near fuel farm with existing power; (**b**) Second site closer to taxiway proposed for operation with solar power.

3. Results

The results of the pilot study of automated mowing were generally positive. There are some important operating considerations and safety features that enhanced safety and ensured that the automated mower would not interfere with aeronautical activities or be a threat to people or objects. These safety elements include both hardware and software, as follows.

- Hard-wire induction loop with current: A small wire (similar to the wire used for an invisible dog fence) was buried along the perimeter of the field. This loop carries a low-voltage current.
- Mower software: The mower will stop if it crosses the induction loop, or if the loop loses power for any reason.
- Geofence: The mower software prevents the mower from operating outside of the perimeter of the designated area. This serves as a safety feature on the airfield, and also means that the mower will not operate if it is stolen or moved.
- Physical barrier: As a redundant feature, a physical barrier was provided to ensure the mower remained in the designated area. Railroad ties were used, although it would have been possible to use stakes in the ground, or a fire hose filled with water. The size of a physical barrier would vary depending on the characteristics of the mower.
- Mower sensors for collision avoidance: The mower uses sonar for obstacle detection and will stop if an obstacle is detected in its path.
- Remote monitoring: The mower can be monitored remotely; this includes checking on the current mower location and status (e.g., mowing or charging) and the capability to send a limited number of commands such as return to station via either an app on a smartphone or a computer with internet service. Messages about the mower are also sent via the app and email if the mower malfunctions and requires a mower rescue.

The primary safety consideration is that the mower does not leave the designated area and pose a threat to aircraft. The numerous hardware and software redundancies, combined with the physical barrier, provided confidence that the mower would remain in the designated area.

A secondary safety consideration is that the mower does not pose harm to people or objects in the airside environment. This is ensured by the mower sensors for obstacle avoidance, as well as compliance with strict safety standards, which were designed to allow the mower to operate in an environment such as a public park, where it may interact with members of the public. In the US, automated mowers must comply with the same

safety standards regardless of location (e.g., requirements for operation in airside, which is a very protected environment, are the same as the requirements for operation in a public park, where the mower could interact with children or other people who do not have any safety training and may not be familiar with the equipment risks). In Europe, the safety standards are different, and automated mowers in a protected area are not required to comply with the same consumer safety standards that are required for operation in areas such as public parks or private yards.

If the mower goes into alarm mode, the mower will stop where it is, send a message via text and email, and remain stopped until someone manually starts the mower on site. The requirement for a physical restart of the mower is a safety feature. If the mower had a camera mounted on it (or if airport cameras could provide a view of the mower), perhaps it would be possible to change the software and allow a remote restart. At KLAF, causes for alarms included: obstacle detection (could be caused by uneven terrain or a small animal), mower tilt (may be caused by a tire in a hole), loss of power to the perimeter wire, loss of a disk blade assembly, and problems with the station connection. In some cases, there would be a mower alarm without an obvious cause; however, the number of alarms reduced significantly over time as changes to the mower system were made, and in some cases, due to changes to field terrain such as filling in low spots. Table 1 shows the operating characteristics for the first and second years of operation. The hours mowing plus the hours charging does not equal the total hours; other states of operation include idle, in alarm mode, go charge at the station, leave station, wait at station, and off. Figure 4 shows the pattern of mowing (blue) and charging (blue), as well as the alarm (red).

**Table 1.** Mower Operating Characteristics at KLAF.

	Days	Total Hours	Total Hours on	Hours Mowing	Hours Charging	Active Time	Number of Alarms
2019 Session 1 19 July to 2 September	46	1104	892	562 (51%)	274 (25%)	859 (78%)	23
Session 2 18 September to 16 October	29	696	657	404 (58%)	160 (23%)	582 (84%)	11
2020 Session 3 27 May to 26 July	61	1464	1351	902 (62%)	399 (27%)	1337 (91%)	7
Session 4 6 August to 20 October	76	1824	1795	1115 (61%)	469 (26%)	1640 (90%)	2

