Intelligence Maintenance Management System via Predictive Analytics

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***Abstract*— Aviation industry has evolved rapidly from propeller airplane to wide body aircraft with modern aircraft engines since the first commercial airline operated hundred year ago. Aircraft maintenance, a critical technical activity which is conducted on the aircraft engine to restore or maintain it in a serviceable condition plays an important role in aircraft operation. It is a highly regulated activity in every part of the world in order to ensure that the aircraft is airworthy and capable of delivering the passengers or cargo to their destination safely and in a timely manner. Traditionally, the common maintenance practice used by aviation industry is preventive maintenance and corrective maintenance even though it has a lot of weaknesses such as economic loss due to poor airline uptime and reliability and increase in maintenance cost because of excessive repair and unnecessary maintenance. Therefore, it has become a main problem with aviation industry. Furthermore, airline companies are in need of a solution that can bring maintenance cost saving and efficient maintenance and inventory management without compromising fight safety. Fortunately, the rise of digital technologies and growing volume of data is now changing how decision is made in the industry. Predictive analytics approaches have been shown to provide a more effective solution in other areas such as fraud detection and medical decision support system. Hence, it has created the motivation to utilize predictive analytics on aviation industry and propose an innovative solution, Intelligent Maintenance Management System via Predictive Analytics that can bring maintenance cost saving and efficient maintenance and inventory management to airline companies. It is a predictive analytics maintenance system which the final goal is to predict when aircraft engine failure might occur, followed by preemptive corrective action such as inventory planning and scheduled maintenance in advance to prevent it. In addition, it can maximize aircraft uptime, minimize unnecessary maintenance, reduce maintenance cost, improve flight safety, reduce flight delays and cancellations and improve inventory management. Moreover, it utilizes state of the art digital technologies such as artificial intelligence, cloud computing, data analytic and many more to enable more efficient and effective business process at reduced costs. Thus, it is not a surprise that predictive analytics maintenance system that can bring maintenance cost saving and efficient maintenance and inventory management is an innovative approach in aviation industry.**

Keywords*— *Predictive Analytics, Maintenance Strategy, Inventory Control, Aircraft, Software System

I. Introduction

With the aviation industry has evolved rapidly from propeller airplane to wide body aircraft with modern aircraft engines since the first commercial airline operated hundred year ago. Aircraft maintenance, a critical technical activity which is conducted on the aircraft engine to restore or maintain it in a serviceable condition plays an important role in aircraft operation. It is a highly regulated activity in every part of the world in order to ensure that the aircraft is airworthy and capable of delivering the passengers or cargo to their destination safely and in a timely manner. Furthermore, it involves all the operations such as manual inspection, overhaul, fault diagnosis, rectification and others to ensure that the aircraft is in good performance and help to prolong useful life of the aircraft and maximize the value of the asset.

Traditionally, the common maintenance practice used by aviation industry is preventive maintenance and corrective maintenance [1]. Preventive maintenance is a type of maintenance that a scheduled or planned maintenance is regularly performed even when the equipment is in a complete functional mode to prevent any breakdowns or problems from occurring expectedly in the future [1]. Nevertheless, preventive maintenance is not as straightforward as it sounds like. In preventive maintenance, maintenance is conducted on the aircraft engine on a regular basic to reduce the probability of failure and asset degradation. Maintenance will still be conducted even if the aircraft has no symptoms of failure. However, there are some weaknesses such as unnecessary maintenance and excessive repair in this practice [2]. This is because the maintenance may not be required upon recommended frequency all the time because the determination of the maintenance interval is mostly based on recommendations, experience or estimated lifetime for the components and each asset has different condition, capability and degradation characteristics in actual condition. Moreover, there are cases of damage to the aircraft caused by preventive maintenance [7]. Moreover, corrective maintenance is a type of maintenance that an unscheduled maintenance will only be performed by the aircraft technician after an occurrence of failure, a report in aircraft logbook or complaint from the pilot [1]. It also has a lot of complexity and weaknesses that come with it, the first being the reduction of aircraft uptime and reliability which is critical to the profit and will cause economic loss [1][2]. It is also unable to ensure passenger safety because it can't prevent unexpected asset failure that can lead to catastrophic failure and accident from happening in the future [2].

