2019-2020 ACRP UNIVERSITY DESIGN COMPETITION

Integrated Preventive Maintenance Solutions for Airport Assets Management

(January 2020 - May 2020)

Design Challenge Addressed: IV. Airport Management and Planning A: Improved Strategies for Airport Asset Management.

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Executive Summary

This proposal presents a solution to the Airport Cooperative Research Program (ACRP) University Design Competition Challenge IV: *Airport Management and Planning, A: Maximizing airport capability; improved strategies for airport asset management* (ACRP, 2019). Between January 2020 and April 2020, our team worked on a proposal to address preventive maintenance planning for airport assets. We propose developing an integrated software package with mobile application, based on a computerized maintenance management system (CMMS). Extant literature revealed that one of challenges associated with the current commercially available Computerized Maintenance Management System (CMMS) solutions is the high initial cost of purchase and maintaining the software, making them almost exclusively affordable to airports with large budgets only. This means small airports must find alternative asset management solutions, which are often less effective. In addition to the high cost, current CMMS solutions do not cater to an airport manager's specific needs.

The proposed integrated software package provides budget and user flexibility to airport managers and maintenance personnel. Assets can be added to the package based on criticality and airport budget. As airport budget increases, other assets can be added to the software as a module. Moreover, the proposed package provides a mobile application for the maintenance personnel filling a gap left by current CMMS software. The proposal was developed based on proven quality techniques of Total Preventive Maintenance (TPM) and Plan, Do, Check, Act (PDCA) considering each airport's unique maintenance needs. The cost benefit analysis shows that an airport can expect 4.6 times benefits over cost ratio with a 3.6 return on investment in four years. Additional project analysis conducted include; safety risk analysis and sustainability impact. Overall this projected had demonstrated high feasibility when implemented.

Table of Contents

Problem Statement and Background

This proposal presents a solution to the Airport Cooperative Research Program (ACRP) University Design Competition Challenge IV: *Airport Management and Planning, A: Maximizing airport capability; improved strategies for airport asset management* (ACRP, 2019). In addition to the ACRP Design competition, while conducting the literature review, our team came upon a Request for Proposal (RFP) dated December 31, 2019, issued by the Transport Research Board (TRB); for research project titled "Quantifying the Impacts of Delayed Maintenance of Airport Assets" (TRB, 2019). According to the RFP, delayed maintenance can be placed under three categories: Financial impact, operational impact and public impact. These are impacts that should be avoided at all cost. Literature review indicates that airport asset management is often overlooked, more so in small and medium size airports. Some of the reasons cited for low asset management planning include high cost of procuring preventive maintenance solutions and solutions that do not provide the expected outcome for asset maintenance plans. Lack of feasible solution leads to running assets to failure (ACRP, 2012).

Developing an affordable and integrated preventive asset maintenance solution can be the answer to the challenges currently faced by airport managers and maintenance personnel. This project highlights the importance of preventive maintenance to avoid the high costs of replacement of the failed assets. The modern airport's infrastructure is highly sophisticated requiring constant monitoring, and routine maintenance for optimal performance. Large airports often use high end Computerized Maintenance Management System (CMMS). However, small and medium sized airports with smaller budgets do not need a complex CMMS software. In addition to the high initial cost, airports must train maintenance personnel on the use of a CMMS once acquired. These constraints contribute to low adoption of CMMS for airports' asset management strategy (ACRP 2018). Lu, Chen, Lee, and Zhao (2018) argue that the CMMS does a good job in storing daily work orders, historical records, and maintenance information but it is difficult to extract the necessary information for day to day activities. So, there is a gap between the acquisition and installation of a CMMS software by an airport and the effective utilization of CMMS software by the maintenance personnel.

Our team proposes the use of an affordable, integrated software package for asset management for all airport sizes, more so for airports with budget constraints like small and mid-sized airport. This solution was developed after conducting a thorough literature review and interactions with industry experts.

Literature Review

This section is a summary of the literature review conducted by the team to identify some of the challenges airport managers face in airport asset maintenance, and the currently available CMMS solutions. The literature review is divided into three sections: lack of preventive asset maintenance, total preventive maintenance (TPM) and challenges with the available solutions.

Low Adoption of Preventive Maintenance

The safety and efficient operation of an airport depends on the reliability of its facilities. Having a sound maintenance program is essential to the daily operations of an airport (ACRP, 2015). Due to challenges such as budget constraints and lack of standardized process, few airports have planned preventive maintenance programs. Especially, small airports with minimal resources (ACRP, 2015). Currently, most airports conduct the bare-minimum maintenance required by law, called operational maintenance, or result to adopting reactive maintenance, characterized by use until it fails approach, which is ineffective and often results to higher costs in the long run. On the other hand, a preventive maintenance program involves regular assessment of the conditions of airport assets and deliberate scheduled maintenance of all components of assets (ACRP, 2015).

Adopting a preventive maintenance program can extend asset life and optimize and maintain asset performance. As demonstrated in ACRP (2012) many airports have adopted a nine-step process '*Guidelines for developing an asset management plan'* that starts by developing an asset registry. Step seven of the process is to '*optimize operations and maintenance investment*'. This step includes a decision diagram to determine the maintenance strategy for the asset under consideration. It suggests that if the failure of the system is not predictable or if the prediction is not feasible, then the best strategy is to adopt reactive maintenance strategy with a corrective failure response. But if the prediction is both predictable and feasible, then use either condition-based maintenance or usage-based maintenance (ACRP 2012). A presumed advantage of this method is that capital costs are not incurred until replacement is needed. A study on the adoption of CMMS into airports shows that, on average airports typically spend far more dollars performing unplanned or unscheduled maintenance than if they were to perform planned regular maintenance (ACRP, 2018). Non-operational assets portray a negative image of the airport potentially driving away valuable business.

Airports play an important role in the global air transport system. And with the aviation industry experiencing significant growth in passenger traffic, the strain on the airports' maintenance department has increased because they are expected to keep the facilities running, 24 hours a day and 7 days a week. Concurrently, spending on facility maintenance has decreased or completely stopped in some cases post September 11, 2001 as the focus was primarily on strengthening the security measures at the airport (ACRP 2018). Preventive or Predictive maintenance has been used in other sectors and has proven effective in improving assets' life. If maintenance activities are scheduled accurately, airports can manage resources, reduce system failures, and extend asset life by improving the wrench time (ACRP, 2015). These benefits add up and help the airport reduce its maintenance costs leading to stable rates and charges for the airlines and tenants (ACRP 2018).

Total Productive Maintenance (TPM) for Airports

In the simplest of terms, Total Productive Maintenance or TPM is a modern maintenance strategy that aims to achieve maximum equipment effectiveness by targeting to accomplish zero breakdowns, zero accidents, zero wastes and zero defects by utilizing the predictive and preventive maintenance strategies (Manihalla, Gopal, Rao, & Javaraiah, 2019). TPM starts with the 5S establishment which is elaborated to Sort, Straighten, Shine/sweep, Standardized and Sustain. Upon this strong base the eight pillars of TPM are erected. They are: Autonomous Maintenance, Focused Improvement, Planned Maintenance, Quality Maintenance, Education and Training, Office TPM, Safety, Hygiene and Environment and Developed Management. It is up to the management to select what pillars are suitable for the particular asset under consideration. Together they make up the TPM approach that focus on improving the Overall Equipment Effectiveness (OEE). (Díaz-Reza, García-Alcaraz, & Martínez-Loya, 2019, Chapter 1).

Few studies have investigated TPM implementation in service organizations. Haddad and Jaaron (2012) investigated the applicability of TPM in healthcare facilities. Chompu, Tipgunta and Sunawan (2008) investigated the implementation and evaluation of TPM for the dental hospitals. Both studies investigated developing a methodology for increasing medical device utilization and reducing equipment downtime (Ali, 2019). Attri, Grover, Dev, and Kumar (2013) argue that implementation of TPM is not easy for an organization because it involves overhaul of culture. The potential barriers that were narrowed down include lack of top-level management commitment and support, and lack of training and education, amongst others. However, if implemented right, the business performance is significantly superior in firms that are experienced and have implemented TPM than in non-TPM firms (Brah & Chong, 2004). Better operations control for the administration, productivity benefits like improving equipment reliability and availability and safety benefits like improving environmental conditions, and prevention and elimination of potential causes of accidents are few benefits of successfully implementing TPM (Díaz-Reza et al., 2019, Chapter 4). Additionally, CMMS can be an invaluable tool in successful TPM implementation. To reap all the benefits of TPM, CMMS can store and organize large amounts of asset information and provide easy access to historical records, performance trends, statistics, etc. Furthermore, CMMS will improve the communication among maintenance personnel and between the management and maintenance personnel, thus, improving organized TPM implementation (Bohoris, Vamvalis, Trace, & Ignatiadou, 1995).