The mower at KLAF used a random mowing pattern. Use of a random pattern reduces efficiency [19], but theoretically may provide some benefits in terms of wildlife management. The coverage over a three-day period is shown in Figure 5. A programmed path using real-time kinematic (RTK) global navigation satellite systems (GNSS) would also provide advantages in terms of the ability to predict the future location of the mower at any point in time, which would be advantageous if the mower is used in a protected area.
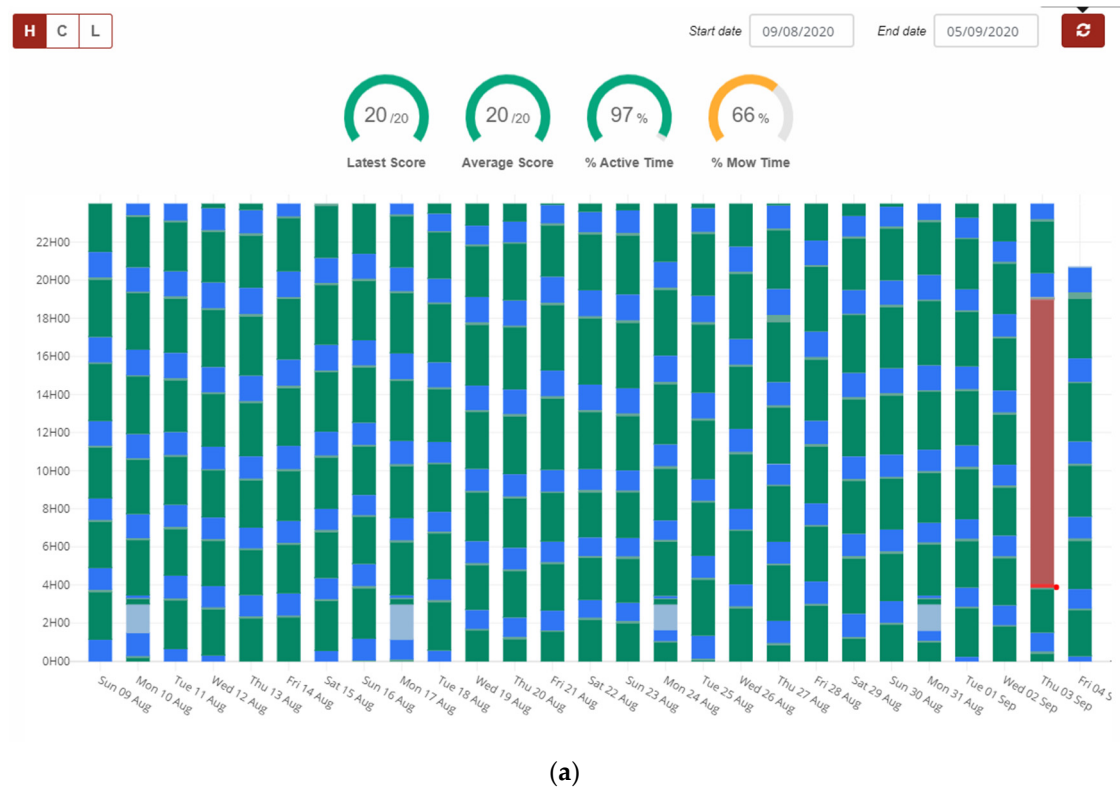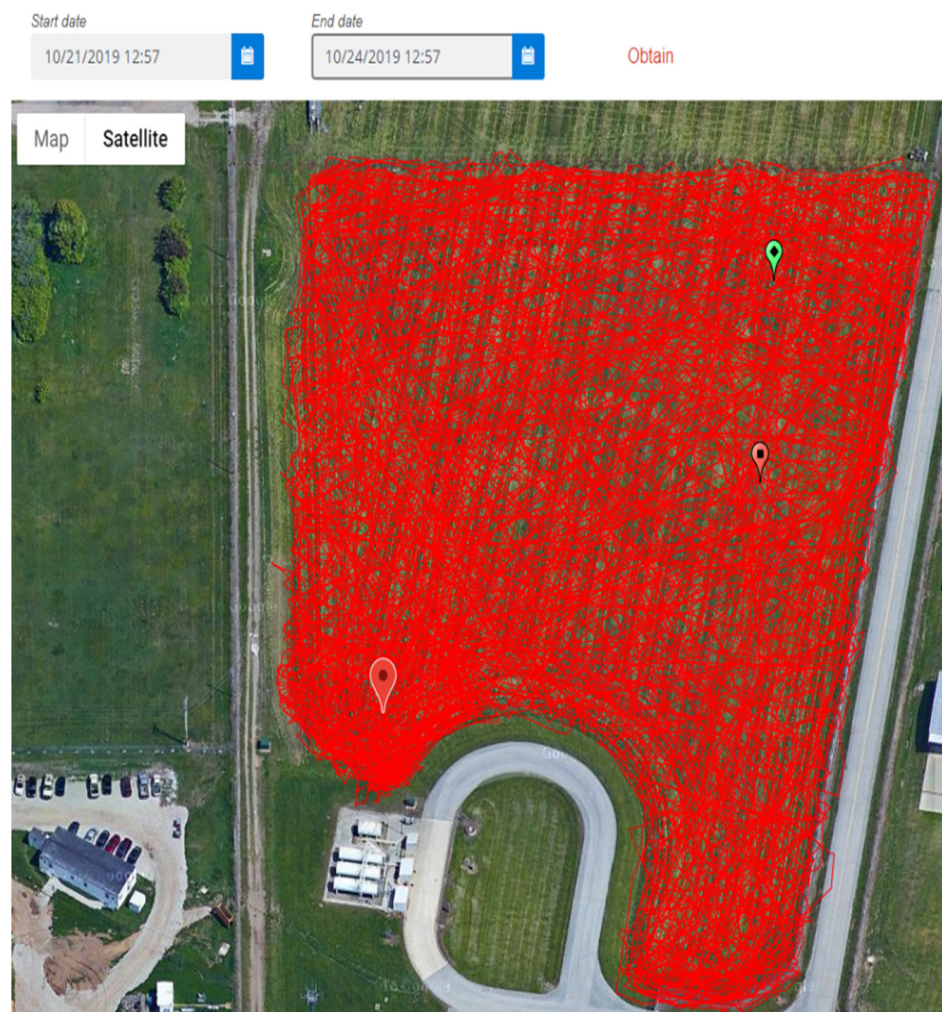
(a)
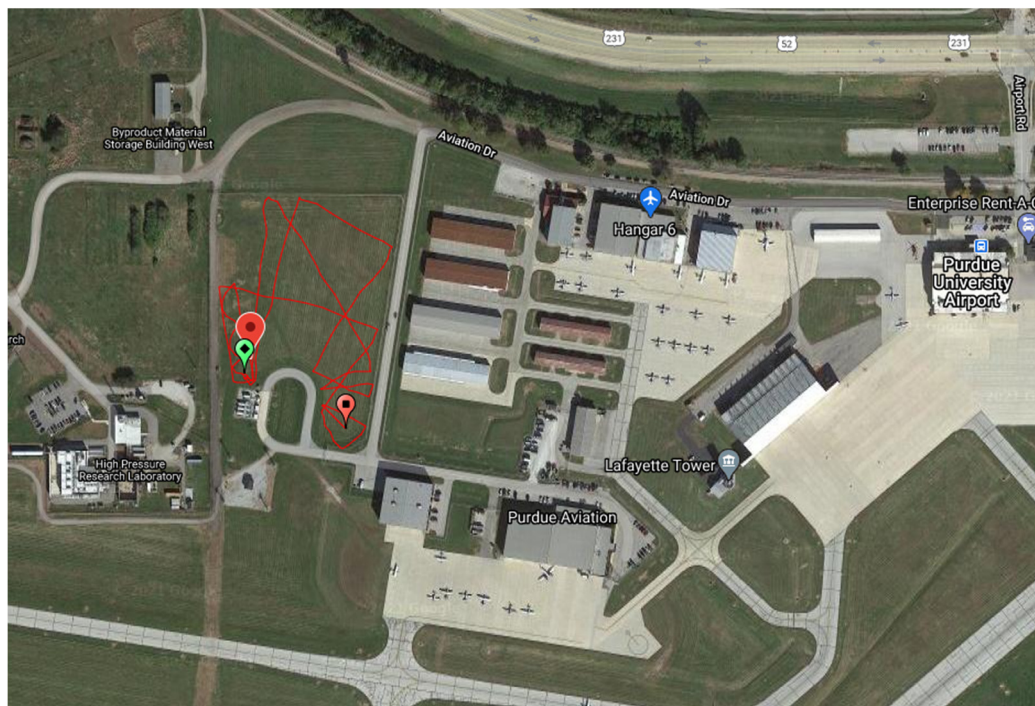
(b)