In recent years, the cost of aircraft engine maintenance is becoming more expensive and cost more than 20 percent of the total operating cost in airline company because of the advanced technology and sophisticated aircraft engine replacement parts [3]. The maintenance requires skilled workers and expensive parts which will increase the maintenance cost and become a financial burden to the company. Furthermore, inventory and maintenance have interconnected influence on each other. Ideally, the number of spare part available in the inventory should be kept to lowest as possible without affecting maintenance operation and optimized to support the maintenance. Innovative approach that can bring maintenance cost saving and efficient maintenance and inventory management has become the main goal that all the airline company are pursuing.

Traditionally, the common maintenance practice used by aviation industry is preventive maintenance and corrective maintenance even though it has a lot of weaknesses such as economic loss due to poor airline uptime and reliability and increase in maintenance cost because of excessive repair and unnecessary maintenance. Therefore, it has become a main problem with aviation industry. Furthermore, airline companies are in need of a solution that can bring maintenance cost saving and efficient maintenance and inventory management without compromising fight safety. In recent years, it is fortunate that the rise of digital technologies and growing volume of data is now changing how decision is made in the industry. Predictive analytics approaches have been shown to provide a more effective solution in other areas such as fraud detection and medical decision support system that is designed to determine the risk of a patient developing certain diseases and support medical decision making. Moreover, predictive analytics approach is also applied to semiconductor industry by analyzing and transforming data to future insight and predict equipment failures, followed by a preemptive corrective maintenance to prevent the failure happens.

Intelligent Maintenance Management System via Predictive Analytics is an intelligence maintenance management system that contains 3 application which are a web service, a web application and an Android application. Web service is featured with prediction system that implement predictive analytics which utilize data mining, predictive modelling and machine learning to analyze the huge amounts of collected aircraft data and make use of useful information to develop a model and predict when aircraft engine failure may occur, followed by preventing it with preemptive corrective maintenance and prior inventory planning. There are different approaches available for developing a predictive model. In this project, it is assumed that the aircraft failure is caused by the breakdown of engine on the aircraft and a study has been made to predict the remaining useful lifetime of aircraft's engine. The models will be constructed based on the engine degradation dataset from Prognostics Data Repository of NASA which is available at https://ti.arc.nasa.gov/tech/dash/groups/pcoe/prognostic-data-repository/#turbofan. On the other hand, Web application is featured with dashboard system. It is designed to allow users to view aircraft historical maintenance log, make a maintenance plan or schedule maintenance for the aircraft and create and approve/reject purchase order in the system which ease and streamline the whole purchase order management process. User can also view and track the spare part in the inventory conduct inventory planning in order to manage and determine the optimal quantity of its expensive and sophisticated assets. Furthermore, Android application is featured with notification system that acts as the channel to notify users about the prediction. When a failure symptom is detected, the system will then automatically send notification to registered user in the Android application. As a result, aircraft technician can be assigned to plan and schedule the maintenance and perform inventory planning before the failure happens.