Challenges in Current Asset Management Solutions

Unforeseen maintenance at an airport tend to have a ripple effect disrupting operations of several airport stakeholders. For instance, a downtime in passenger boarding bridge may cause an airline to reschedule flights. Consequently, connecting passengers miss their connecting flights at destination airports. Preventive maintenance programs help an airport to plan maintenance accordingly to avoid unexpected asset failure. Computerized Maintenance Management Systems (CMMS) are commercially available software that can be purchased by airports and used to plan and record maintenance. Although considered effective, CMMS software are complex systems that require extensive staff training before they are adopted (ACRP, 2018). Plus, due to the high cost of purchase and additional training cost, CMMS are an out of reach expense that cannot be afforded by small airports with smaller budget. The challenges of using a CMMS software are amplified further by their low success rates, failing to solve airport specific conundrums and failing to integrate CMMS with other airport systems (ACRP, 2018).

Ideally, airports of all sizes should have a preventive maintenance program. However, the decision to adopt a CMMS or other preventive maintenance solutions is unique to each airport depending on the airport asset registry and budget. In ACRP (2018), case studies conducted at six airports and non-airport organizations showed that successful implementation of a CMMS can be of benefit to airport managers in understanding the diverse airport assets and incorporate asset management in the overall organization strategy (ACRP, 2018). Although small airport managers may understand the benefits of using a CMMS, the cost of investing in such a software may not seem as a feasible investment option. However, if offered an affordable solution, most managers would invest in a CMMS. It is imperative that the airport industry introduces an affordable asset maintenance solution. Although no literature was found on adoption of TPM and CMMS together at the airports, our team argues that, based on adoption of TPM in other service industries, this approach can be adopted and used in maximizing the utilization of airport assets. Therefore, our team combines two modern approaches to maintenance to develop a cost effective and efficient airport asset maintenance solution.

Problem-Solving Approach

Due to the nature of airport maintenance management, the team decided to use two approaches: I. The Plan-Do-Check- Act (PDCA) & II. Total Preventive Maintenance (TPM). A discussion on how the two approaches can be combined to improve asset management at airports follows:

I. Plan- Do-Check- Act (PDCA)

A process approach was considered most suitable for developing a problem-solving approach for preventive maintenance of airport assets. PDCA is a continuous improvement methodology developed by Quality Guru, Walter Shewhart (Saier, 2017). PDCA model provides a basis for developing a measurable plan and decision making with facts.

II. Total Preventive Maintenance (TPM)

TPM is a team management program with an emphasis on employees' empowerment and based on principles of continuous improvement and total quality management (TQM) with the aim of attaining zero defects and stoppages (Stephens, 2004; Kiran, 2016). TPM was used in manufacturing facilities in Japan (Madewell, 1998). The Total Preventive Maintenance philosophy comprises of three main elements: a) regular maintenance (housekeeping); b) periodic overhauls (pre-failure replacement) and c) zero tolerance of deficiencies (Kiran, 2017). TPM was originally designed in Japan by Seiichi Nakajima for production and manufacturing plants but can be applied to any maintenance requirements in any industry. TPM takes advantage of operators' experience in handling an equipment to reduce repair time and gives the operator room to develop preventive measures that work best for their specific equipment. Applying TPM means to be consciously aware of the daily maintenance requirement in an organization.

Incorporating TPM with the standard PDCA approach in Airport Maintenance

Our team proposes an innovative approach grounded on TPM and PDCA tenets. The team uses PDCA as the overarching, long term management philosophy. The TPM approach used follows the structure outlined by Kiran (2017). The resulting model can be used by airports to manage daily maintenance needs while incurring minimal financial cost and reducing downtime from asset break down. Figure 1 shows a process map with the steps identified as necessary in implementing TPM for airport assets management. A discussion on how the process can be applied in airport maintenance follows:

Phase 1: Plan

One of the significant barriers to the successful implementation of TPM is lack of commitment and involvement from top-level management (Attri et al., 2013). To achieve the best outcome with TPM, airport management should make it clear to the maintenance team and other stakeholders that the airport is committed to adopting the TPM approach for improving its maintenance strategies. Once the need for adopting TPM has been established, the airport management can follow the process map shown in Figure 1 to develop a maintenance plan.

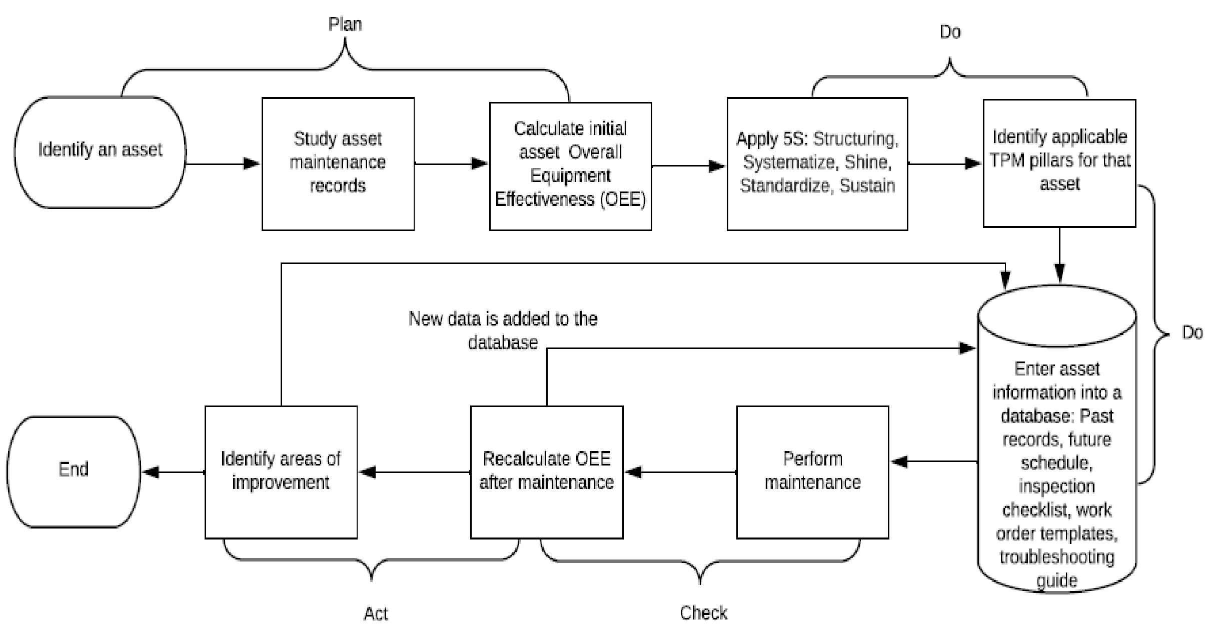

Figure 1. Process map developed by the team to show how TPM can be incorporated in the PDCA process approach

In the first step the airport needs to identify the asset it wants to include in the software, considering airport budget and criticality of the asset. *ACRP Report 69: Asset and Infrastructure Management for Airports Primer and Guidebook (2012)* gives a formula to calculate criticality:

Criticality/Risk Exposure = Cost of failure* × *Probability of failure

Taking the example of passenger boarding bridge (PBB), the tangible costs of failure would include the cost of repair and fines incurred due to delay of the flight, among others. But the other intangible costs like upset customers and stakeholders (airlines) could prove detrimental for small-hub airports.

The next step is to review past maintenance records of the asset and determine all the information mentioned in Table 1.