Figure 4. Records of Mower Activity Can be Accessed via the Internet. (**a**) Example Display of Mower Status (8 August to 4 September 2020); (**b**) Example Display of Mower Location (11:00 a.m. to 1:00 p.m. on 8 August 2020).

Figure 5. Example Mower Coverage over a Three-day Period in 2019.

Future research will document a comparison of the efficiency of automated mowing with traditional mowing by human operators. Qualitatively, the gains include reduced personnel time with time savings associated with the mowing operations, the travel time to reach the mowing area, and the time required for mower refueling.

4. Discussion

The results of the case study illustrate that an automated mower can be successfully implemented at an airport and that conventional mowers can be replaced to eliminate emissions, if power is available and if the site to be mowed is compatible with the mowing capabilities.

One of the most significant potential benefits of automated mowing is to reduce the personnel required for mowing. This benefit is offset by personnel time required for inspections, maintenance, and mower rescue, however these requirements are low compared to the time required for mowing. The recommended inspection interval would vary depending on the site and mower characteristics. A reasonable interval would be one or two weeks, which would ensure a check of the mower, charging station, integrity of physical barriers, and confirmation that the height of the grass is consistent with the airport Wildlife Hazard Management Plan. The mower used at KLAF allowed remote monitoring of location and status (e.g., charging or mowing), as well as alarms if the mower experienced a tilt or obstruction. The mower may experience a tilt if someone tried to lift or move it, or if a wheel went in a hole at a certain angle.

Maintenance activities include changing the blades, blowing grass out from under the mower to ensure unobstructed movement of the blades, cleaning of the housing, and station maintenance. A reasonable interval for changing the blades may be one or two months, although this would vary depending on the type of vegetation. The mower shell tends to attract dirt and pollen due to static electricity.

The frequency of alarms which require personnel to be dispatched to the site varies significantly depending on the characteristics of the mower and the characteristics of the field. Characteristics of the mower include the physical platform and components, the programming and software (e.g., tolerance for acceleration and differential lift, and sensor capabilities and tolerance for potential obstacles including small ground animals), and operating characteristics (e.g., tolerance for differential forces and acceleration). Characteristics of the field include terrain, holes, vegetation, ponding, and soil saturation. Different mowers may have different capabilities in terms of performance in wet conditions. At KLAF, the field had good drainage characteristics. It would be possible to park the mower if the field was too wet. It would also be possible to geofence zones to avoid where ponding is present after a heavy rain. At the KLAF mowing site, the mower went into alarm mode when there were power interruptions (e.g., due to a storm).

Automated mowing may be especially helpful for remote areas of the airfield. Remote areas can be time-consuming for personnel to access, and remote areas may be ideal in terms of safety for initial deployments, since they provide a buffer from protected areas of the airfield where aeronautical activities occur. Remote areas are probably less likely to have power, which suggests that a system with reliable solar power would be appropriate. Similarly, the remote area must have signal connectivity to allow communication regarding mower status and to allow remote commands; the mower used at KLAF utilized a cellphone signal.

4.1. Other Implementation Considerations

In addition to considerations previously discussed, such as ensuring safety and matching the capabilities of the mower to the field, implementation considerations include coordination and approval with the Federal Aviation Administration (FAA) and coordination with the mower vendor. Future deployment in protected areas such as the RSA would require demonstration of frangibility, which would require additional testing and approval. While the airport environment presents some benefits and opportunities when it comes to the integration of new technology, it also presents some challenges.

At KLAF, coordination and concurrence were obtained from the appropriate FAA Airports Certification & Safety and Airport Compliance offices. The Purdue University Airport is a public-use airport included in the National Plan of Integrated Airport Systems (NPIAS) and holds an FAA Airport Operating Certificate in compliance with 14 CFR Part 139.