II. Methods

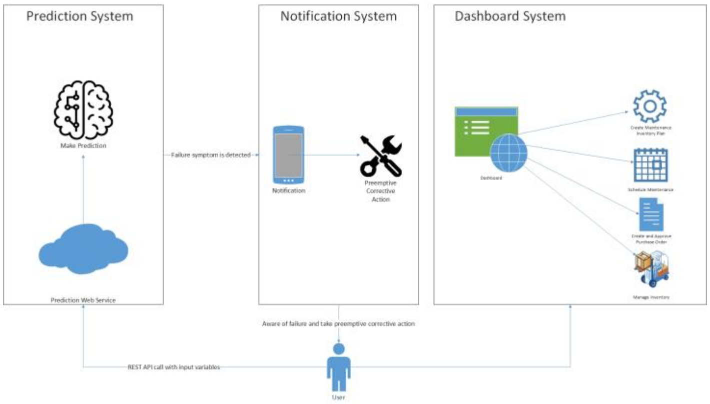

FIGURE 1: ILLUSTRATION OF PROPOSED SOLUTIONS

Intelligent maintenance management system via predictive analytics is a project that act as a predictive analytics maintenance system which the final goal is to predict when aircraft failure might occur, followed by preemptive corrective action such as inventory planning and scheduled maintenance to prevent it. It is made up of 3 modules which are prediction system, notification system and dashboard system. Figure 1 illustrates the overall system.

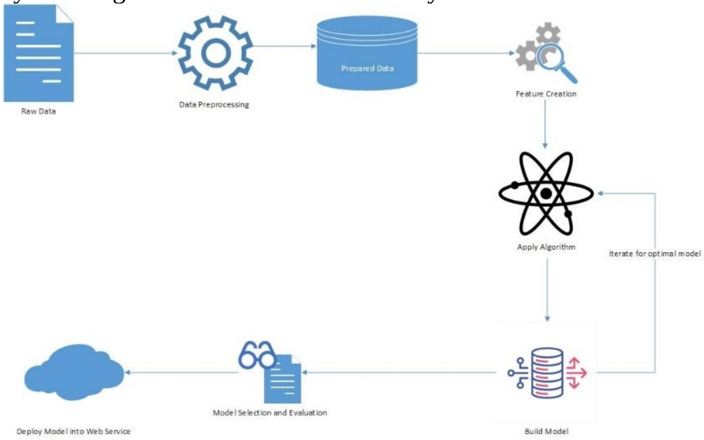

FIGURE 2: ILLUSTRATION OF PREDICTION SYSTEM

In prediction system, raw data of the aircraft engine is extracted from a dataset. However, the raw data is often incomplete and contain many errors. The raw data have to undergo data preprocessing so that it can be transformed into understandable format. After that, features are created from the prepared data so that the parameters in the aircraft can provide the information needed to identify the noteworthy patterns or changes that can develop failure. The next step is to develop a predictive model by applying machine learning algorithm and this process is iterated. It will then undergo model selection and evaluation so that the best optimal model is chosen for the data. We can make use of the model by deploying the model into the web service. We can then make failure prediction on the remaining useful life of the selected engine by making a REST API call with input variable to the web service.

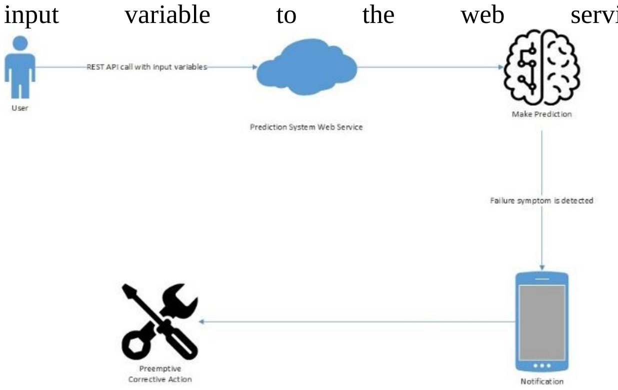

FIGURE 3: ILLUSTRATION OF NOTIFICATION SYSTEM

In notification system, it is an Android application that is developed using Xamarin and C# in Microsoft Visual Studio. The user will make a REST API call with input variables to the prediction system web service and it will then make a prediction based on the input. When a failure symptom. which is found by doing predictive analysis on historical engine datasets and this will be explained in system implementation is detected, the system will then automatically send notification and email to registered user in the Android application so that the users are aware of it and a prior scheduled maintenance and inventory planning can be made before the failure happens. User can then proceed to the web application to plan pre-emptive corrective action such as inventory planning and scheduled maintenance before the failure.