Table 1. Key indicators for asset performance

Breakdown time	Time lost due to asset failure
Setup and changeover time	Time needed to repair the asset and return to operational status
Downtime loss	Breakdown time + Setup and changeover time
Planned time available	The time the asset is desired to be operating
Planned downtime	The scheduled time to do preventive maintenance
Net available time	Planned time available – Planned downtime
Actual operating time	Net available time – Downtime loss
Total cycles	The number of cycles the asset is operated. For e.g., the times the PBB is moved and attached to the aircraft, the number of times the elevator is operated.
Design cycle time	The theoretical time the asset needs to complete one cycle
Defective cycles	The number of cycles that the asset did not perform to the required standard. For example, the times when the PBB did not extend to the desired distance, the elevator did not stop exactly at the desired level.

The last step under the Plan phase is to calculate OEE. TPM uses OEE as a quantitative metric to track performance and the overall goal is to raise the OEE for the asset. This methodology incorporates all the necessary metrics to help the operations teams increase equipment performance and reduce asset cost of ownership (COO) (Ahuja & Khamba, 2008). As the formula to calculate OEE is used primarily in manufacturing setting, but following the example of Ali (2019), the team was able to use this formula for airport:

OEE = Availability (A) × Performance efficiency (P) × Rate of quality (Q);

$$Availability\ (A) = \frac{Actual\ operating\ time}{Net\ available\ time} \times 100$$

$$Performance\ (P) = \frac{Design\ cycle\ time\ \times\ total\ cycle}{Actual\ operating\ time} \times 100$$

$$Rate\ of\ quality\ (Q) = \frac{(Total\ cycles - Defective\ cycles)}{Total\ cycles} \times 100$$

Phase 2: Do

The planning phase of PDCA is followed by communication and implementation of the plan (Chris, Kathleen, and Marilyn, 2014). As with TPM, communicating the maintenance plan is essential to the successful implementation of a new plan. All the affected parties within the organization need to be notified of the changes. Where resources are available implementation should start at a small scale before fully implementing to the large system. Data should be collected from the test plan, any changes should be noted and used to make any necessary adjustments before moving to the full implementation.

The proposed TPM model implementation phase consists of three action items: the 5S, selecting applicable TPM pillars, and entering asset information into a database.

5S – 5S is a lean tool (Chris, et al., 2014).). The first step in clearing the unnecessary things in order to create an orderly workplace. A clean workplace increases efficiency and reduces any chances for error. Efficiency and quick flow are essential in maintenance, especially in high stakes business such as an airport. The 5 Ss are shown on Table 2

The 5S tool can be applied by putting together a maintenance kit consisting of materials and tools required to complete a quick maintenance routine. For instance, the maintenance team could develop a ‘crash cart’ ready for immediate action in case an equipment needs to be repaired quickly. Once the 5S tool kit is in place, the next step is to identify the TPM pillars applicable to each asset maintenance process. There are eight pillars that support the TPM approach (Kiran, 2017). All eight pillars do not apply at once. Each process requires one or more pillars considered essential to the successful implementation of the process. The eight pillars of TPM are shown in Figure 2.

Table 2. The 5S lean tool

Structuring/Sort	Separating needed tools, parts and instructions and eliminating unnecessary materials.
Systematize	Having the right tools and parts at the right place.
Shine	Identify and eliminate the original source of waste
Standardize	Develop a standard organization plan. Where everything can be found.
Sustain	Maintain discipline and apply to all procedures.

Note. Adopted from Chris et, al. (2014. p. 77)

1. Focused improvement	Continuous improvement
2. Planned maintenance	Ensuring the equipment is available, minimizing breakdowns
3. Early equipment management	Having in place a system where knowledge gained from use of TPM can be applied to other new equipment
4. Education and training	Minimize knowledge gap associated with implementation of TPM for management and maintenance personnel
5. Autonomous maintenance	Maintenance personnel have the know how to maintain their own equipment
6. Quality maintenance	Setting equipment conditions that minimize defects, errors and sustain zero defects
7. TPM in administration	Applying TPM in the office space
8. Safety, health, and environment	Promote a safe and healthy work environment and environmental conscious

Figure 2. The eight pillars of TPM. Adopted from (Kiran, 2017).

Records for each asset are identified and entered in a database. Asset records include, historical maintenance records, future scheduled maintenance, inspection checklist, work order templates, and troubleshooting guide. These records will be used in the proposed software package to monitor asset performance and improve maintenance personnel efficiency.

Phase 3: Check

Airport management can now access and use the database to monitor performance of the assets and efficiency of the maintenance personnel. Resources such as funding, staffing, equipment/tools, and external contracts can be acquired by airport management as suggested by ACRP (2015). Simultaneously, by using the iPads, authorized maintenance personnel can access the inspection checklist, open work orders and troubleshooting guide from the database and perform preventive maintenance accordingly. Information in the database will be updated each quarter and new information will be added to the database. The software will recalculate the OEE and measure it up to the initial OEE to highlight either progress or decline in asset performance.

Phase 4: Act

Based on the new OEE generated, areas of improvement such as the inspection schedule for an asset needs to be updated, a major repair for the asset needs to be scheduled, routine maintenance needs to be scheduled more often, etc. These changes will be added into the database and the software will renew the corresponding schedules and update the frequency of the pop-up notifications.

Application of TPM and PDCA for Airport Asset Management

Proposed Dashboard and Mobile App

From the review of existing literature, a CMMS solution complements the TPM approach. However, the current CMMS solutions available to airport managers indicated a lack of integration between different airport asset systems and small airports cannot afford them. Furthermore, current solutions do not offer a dedicated mobile application for the maintenance personnel. So, the team is proposing an integrated software that will have the capability to integrate all the asset systems owned by the airport, so it becomes a one-stop shop for the airport managers and maintenance personnel. The software package will include a dashboard for managers and a mobile app for the maintenance personnel. A series of figures illustrate the proposed dashboard and the mobile app.

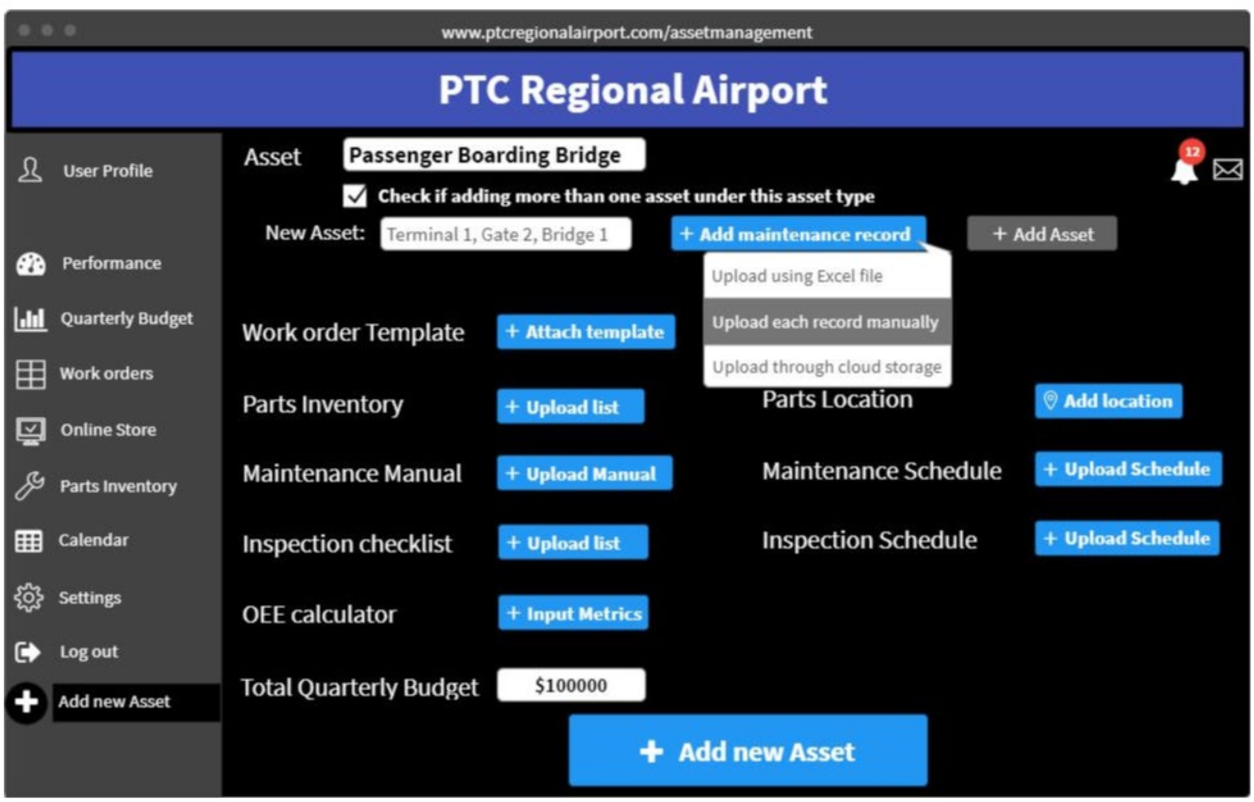

Figure 3. Dashboard view developed by the team showing different options as seen by an airport manager