Ideally, future operation would include automated mowing next to runways and taxiways in the runway safety area and taxiway safety area. For operation in the RSA for an active runway, an automated mower would need to be tested and certified as frangible. Frangibility requirements are defined in AC 150/5220-23A, Frangible Connections [20] and in FAA's Frangibility Guidebook [21]; however, much of the guidance regarding frangibility was developed for fixed objects in the RSA and the information may require modification for a mobile device such as an automated mower. A frangible object is designed to have minimal mass and absorb a minimal amount of energy during impact. Frangible objects typically break away upon impact, minimizing the potential to cause aircraft damage, impede aircraft motion, or alter the path of an aircraft. It may be appropriate to use a fleet of small mowers in the RSA, and it may be possible to show that small mowers meet frangibility requirements due to their low profile, and the capability for even a small aircraft to push them out of the way.

An alternative to demonstrating frangibility may be to use automated mowers at night, when aeronautical activity is low and a runway can be closed for mowing with less

disruption to aeronautical activities. For use in the RSA, it would be desirable to have mowers that can be programmed to follow a specific path, both to ensure that mowing is completed as quickly and efficiently as possible, and to enable the capability for the mower (or mowers) to move out of the RSA if there is aircraft that needs to take off or land.

Partnership with industry is very helpful for the deployment of new technologies since the airport represents a unique environment for a number of reasons. On the positive side, the airport may have some sovereignty to make rules and regulations for operations on airport property, there is a well-defined geographic area, all personnel have passed required training, and all activities on the airport are well defined. On the challenging side, there are numerous regulatory constraints and deployment may require coordination with multiple FAA offices. The need for safety is important; however, an unintended consequence of the strong safety focus is that it may create a bureaucracy that impedes innovation. Another challenge to technology deployment is the high-stakes environment; this is due to the proximity of operation near expensive aircraft, the high cost associated with any aircraft delay due to equipment malfunction, and different aeronautical activities conducted by a wide variety of users. Furthermore, many automated vehicle technologies were designed for the roadway sector, and the sensors may not be calibrated or proven in the airport environment. This consideration is less relevant for automated mowers, since the primary area where they operate does not involve interaction with aircraft.

The philosophy and characteristics of activities at an airport are diametrically opposed to the philosophy of many technology firms, which may advance with a "fail fast" framework that supports trial and error to support progress. Airports often do not have a streamlined, structured, and well-defined process for the approval and integration of new technologies, which may dissuade technology firms from working with airports, and puts a greater burden on the airport that wishes to implement new technologies. One example provided by an industry partner is that a technology firm can get a UL-Listed seal by submitting the device to a participating lab for testing and approval. This process is well defined and the associated cost from the participating lab can be determined before the process begins. This varies dramatically from the process for demonstrating the safety of a product for use at an airport, where approvals may be needed from multiple agencies (and from multiple offices within FAA), and approval at one airport in one Airport District Office (ADO) does not necessarily imply blanket approval at all airports in all ADOs, since each airport has different operating and physical characteristics that must be considered, and different ADOs may have slightly different priorities and slightly different interpretations of policy.

4.2. Additional Benefits

In addition to the benefits mentioned previously (e.g., the potential for reduced personnel costs and increased safety by removing people from mowing activities), automated mowers can contribute to airport sustainability efforts. Shifting from gasoline-powered mowers to electric mowers, or better yet, electric mowers powered by solar power, reduces airfield emissions and the airport carbon footprint. Moreover, airports can use automated electric mowing to showcase their innovation and sustainability efforts to the community.

Automated mowers in remote areas of the airfield can also increase efficiency, since it can be time-consuming and inefficient to deploy mowing personnel to remote areas of the airfield. Of course, personnel would still need to perform periodic checks of the mowers and remote fields, and on occasion may need to provide a mower rescue if there is a malfunction. As the mowers become more efficient and reliable, the need for these checks may be significantly reduced.

5. Conclusions

The Purdue Airport (KLAF) is in a unique position due to its affiliation with Purdue University, a major research university with a wide variety of academic programs, creating opportunities to participate in a variety of research projects. This research provided the

opportunity to investigate automated mowing, which holds promise for supporting the management of airfield grassland to support airport safety, efficiency, and sustainability. Although it is not practical at this point to completely replace traditional mowing activities with automated mowing, there are airfield locations and circumstances in which automated mowing presents a viable alternative.

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