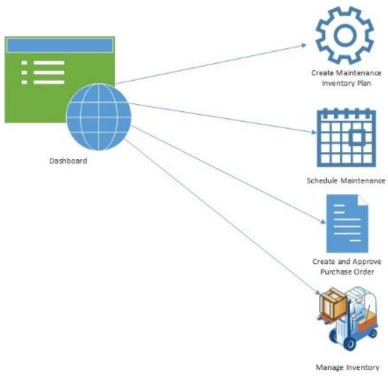

FIGURE 4: ILLUSTRATION OF DASHBOARD SYSTEM

In dashboard system, it is a web application that is developed using ASP.Net Core, C#, HTML, CSS and JavaScript in Microsoft Visual Studio that allows the user to make a maintenance inventory plan or schedule maintenance for the aircraft. Furthermore, user can create and approve purchase order in the system which ease and streamline the whole purchase order management process. It also served as a spare part inventory management system that allow the user to view the spare parts in the inventory which assist in inventory planning in order to manage and determine the optimal quantity and timing of its expensive and sophisticated assets so that it won't become a financial burden to the airline company by integrating maintenance process, purchase order management and inventory tracking together.

III. RESULTS

The machine learning models will be constructed based on the engine degradation dataset from Prognostics Data Repository of NASA which is available at https://ti.arc.nasa.gov/tech/dash/groups/pcoe/prognostic-data-repository/#turbofan. In this dataset, it has:

- 4 raw training datasets that contain the aircraft engine run-to-failure data
- 4 raw testing datasets that contain the aircraft engine run data without the failure point and the remaining useful life is provided in its corresponding truth dataset
- 4 raw truth datasets that contain the real remaining useful life for each engine at its last cycle in the respective testing data set

After understanding the attributes and properties data in the dataset, research and interpretation is done to give insights on how to turning the data into useful information. In the whole dataset, we have raw training, testing and truth dataset for different unit which is named as Dataset 1, Dataset 2, Dataset 3 and Dataset 4. It also shows that datasets for each unit can be used as separate models and 4 predictive models can be built. First, raw data of the aircraft is extracted from datasets. However, the raw data is often incomplete and contain many errors. The raw data have to undergo data pre-processing which take steps to clean and prepare the data before it can be transformed into useful information in understandable format. A new feature called RUL (Remaining Useful Life) is created from the prepared data for the modelling of machine learning models. It is also introduced to the dataframes as a new column. By using regression modelling algorithm, we can now predict the RUL before the engine fails. In the section, dataframes are joined based on a common key, the id of engine which is the aircraft engine identifier using Pandas dataframes methods such as merge() and drop(). Furthermore, different strategies are applied on training and testing data. Training dataset contains the aircraft engine run-to-failure data, which mean the last cycle in each engine in this dataset is considered as the failure point of the engine. Therefore, training data is prepared by finding the last cycle for each engine in the training set first. The RUL is the value of the last cycle minus current cycle of that particular engine. In testing dataset, the real remaining useful life at the last cycle in each engine is provided in another separate file which is the truth dataset. Therefore, testing data is prepared by merging two datasets, testing dataset and truth dataset. In addition, we only keep the record that has the last cycle for each engine in testing dataset and it is merged with the record in truth dataset based on the engine's id. This means each record in the testing data only contain the data of the last cycle for each engine from testing dataset and the real remaining useful life from truth dataset. In other words, testing data for dataset 1 only contain 100 records which match the rows of RUL in truth dataset 1. The final training and test data were saved to csv files that can be used for modelling. All data pre-processing and feature creation processes were repeated for dataset 2,3 and 4. After the process of data pre-processing and feature creation on the datasets, different regression models were built and used to predict the engine remaining useful life (RUL). The following algorithms: Linear Regression, Lasso Regression, Ridge Regression, Random Forest and Decision Tree were used to build up the model. To choose the best optimal model, the key evaluation metric is root mean squared error, a standard way to measure the error for regression algorithm. The goal is to find the algorithm that has the lowest root mean square error value. 5 different regression algorithms were used to train the model. The calculated root mean square error values were then plotted into a bar graph.