The Figure 3 shows one screen of the dashboard. This screen shows the first step that the airport will need to undertake after acquiring the software. Following the process map, the information needed to be put into the system is already gathered under the Plan phase. As it can be seen here, the maintenance records can be uploaded to the software in any of the three formats. This gives the airports complete control and flexibility. Other features included here are the ability to add multiple assets under the same asset category, the work order for a particular asset that will be utilized by the mobile application, inspection checklist and schedule, maintenance manual and schedule for automatic reminders, parts inventory and location, OEE calculator based on the data gathered and entered and the budget that the airport manager wants to spend on the maintenance of this asset.

Figure 4 shows an output screen that the manager can expect to see after inputting all the information in the initial set-up phase. This screen specifically shows the Quarterly budget use for the selected asset. For ease of selection, a quick toggle bar at the top is displaying all the assets that are added into the system. Next it displays the dollar amount spent on maintenance of the asset for the current and previous quarter. This information will be generated from the work orders submitted and completed by the technicians and the parts used up for the repairs and new parts ordered for the repair. To give a better understanding of the specific asset spending, options to do that are included at the bottom. This is provided to determine which asset is draining more resources and if it needs a major repair.

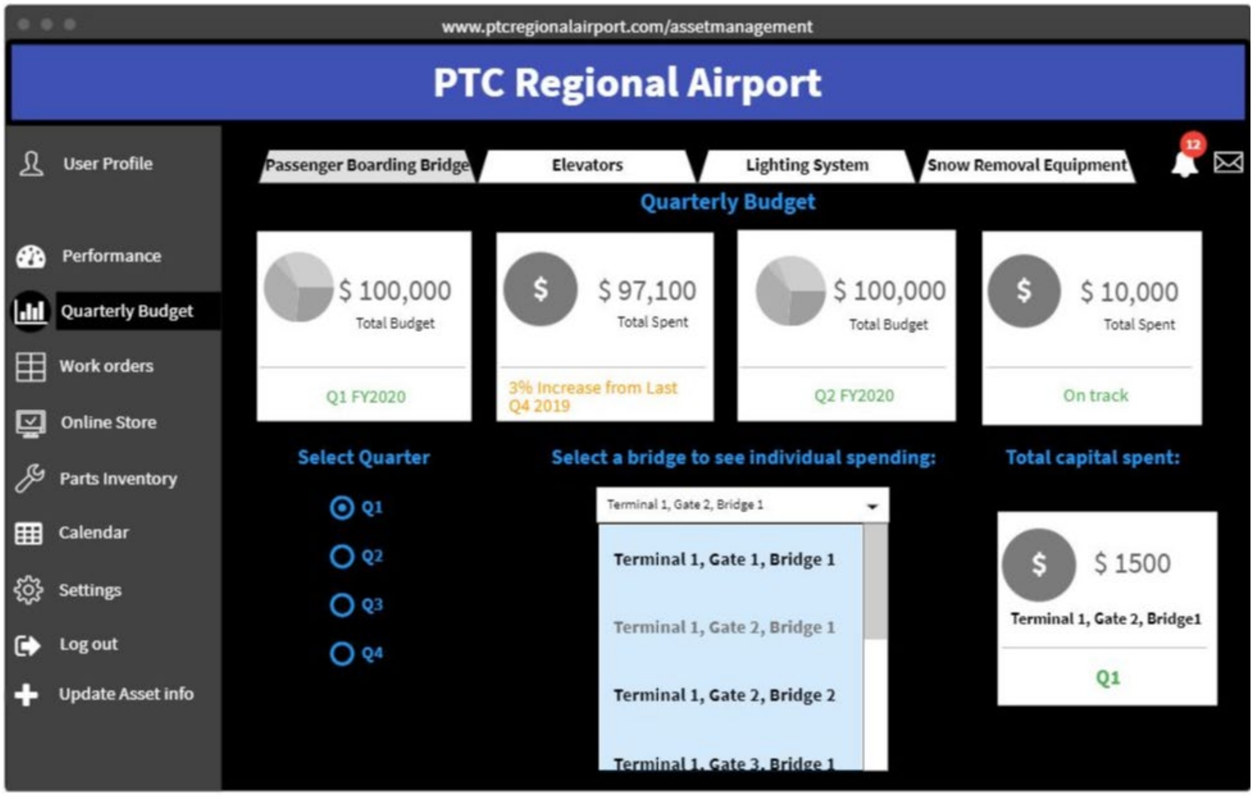

Figure 4. Dashboard view developed by the team showing asset budget allocation and spending

As it can be seen on these two dashboard images, the left pane is equipped with all the important options the airport manager would like at their fingertips. All the options are self-explanatory and easy to follow. The performance tab will show the OEE metric for each asset added to the system showing the specific Availability, Performance and Rate of Quality information. This information can be used to perform the Check and Act phases of the PDCA approach. The other stand out feature included here is the online store. This is a store for airport managers around the country to connect to each other and sell those parts from the inventory that are reaching the shelf life and would have to be discarded or recycled. The store can also be used in an immediate need of a part for repair, in case the manufacturer has stopped part production, or the part is out of stock.

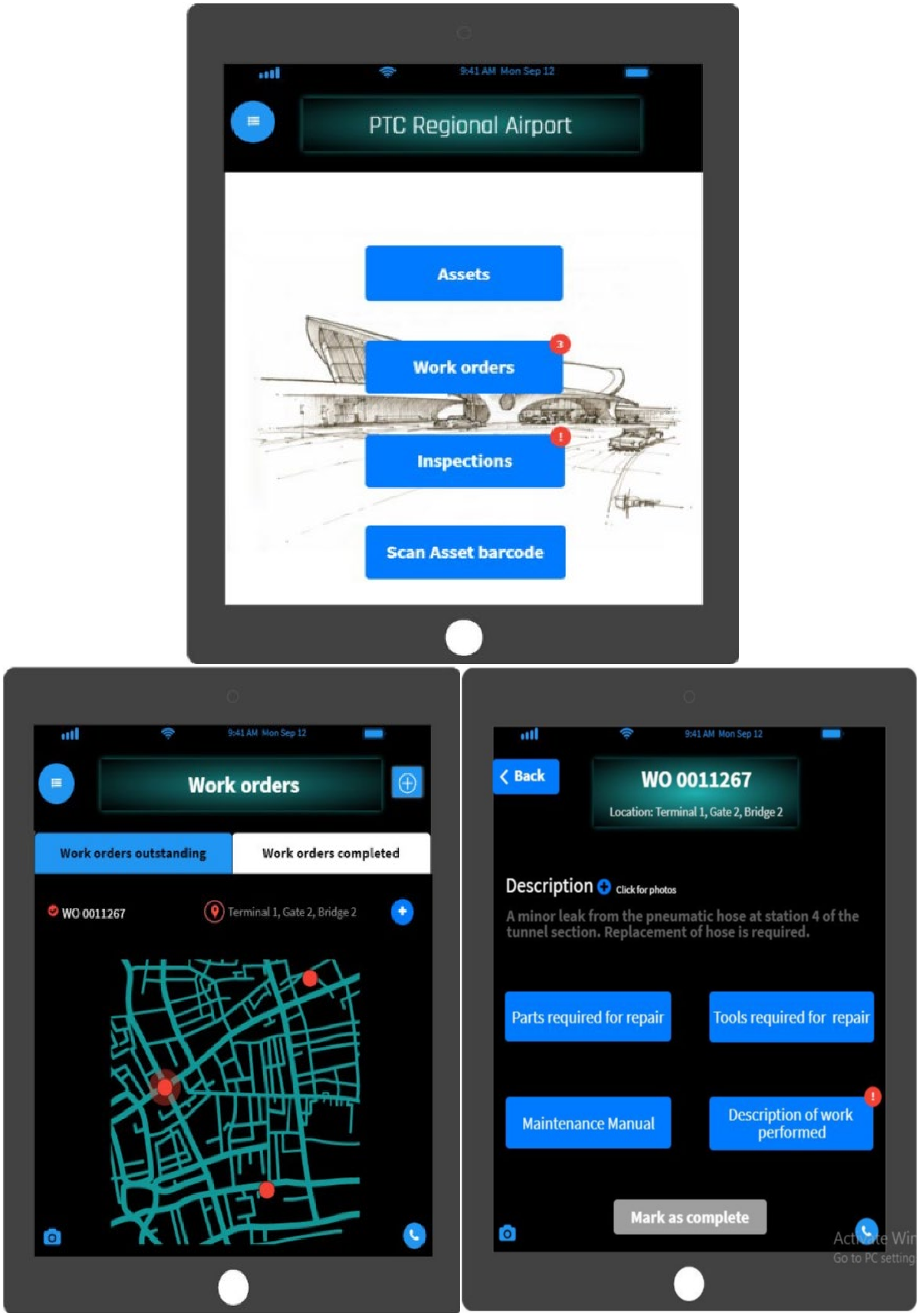

Figure 5. Shows different screens showing the proposed mobile app view

The top center image on figure 5 is the home page. The options icon on the top left will display the profile of the maintenance technician using the app and additional options to make changes to the profile. At the center of the screen are the main options displayed: Assets, Work orders, Inspections and Scan the Asset barcode. Under the Assets tab, the technician will be able to see a summary of all the assets in the system. The inspections tab is built keeping in mind the FAA part 139 required inspections that needs to be routinely performed. The technician can perform the inspection and then submit the report directly to the FAA. This can also be viewed by the manager on the dashboard. At the end, the option to scan the asset barcode is provided to quickly jump into the asset performance and maintenance history. The red notification number on the Work order tab gives a quick glance at the number of outstanding work orders and the exclamation point on the Inspections tab alert the technician of an upcoming inspection.

The bottom left image on figure 5 shows the view once the work orders tab is selected on the home screen. This screen shows a map which reflects the airport layout and outstanding work orders as a red dot at the location of the asset so it can be easily interpreted by the technician. When one of the dots is clicked, it will show the work order number along with the specific location of the asset. By clicking on the plus icon, the app will take the technician to the next screen. Other options available include Work orders completed, an ability to create a new work order, a camera icon to take images of the repair and a call icon to make calls to the maintenance office number at the airport in case the technician needs something for the repair.

The bottom right image on figure 5 shows the view when a specific work order is selected. On this screen, along with the work order number and the location, a description of the work that needs to be done is provided. The description and the photos were added when the work order was created. The options below the description show the parts required for repair.

Selecting this option will take the technician to the screen displaying system generated required parts, part numbers and the location of the parts for easy access. By clicking on the tools required tab, the technician can see the list of the required tools and the location of those tools. Both will be generated by the system based on the information added into the database of the software. While performing the repair, the technician can look at a copy of the maintenance manual. Once the repair is completed, the description of the repair will be added, and photos of the repair will be attached to mark the work order as complete.

Safety Risk Assessment

Safety risk assessment is an important part of the safety management systems (SMS). This section highlights a safety risk assessment for the proposed solutions. Specifically, identify, analyze, assess, and control risks that might affect the operations of the proposed preventive maintenance program. The objective of the safety risk management process is to reduce the systems risk to a practicable level (Timmons, 2016). The safety risk assessment was conducted based on the guidelines provided by (Timmons, 2016) and two FAA Safety Management Systems documents; FAA *Safety Risk Management Guidance: The 5-step process* (FAA, 2018) and FAA advisory circular, AC (Advisory Circular) 150/5200-37 (FAA, 2007). The 5-phase process used is adopted from (FAA, 2018).

Phase 1. Describe the system

The proposed preventive maintenance system consists of data collection process, developing a forward-looking maintenance schedule, also known as a preventive maintenance schedule, and ultimately developing a customized mobile application package. Data collected will be backed up in a server within an airport or cloud services with back up. The system is designed to be used primarily by airport management and maintenance personnel. Other authorized users may access the system. Management can view a dashboard with a summarized report on airport assets. Maintenance personnel can access checklists, troubleshooting guides, as well as enter and finish work orders.

When describing a system, certain consideration needs to be assessed. The 5M model can be used to show the major interactions within the system as shown in Table 3.

Table 3. The 5M Model

Mission	The objective of the system is to provide an affordable, easy to use and customizable solutions for preventive maintenance within an airport.
Man	Consists of all personnel that will interact with the system. In this case, management and maintenance personnel are the primary users.
Machine	Consist of the equipment that enable the functioning of the system. For example, mobile devices, computers, data storage servers.
Management	The use of the system to achieve the system of objective of providing preventive maintenance around an airport. Maintenance personnel is issued a mobile device with access to all the system data and have editing rights. These must be done right for the system to function properly.
Media	It is the environment within which the system operates. The proposed asset maintenance approach will operate within the large airport system.

Note. Adopted from FAA (2018)

Phase 2. Identify potential hazards

Potential hazards may arise from each of the five dimensions mentioned in phase 1. The list of potential hazards associated with the proposed maintenance system include:

1. Software failure
2. System hack
3. User error
4. Distractions while using mobile app
5. Power outage
6. Internet failure

Phase 3. Determine the risks

In this phase, the team determined the risks associated with the identified hazards shown in the table 4.

Table 4. List of potential hazards

Hazard	Risk
Software failure	Delayed maintenance
System hack	Data loss/data mishandling
Data input error	Accidents/incidents
Distractions while using mobile app	Accidents/incidents
Power outage	Data loss
Internet failure	Delayed maintenance

Phase 4. Assess and analyze the risk

In this phase the team assigned each hazard a severity and likelihood code. The hazards are classified into three categories: low risks (code green), moderate risks (code yellow) slightly high (code amber), high risks/unacceptable (code red). A risk matrix shown on figure 6 and figure 7 were used to provide guidance on risk assessment.

Hazard	Level	Severity	Likelihood	RAL	Suggested Mitigation
Software failure	Moderate	4	2	8	Scheduled software maintenance
System hack	Moderate	5	1	5	Encryption / Limit users' access
Data input error	Moderate	4	3	12	User training and data entry verification
Distractions while using mobile app	Moderate	5	3	15	Training/ and provide customized devices
Power outage	Low	3	1	3	Having a backup source of power
Internet failure	Moderate	3	2	6	Using a data backup option

Figure 6. Project Risk Assessment Matrix. Note. RAL is Risk Assessment Level

		No Safety Effect	Minor	Major	Hazardous	Catastrophic
Likelihood		1	2	3	4	5
Extremely Improbable	1	1	2	3	4	5
Extremely Remote	2	2	4	6	8	10
Remote	3	3	6	9	12	15
Probable	4	4	8	12	16	20
Frequent	5	5	10	15	20	25

Figure 7. Risk Assessment Matrix. Adopted from (FAA, 2018)

Phase 5. Mitigation strategy

In this phase, a strategy for managing the identified risks in phase 4 is developed. There are four strategies for managing risks (FAA, 2018; Timmons, 2016): a) transfer b) eliminate c) accept and d) mitigate. Risks in the green code do not pose a threat to the system and can be accepted for the present moment but should be monitored. Risks in the yellow and amber code pose moderate threat to the system and should be either transferred, eliminated, or mitigated. Risks in the red code are unacceptable and should not be allowed to happen.

In Figure 6, two threats identified by the team are under the amber code and steps have been proposed to mitigate the risks. To manage the hazard of data input error, familiarity to the software is required through periodic training. To further reduce the likelihood of error, data verification is recommended before submitting data. An option to update the data once entered will also be added as a safety net in case information for assets needs to be updated or changed. To reduce the likelihood of distractions caused due to the use of hand-held devices during maintenance operations, proper user training is recommended. In addition, airport provided devices will reduce the distraction of personnel.