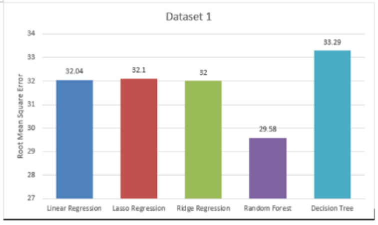

FIGURE 5: ROOT MEAN SQUARE ERROR FOR DATASET 1

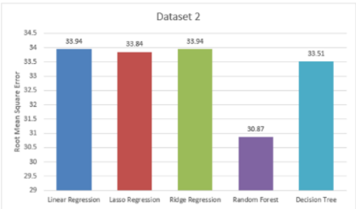

FIGURE 6: ROOT MEAN SQUARE ERROR FOR DATASET 2

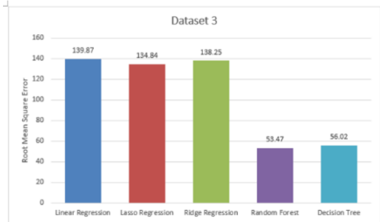

FIGURE 7: ROOT MEAN SQUARE ERROR FOR DATASET 3

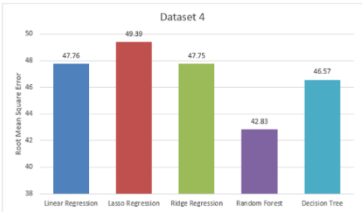

FIGURE 8: ROOT MEAN SQUARE ERROR FOR DATASET 4

	Linear Regression	**Lasso Regression**	**Ridge Regression**	**Random Forest**	**Decision Tree**
Dataset 1	32.04	32.10	32.00	29.58	33.29
Dataset 2	33.94	33.84	33.94	30.87	33.51
Dataset 3	139.87	134.84	138.25	53.47	56.02
Dataset 4	47.76	49.39	47.75	42.83	46.57
Mean	63.4025	62.5425	62.985	**39.1875**	42.3475

FIGURE 9: MEAN OF ROOT MEAN SQUARE ERROR VALUE

Based on the analysis and observation, non-linear regression algorithm like random forest and decision tree performs better than linear regression algorithm like linear regression, lasso regression and ridge regression. The results show that random forest regressor algorithm is the best optimal model because it scores the lowest root mean square error value. As a result, random forest is chosen to be the model in this project. Furthermore, we can see that the random forest regression scores 39.1875 in the mean of root mean square value. Root mean square error value is the measure of differences between the values predicted by a machine learning model and the actual observed values. Therefore, it is safe to say that failure indicator in this project is less than 40. In other words, the aircraft engine is assumed to be in going-to-fail state if the returned prediction result is less than 40. In addition, it indicates a maintenance is needed which can be utilized. This indicator is installed in the system which is used to improve the functionality of the system such as notifying the users when there is an aircraft going to fail soon so that they are aware of it and more. After the process of model selection and evaluation, the chosen models are built and ready for deployment as a web service. It will then be deployed to Azure Machine Learning Lab as a web service. After the model is deployed as a web service, we can then make prediction on the remaining useful life of the aircraft by making a REST API call with input reading variable through application on different platform such as web application or Android application to the API endpoint which act as a web service. Lastly, all the 3 modules, prediction system, notification system and dashboard system are now completed and integrated to form a whole complete system.