Cost and Benefit Analysis

This section provides additional information on the cost versus benefits expected from implementing the proposed asset management approach. For the product to be considered for adoption, it should be financially feasible. That is, the overall benefits must outweigh the cost of implementation. However, some benefits are not quantifiable and will be discussed under qualitative benefits section. Three types of benefits were considered for this project: quantitative, qualitative and sustainability benefits. Additionally, costs were considered at three levels: a) cost of developing an alpha product, b) cost of developing a beta product or a prototype and c) cost of producing product at a large scale, for 100 airports.

Cost Assessment

Research and Development Cost (alpha)

The costs associated with the initial research and development (alpha) of the proposed system are evaluated as shown in the Table 5. These costs include the labor costs (students and faculty advisor) for the first step of proposed project at Purdue University.

Table 5. Research and development cost (Alpha)
Research and Development Cost (alpha) for the Proposed System

Item	Rate	Quantity	Subtotal	Remarks
Labor – University Design Competition				
Students	$25/hr.	120	$3,000	3 Students, 40 hours each
Faculty Advisor	$100/hr.	40	$4,000	1 Advisor, 40 hours
Subtotal			**$7,000**	

Note. This table was inspired by Guidance for Preparing Benefit/Cost Analysis (Byers,2016)

Research and Development Cost (beta)

In this step, the proposed system is fully developed by outsourcing software specifications design, web and application development to India (for cost savings) and tested by a software engineer. Table 6 presents the software specifications cost, outsourcing costs, labor costs (software engineer) and material costs (computer) associated with the development and testing of the system.

Marketing, Sales & Distribution

The Table 7 outlines the marketing, sales and distribution costs of the proposed system. The costs of marketing, sales & distribution include commission for sales representative, advertising costs (airport magazines & air shows) and installation costs for 100 airports.

Table 6. Research and development cost (Beta)
Research and Development Cost (beta) for the Proposed System

Item	Rate	Quantity	Subtotal	Remarks
Software Specification Costs				
Software Specifications			$5,000	Software Specifications Development for Outsourcing
Outsourcing (India) (6 months)				
Outsourcing			$15,000	Web and Application Development
Testing (Simultaneously)				
Software Engineer	$105/hr.	100	$10,500	1 worker
Expenses				
Materials (computer)	$2000	1	$2,000	
Subtotal			**$32,500**	

Note. This table was inspired by Guidance for preparing Benefit/Cost Analysis (Byers, 2016)

Table 7. Marketing, sales & distribution cost
Marketing, Sales & Distribution (100 airports)

Item	Rate	Quantity	Subtotal	Remarks
Labor – Marketing & Sales				
Marketing & Sales	$50,000	1	$50,000	Sales Rep (Commission)
Expenses				
Marketing & Sales			$10,000	Advertising/Air shows
Distribution	$500/each	100	$50,000	Installation
Subtotal			**$110,000**	Avg **$1,100** per airport

Note. This table was inspired by Guidance for preparing Benefit/Cost Analysis (Byers, 2016)

Operations & Training for one airport (10 years)

Table 8 shows ten-year operational and training costs for one airport after installing the proposed system. These costs include initial training cost for operators' personnel (one-time), yearly upgrade training cost (due to software update), expenses and material costs. For expenses, airport has to pay for cloud services (server and storage) to access software remotely, securely and to store large amounts of asset data.

With enough training, existing operators' personnel and maintenance personnel will be able to manage operations and perform preventive maintenance by using the software and mobile application accordingly. For material costs, Apple iPads and computer costs are considered.

Table 8. Operational and training cost
Operations & Training for One Airport (10 years)

Item	Rate	Quantity	Subtotal	Remarks
Training				
Training Program	$3000	1	$3,000	For Personnel (one-time)
Upgrade Training	$500/yr.	10	$5,000	Update of training program due to software update
Expenses				
Materials (Apple iPad mini)	$400/each	2	$4,000	For 10 years (replace the two units every 2 years)
Cloud Services	$1200/yr.	10	$12,000	For 10 years (server & storage)
Materials (Computer)	$2000	1	$6,000	For 10 years (replace once in every 3 years)
Subtotal			**$30,000**	

Note. This table was inspired by Guidance for preparing Benefit/Cost Analysis (Byers, 2016)

Cost Summary for one airport (10 years)

Table 9 summarizes the overall ten-year costs associated with the proposed system for one airport. We estimated the development costs by assuming that the system will be used by 100 airports, which lowers the development cost per airport. The average development cost for one airport is estimated by adding alpha, beta and marketing costs and dividing the costs by 100.

Development costs for one airport = ($7000 + $ 32,500 + $110,000) / 100 = $ 1,495

In order to cover margin and profit, we propose to sell the system at a price that is three times the development costs.

Selling price of the system for one airport = (Development costs) x 3 = ($1495) x 3 = $4,485

Qualitative Benefit Assessment

The qualitative benefits associated with the implementation of proposed system are shown in table 10. For example, through immediate notifications, there will be an improvement in the operator's personnel response time. Benefits related to operational safety and operational efficiency are listed.

Table 9. Cost summary for one airport over a 10-year period Cost Summary for one Airport (10 years)				
Item	Rate	Quantity	Subtotal	Remarks
Costs				
Purchase Price	$4,485	1	$4,485	Three times the development costs to cover margin and profit.
Operations & Maintenance	$30,000	1	$30,000	Table 8
Subtotal			**$34,485**	
Note. This table was inspired by Guidance for preparing Benefit/Cost Analysis (Byers, 2016)				

Table 10. List of qualitative benefits Qualitative Benefit Assessment	
Benefits	How
Operational Safety	
Hazard prevention	By carrying out preventive maintenance (OSHA, 2016)
Operational Efficiency	
Reduction in office materials	No more paper-work orders
Improvement in OEE	By incorporating TPM into PDCA
Lower wear and tear on vehicles	Preventing back and forth travel by sequencing PM’s
Improvements in auditing records and records storage	By using cloud storage
Remote access of work orders	Through cloud-based server
Improvement in response time	Through immediate notifications
Reduced Work in Progress (WIP)	Software contributes to efficient management of inventory
Passenger satisfaction	By the increase in quality of assets
Efficient Parts Inventory Management	By utilizing the online store feature in the dashboard
Note. This table was inspired by Guidance for preparing Cost/Benefit Analysis (Byers, 2016)	

Quantitative Benefit Assessment

Table 11 shows ten-year quantitative benefit assessment for one airport. The proposed system facilitates the automation of preventive maintenance management process and saves a significant amount of personnel time. This will significantly improve the response time, reduces travel time (Ex: Ramp to office) and saves time spent by personnel on filling out paper workorders. This system also minimizes Work in Progress (WIP) through the efficient management of inventory. However, the benefits of the TPM model are not immediate. It usually takes a minimum of three years to see quantitative benefits (Pai, Ramachandra, Srinivas, & Raghavendra, 2018). For the purpose of this assessment, the team has shown the quantitative benefits after four years. Overall, the use of the proposed software package will result in 40% reduction in the operator's personnel labor hours.

Total labor hours saved over a period of ten years = 0.40 x 2000 x 6 = 4800 hrs.

Table 11. Quantitative benefits analysis
Quantitative Benefit Assessment for one Airport (10 years)

Item	Rate	Quantity	Subtotal	Remarks
Labor costs saved – Operators' Personnel				
Operators' personnel	$33/hr.	4800 hrs.	$158,400	40% of labor hours saved by increased response time, reduced WIP, reduced travel, data entry & auditing times.
Subtotal			**$158,400**	
Note. This table was inspired by Guidance for preparing Cost/Benefit Analysis (Byers, 2016)				

Benefits vs Costs Analysis (10 years)

Table 12 shows the ten-year benefits vs costs analysis for one airport. The estimated total costs of the proposed system are $34,485 (see table 9), while estimated quantifiable benefits are $158,400 (see table 11) over a ten-year period. The ratio of benefits/costs is 4.6 which means that the benefits outweigh the costs of the system for an airport. The airport will be able to recover its investment within six years after implementing the system.

Return on Investment (ROI) = (cumulative net annual gains from the investment – Total investment) / Total investment

ROI = ($158,400 – $34,485) / $34,485 = 3.6

Table 12. Summary of cost benefit analysis
Benefits vs Costs Analysis for one airport (10 years)

Item	Subtotal	Remarks
Total costs	$34,485	Table 9
Total Benefits	$158,400	Table 11
Ratio benefits/costs	**4.6**	Benefits outweigh costs
Return on Investment (ROI)	3.6	
Break-even point	6 years (approximately)	
Note. This table was inspired by Guidance of preparing Cost/Benefit Analysis (Byers, 2016)		

Financial Impact

Literature review revealed that high cost is one of the major concerns in implementing a preventive maintenance program in airports. Airport managers, especially in small airport, do not have enough budget to implement the currently available market solutions. This results in taking a hands-free approach where assets are often let to run until they fail and then a solution is sought for a replacement. Our team's interactions with industry experts confirmed initial findings that this is an ineffective approach to airport asset management. Our team embarked on this project to show that maintenance costs can be minimized by taking a preventive maintenance approach. The cost benefit analysis shown in table 12 show that using the proposed approach, an airport can begin to see a significant change in maintenance cost with an estimated break-even point at 6 years. The analysis shows the benefits outweigh cost by 4.6 times.

Qualitative impact

Our team's discussion with industry experts indicated that often, airport managers do not have visibility to an airport asset management plan. We show that using the proposed software, management as well as maintenance technicians can view a dashboard showing all current maintenance schedules, workorders, and maintenance checklists. This tool gives management control over the airport assets they manage.

Additionally, the proposed software will also improve efficiency in maintenance processes. As discussed with experts, most airports procure third party services to conduct maintenance within the airport. Often, the third party may take time to respond to an immediate need. With planned maintenance, airport maintenance technicians can see projected maintenance needs and give an advanced noticed to the third party avoiding the previously unpredictable delays. Better yet, the airport maintenance personnel can be trained to handle maintenance needs within the airport.

Interactions with Industry Experts

Our team had initially planned to contact at least six industry experts with questions regarding maintenance practices for airports. Due the current global crisis on COVID-19, which led to school disruption our team was only able to correspond with two experts. Fortunately, the two experts we spoke to have extensive industry experience on airports management for different airport sizes. The experts contacted are:

Dr. Stewart Wayne Schreckengast, PhD, FRAe

"Dr. Schreckengast is a member of the Graduate Faculty of Purdue University and the University of South Australia. He conducts undergraduate and graduate courses in aviation safety and security, along with applied research in airport development, safety management and multi-modal security programs. In addition to his extensive knowledge of FAA regulations for airport development and safety management, he has assisted in the development and implementation of International Civil Aviation Organization (ICAO) Annexes 1, 6, 8, 11, 13, 14, 17 and 19. He has extensive experience as a facilitator in workshops for Airport Inspections, Safety Management Systems and Security through symposiums and training conducted for MITRE/CAASD, ICAO, FAA, University of South Australia and Purdue University.

Dr. Schreckengast is a graduate of US Navy Aviation Safety School, Canadian Forces Flight Safety School, Australian Transportation Safety Board and the University of Southern California Safety Courses. He has approximately 4000 flight hours as aircraft commander and flight instructor with extensive international experience.

He is a Board member and Former Council President and District Chairman, Boy Scout of American Sagamore Council covering 16 central Indiana counties. He is an Eagle Scout with Silver Beaver and Award of Merit among his many achievements". (Purdue, 2020b)

Mr. Adam Baxmeyer, Manager of Purdue Airport in West Lafayette.

Mr. Baxmeyer has vast experience managing airports ranging from small airports to mid-sized airports. Under his leadership, Purdue Airport started using *APP 139*, a commercially available, cloud-based software used for inspections and work orders all for airside operations, focusing mostly on the FAA Part 139 inspections.

Discussion with industry experts was guided by the following questions.

Q1. What are the current maintenance practices for managing airport assets? For example, passenger jet bridges, HVACS, elevators

Q2. What is the estimated cost, a. to the airport and b. to airport concessionaires if an essential equipment like a jet bridge breaks down?

Q3. What other specific maintenance challenges are encountered by a. maintenance personnel and b. airport managers especially for small and medium sized airports?

Summary of Feedback from Industry Experts

The insight gained from the two experts coupled with extensive research has enabled us to prepare a comprehensive report with suggestions for improving airport maintenance practices. Where information may be misreported, the fault falls on our team members who might have interpreted information in a different manner from that intended by the experts.

The discussion with the industry experts revealed some of the challenges faced by airport managers in planning for maintenance for airport assets. Some of the common challenges include, a) high cost of planning for a preventive maintenance program, b) integrating all airport assets into one maintenance program, c) visibility of asset maintenance schedules by airport managers, and d) using a reactive approach to asset maintenance.

By engaging the industry experts, our team wanted to find out how airports plan for maintenance, especially for high impact assets which may result in ripple effects if broken. As we had initially found out through literature review, challenges stemming from high costs often lead to airports adopting a reactive asset maintenance plan, often running equipment to failure. Assets in most airports are maintained by third parties who are often slow to respond to maintenance calls from airport. Maintenance schedules are not visible to airport managers leading to uncertainty as to when an asset may require routine maintenance. Because different assets in one airport can be maintained by different third-party companies, airport maintenance systems are not integrated. The high expenses associated with third-party companies to conduct regular maintenance can be a financial burden for small airports which means if an airport cannot afford to incur such expenses regular asset maintenance becomes a secondary priority for the airport.

One way to ease the cost of developing a preventive maintenance program would be to have a module-based maintenance planning system. A module-based maintenance planning system allows airport manager to choose which assets to add to a maintenance software package based on the airport budget and the impact of an asset to airport operations. Additionally, managing inventory is an important cost saving measure that can be adopted by airports. For instance, having an integrated online platform where various airports can buy and sell maintenance parts and materials can save airports the costs incurred when materials are stored until end of their shelf life.

The lack of visibility on maintenance programs can be resolved by having a dashboard report. A dashboard view can be customized to show a summary of budget allocations and spending, maintenance schedules, workorders and maintenance checklist. A dashboard integrates all aspects of a maintenance program and provides airport managers with summarized information making the task of decision making easier. Handling maintenance records manually should be avoided at all cost.

In summary, the discussions with industry experts led our team to focus on developing an innovative preventive maintenance package that will be affordable to airports of all sizes and provides integration so that both airport managers and maintenance personnel have the visibility on maintenance schedules. Additionally, the airport will have the flexibility of having an inhouse maintenance plan and avoid the cost of third-party solutions.

Projected Impacts of Design

Once implemented, this proposal is expected to have a significant impact on the overall asset management plans for airports of all sizes. The impact would be most significant to small airports which are faced with financial constraints and must use limited funds to support assets maintenance around airports. This project is designed in such a way that airport managers have flexibility on the assets they can include in the preventive asset management software, referred as modules. The cost benefit analysis shows that an airport can save significantly on the budgets they allocate to asset maintenance. Qualitative benefits such as increased efficiency in airport operations is evident. Additionally, this project considers a sustainability dimension based on the ACI-NA EONS model and the UN SDGs.

Sustainability Impact

In addition to the guidelines presented by the ACRP design competition, our team evaluated the impact of our project on airport sustainability. Airports Council International – North America (ACI- NA), the organization that represents the voice of airports across the globe defines Airport sustainability as "a holistic approach to managing an airport so as to ensure the integrity of the Economic viability, Operational efficiency, Natural Resource Conservation and Social responsibility (EONS) of the airport." (Sustainable Aviation Guidance Alliance [SAGA], 2015, p. 8). Sustainability is a critical issue when considering the impact of any airport project. Based on the ACI-NA definition of sustainability, a project can be assessed on these dimensions; a) economic viability; b) operational efficiency; c) natural resources conservation; and d) social responsibility. The team goes a step further in also aligning the sustainability outcomes with the Sustainable Development Goals (SDG) set up by the UN. Figure 8 shows sustainability impact of the design.

Economic: Asset management reduces the rate of asset failure thus, reducing premature costs to the airport and promoting the UN SDG 8 of sustainable economic growth. Resilient infrastructure will prevent delays in passenger flights and cargo supporting UN SDG 9.

Operational: By conducting regular maintenance on airport assets, the life of the airport asset is increased, and the asset performs at its peak efficiency helping the airport in contributing to the UN SDG 9.

Natural Resources: As the assets are running at their peak efficiency, they will consume less power reducing the strain on the depleting natural resources and promoting innovative sustainable industrialization.