IV. DISCUSSION

In traditional maintenance practices such as corrective maintenance and preventive maintenance, unnecessary maintenances are often carried out to reduce unplanned engine downtime. However, this can result in poor planning of resources because the failures are unpredictable and aircraft is not utilized fully. The proposed system can minimize unnecessary maintenance, maximize aircraft uptime, deliver significant cost savings and minimal disruption to the aircraft operation by making prediction on the remaining useful life of aircraft engine so that we know when aircraft failure happens and a maintenance is only performed when needed which is a significant improvement to the aircraft operation. It can also be used to improve flight safety and reduce flight delays by reducing the probability of unexpected failure of assets in aircraft because it is able to identify anomaly in the aircraft and technician can make sure of the prediction to carry out the maintenance before they result in catastrophic failure that can turn into disastrous accident. It can be used to improve inventory management and optimize maintenance cost by forecasting needed spare part for the maintenance. The proposed system does not require airline company to have a large amount of spare part available in the inventory which is costly since we can predict when will aircraft engine failure happen and inventory purchasing can be planned in advance. In conclusion, the proposed system is able to deliver maintenance cost saving and efficient maintenance and inventory management without compromising fight safety.

On the down side, the implementation of predictive analytics will require considerable funding at the beginning because hiring the right person and building the necessary technologies and tools is a huge investment. Not only the implementation and maintenance of the solution requires a sizable project team consist of people with expertise in related field, the end user also need to undergo a series of training and learn how to manage and utilize it. However, it is proved that it can deliver significant cost savings that can recover the initial cost and minimal disruption to the operation.

Practically, input reading should be collected as soon as it is available and send it to the system in real-time in order for the system to make a prediction on remaining useful life based on it. The proposed system does not have this functionally due to various constraints such as insufficient financial support and high complexity. However, it is interesting and important to validate this proof of concept project and proof that it is feasible because predictive analytics approach is still relatively new to aviation industry. Furthermore, sufficient historical data for the aircraft engine must be available in order for the system to build up a good machine learning model so that accurate result can be predicted. In this project, it is assumed that the aircraft failure is caused by the breakdown of engine on the aircraft and a study has only been made to predict the remaining useful lifetime of aircraft's engine. It also does not allow customization and personalization for each user based on their preferences.

In future, the proposed system can be improved by improving the accuracy of regression by introducing more datasets that are relevant to the project and adjusting the data training set. Furthermore, the proposed system can also be refined by implementing real-time technologies. For instance, input reading should be collected as soon as it is available and send it to the system in real-time in order for the system to make a prediction on remaining useful life based on it. However, the proposed system does not have this functionally due to various constraints such as insufficient financial support and high complexity. The Android application of the proposed system can also be improved so that it can have the same functionalities to the dashboard system. Planning optimization process and decision-making process for different aircraft’s component can also be implemented if sufficient dataset is available. These problems will be studied in future research.

V. CONCLUSION

Nowadays, maintenance management has gained an increasing interest and importance in the aviation industry because it is still considered as the core activity to ensure flight safety. However, it poses a challenge to aviation industry to try to optimize maintenance management and achieve saving without compromising flight safety. Fortunately, with the advancement in technologies, it is now changing how decision is made in different industries. Predictive analytics approaches have been shown to provide a more effective solution in other areas such as medical decision support systems and fraud detection in banking or insurance. Moreover, predictive analytics approaches may also be adopted to solve the difficulties of maintenance management by analyzing and transforming data to future insight and predict equipment failures, followed by preemptive action such as corrective maintenance and prior inventory planning to prevent the failure happens. Hence, it has created the motivation to utilize predictive analytics on the aviation industry and come up with this project, Intelligent Maintenance Management System via Predictive Analytics that can help to optimize maintenance management for aviation industry and makes it possible to replace certain components before it gives harm to the aircraft. The main idea of this project is to introduce the analysis and system architecture of maintenance management system based on predictive analytics technology for aviation industry. Furthermore, it is interesting and important to validate this proof of concept project and proof that it is feasible because predictive analytics approach is still relatively new to aviation industry.

Last but not least, as the world is slowly becoming technologically advanced, the rise of digital technologies has become a hot topic in recent years. These technologies have slowly changed the world around and many industries are now taking advantage of digital technologies such as artificial intelligence, cloud computing, data analytic and many more to deliver better services or product at reduced costs. In the next few years, there will be more and more innovative ideas that utilize predictive analytics techniques to enable more efficient and effective business process that make significant contributions in different fields.

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