Social: Asset maintenance generates jobs for the maintenance personnel. Regular maintenance of the airport assets will reduce the likelihood of unexpected asset failure, thus providing a safe workplace for the airport workers promoting the UN SDG 8.

	Economics: Economic viability for the airport's economic impact to the community.	**Operational**: Maximizing the useful life of assets to support airport operations.	**Natural Resources:** Consideration for natural resources.	**Social/People:** Includes decision making that support airport employees and communities around the airport.
SDG 8: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.	Asset management supports sustainable economic growth of airport by reducing the rate of asset failure.	×	×	Asset maintenance provides employment to the maintenance personnel and it decreases the likelihood of asset failure increasing safety for the airport workers.
SDG 9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster Innovation.	Airports are an important part of a country's infrastructure that support mobility of people and goods. Sustainable airport management supports innovation.	Improving life cycle management of airport assets, our project support SDG9 goal of building resilient infrastructure.	Airports consume a high amount of energy. Increasing efficiency of assets reduces power consumption.	×

Figure 8. Sustainability Impact Areas. Note. × means not applicable

Project Alignment with ACRP goals

Airport asset and maintenance needs can be easily overlooked. The main business of airports is to link passengers with airlines, acting as the middleman in air transport business. The machines and equipment that support the airport business are not obvious to passengers unless something highly distractive happens, like a passenger bridge breaking down and passengers must walk through the airside to the aircraft. Although such highly disruptive events do not happen often, when they do, they can distract the entire airport business.

"The Airport Cooperative Research Program (ACRP) carries out applied research on problems that are shared by airport operating agencies, not adequately addressed by existing federal research programs" (ACRP, 2019, par 1). The problem addressed in this project is in line with the ACRP goals. Implemented, the proposed solutions will help airport managers to better manage airport assets with reduced cost and increased efficiency.

Airports are vital to the U.S. economy and it is important to address the challenges faced by the airport industry. With the very limited resources, airport operators are constantly looking for more efficient and effective ways to maintain the assets. Throughout the years, many advancements have been made to improve the asset management strategies of the airports. One of the examples is the development of the CMMS, but most of the airports cannot afford it due to budget constraints. Thanks to this proposed customized mobile application for preventive maintenance, airports will not only be able to maintain their assets efficiently, but also economically. Therefore, by addressing the challenge, carrying out the research and proposing a viable solution, this project meets the ACRP goals.

Conclusion

This project proposal started with identifying an area of improvement in the ACRP University competition guidelines. Our team selected *Challenge IV: Airport Management and Planning; Improved strategies for airport asset management, including land use.* A thorough literature review was conducted to identify a specific area in assets management. Literature review revealed that preventive asset management is rarely used in airports management. It is evident that a break down in airport assets can result in major disruptions in airports including dissatisfied concessionaries and perceived compromise on safety by travelling passengers. Additionally, these effects can ripple down to other airport services such as delayed flights.

This project proposes a total preventive management (TPM) approach using an affordable software solution that allows airport managers to have high visibility on maintenance needs around the airport. Airport managers can view maintenance schedules and allocate budgets for asset maintenance. At operational level, maintenance personnel have more control of the assets they maintain around the airport. A maintenance personnel can add and close work orders, they can view a maintenance check list and troubleshooting guidelines and monitor any open work orders for immediate action.

The TPM approach allows an airport to manage assets before they breakdown and cause a major disruption at an airport. Based on the cost benefit analysis, this approach has potential to save an airport finances and provide a better financial planning approach. Using the proposed solution, an airport can expect close to four times benefits over cost in a period of four years. This approach will also provide several sustainability benefits for airports that want to include sustainability in their reporting, specifically, economic and operational sustainability as defined in the EONS airport sustainability framework. Finally, this approach has potential to increase customer satisfaction for airport customers, i.e. airport concessionaires and travelling passenger. In addition to cost and benefit analysis, a safety risk analysis was conducted to identify the safety issues that may result from implementing this project. The analysis shows minimal safety risk, most risks associated with the project can be easily mitigated.

The project analysis was also enhanced by conversations with industry experts. Overall, our team is confident this proposal can be applied to all airports. It would be most useful to small and medium hub airports who experience financial constraints in effective implementation of an asset's management plan.

Appendix A: Contact information

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Appendix B: Description of Purdue University

"Purdue University is a vast laboratory for discovery. The university is known not only for science, technology, engineering, and math programs, but also for our imagination, ingenuity, and innovation. It's a place where those who seek an education come to make their ideas real — especially when those transformative discoveries lead to scientific, technological, social, or humanitarian impact. Founded in 1869 in West Lafayette, Indiana, the university proudly serves its state as well as the nation and the world. Academically, Purdue's role as a major research institution is supported by top-ranking disciplines in pharmacy, business, engineering, and agriculture. More than 39,000 students are enrolled here. All 50 states and 130 countries are represented. Add about 950 student organizations and Big Ten Boilermaker athletics, and you get a college atmosphere that's without rival". (Purdue, 2020, par. 1-2)

Purdue University, School and Transportation Technology

"Purdue University's School of Aviation and Transportation Technology, one of six departments and schools in the Purdue Polytechnic Institute, is recognized worldwide as a leader in aviation education. All seven of Purdue's Aviation and Transportation Technology undergraduate majors are world-class educational programs". (Purdue, 2020, par 3)

Appendix C: Description of Non-University partners involved in the project

None

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

Students: The responses are collective thoughts from the three team members

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

This project has been an insightful learning experience for our team. As we worked through the project, we felt challenged and equally motivated to come up with a feasible solution to a problem that we had identified in the aviation industry. Through interactions with industry experts, we learned about some of the challenges facing airport managers. The interaction with experts helped our team to narrow down our topic, focusing our solutions to a specific area of airports management. This project also provided a great opportunity to learn from each other as a team.

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

One of the apparent challenges, as with all the teams participating in the competition is the disruption of the school semester by the current global concerns with COVID-19. Despite this challenge, the news of the impact of the crisis to the air transport industry motivated our team to keep working virtually. Working on a project virtually was challenging, we had to coordinate times and draw new schedules as well as finding the right virtual working tools. Additionally, our plan to contact more industry experts were disrupted as most industry experts were now dealing with the impacts of current crisis in their organizations. We had to reorganize our experts list and make the best use of the few we had already contacted.

As with many teams, we have different education backgrounds which can be challenging. Our team leveraged on our different backgrounds strengthen the breadth of our proposed solution.

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

Our team started this proposal working towards asset management strategies and soon realized that it was a broad topic and we need to zone down on a specify asset management strategy. This happened when we were looking at the *ACRP Report 69: Asset and Infrastructure Management for Airports Primer and Guidebook (2012)* which describes a process for selecting maintenance strategy for different airport assets. The team thought that the run-to-failure model can be changed to a more preventive approach. Further review of literature and interaction with the industry experts helped us in creating an integrated software solution for the preventive maintenance of airport assets.

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

The participation by the industry experts was meaningful and useful to get an idea of feasibility of the project and the potential problems faced by the industry on an everyday basis. As students, we can come up with a variety of ideas which may not be feasible in the real-world use because either it does not solve a problem or the costs of implementing it is too high. With the help of the industry experts we were able to make the proposal more useful in a real-world scenario.

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?

With this project, the team members learned about developing a safety assessment and doing a cost-benefit analysis. Other indirect benefits for the team was learning about asset management at airports, TPM, CMMS and impacts of asset failures on the airport and the aviation industry in general. All this knowledge acquired through the course of this project has helped each team member become more confident about the airport industry. Two of the team members were working in a team for the first time for any kind of competition and this proposal was a first-hand experience into learning the team dynamics and accomplishing a common goal.

Faculty – Dr. Johnson

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 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! 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 since 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 to a better solution.

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 was a game changer for this team as they moved from a generic airport asset management approach toward a much more specific airport maintenance management system designed to integrate several airport equipment and asset management lists, inventories, and maintenance history information. This shift opened the world of maintenance management systems from not only airports, but also other large facilities such as universities, hospitals and manufacturing plants. This shift was also due to interactions with airport managers.

What challenges did the students face and overcome?

The first challenge for this team was honing in on a specific part of airport maintenance management systems that would improve the airport's ability to meet the needs of the airlines, concessionaires, aircraft owners and pilots, and the flying public. 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.

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.

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.

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