AIRCRAFT SPARES CONSUMPTION PREDICTION MODEL FOR THE SMALL AIR OPERATORS

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Degree of Master of Business Administration in Supply Chain Management

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DECLARATION

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ABSTRACT

When an aircraft spare or component found defective on ground or during the flight that might compromise the aircraft's safety, it is important to remove it and replaced with serviceable component always. However, in order to avoid delays in the operations, it is critical that the availability of the replacement at the aircraft parts store for a quick turnaround.

Aircraft spares consumption prediction is so important. While excess inventories expensive due to additional inventory holding cost, inventory obsolesce, tying up capital. As well as stockouts creates huge capital losses to the air operators through costly flight delays or cancellations, loss of brand reputation, over utilization of other aircraft in the fleet, etc. So that availability of the right quantity at the right time of the aircraft spares is so vital, for that aircraft consumption prediction plays the key role.

Regression analysis and the consumption prediction is classical and practical forecasting method. Four years of Cessna 208 series aircraft Main Wheel consumption details used for the analysis. Initially data analysed with linier regression analysis and found relationship with the Aircraft Flying Time and Main Wheel consumption is significant, but it is non linier relationship. Then same data was analysed with Poisson regression analysis and the final model was developed. It can be used for the consumption prediction model as well as a decision-making tool for the inventory level estimations.

Key words: aircraft spares, consumption prediction, linier regression, Poisson regression

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LIST OF ABBREVIATIONS

AMP	Aircraft Maintenance Programme
AOC	Air Operator Certificate
AOG	Aircraft on Ground
ATA	Air Transport Association of America
BIA	Bandaranaike International Airport
CAASL	Civil Aviation Authority of Sri Lanka
CASA	Civil Aviation Safety Authority of Australia
DHL	Deutsche Post/Dalsey Hillblom Lynn (International Shipping Courier Service)
EASA	European Aviation Safety Agency
FAA	Federal Aviation Administration
Fedex	Federal Aviation Express (International Shipping Courier Service)
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IPC	Illustrated Parts Catalogue
LEAP	Leading Edge Aviation Propulsion
MMEL	Master Minimum Equipment List
MRO	Maintenance Repair Organization
MRP	Material Requirement Planning
NASA	National Aeronautics and Space Administration
OEM	Original Equipment Manufacturer
SCM	Supply Chain Management
SLTDA	Sri Lanka Tourism Development Authority
UPS	United Parcel Services Inc
USA	United State of America

1. INTRODUCTION

This Chapter will be discussed on the background of this study, including Sri Lankan domestic aviation sector, different types of aircraft maintenance activities, aircraft spares and components classification and aircraft parts ordering procedure. And, the research problem, research objectives as well as research scope discussed in this Chapter.

1.1 Background of the Study

Sri Lankan aviation sector is set for expansion after the cessation of thirty (30) years long running terrorism situation in the country. Foreign direct investments and inbound tourism was seriously weakened by a lack of confidence of the country's security levels. As the prevailing peaceful and stable situation of the country is acting as one the key features to improve confidence levels, for tourists and businesses alike. It is reported during the year of 2018 amounted to 2,333,796, tourist arrivals to Sri Lanka, with a 10.3% increase compared to the year 2017 (SLTDA, 2018).

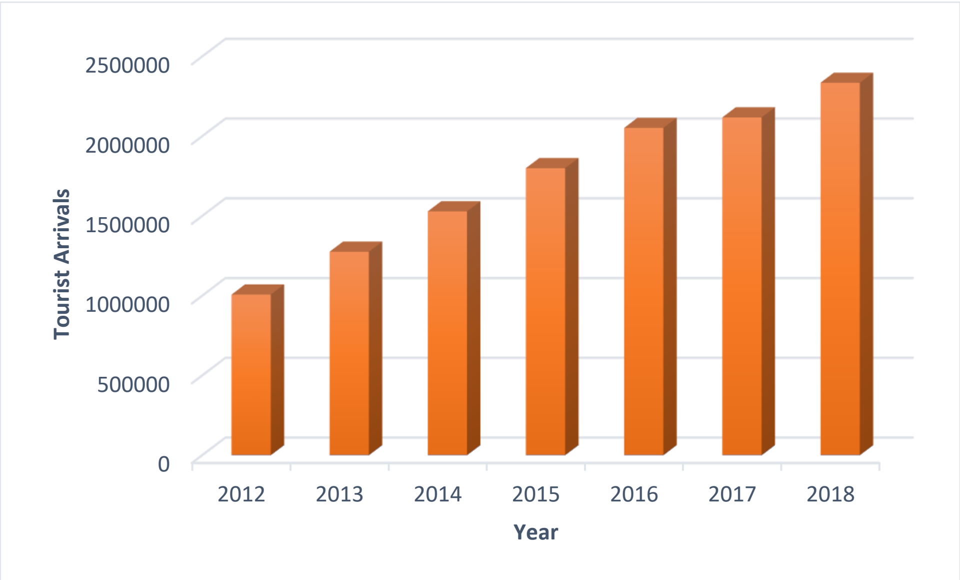


Figure 1.1: Tourist Arrivals to Sri Lanka

Please refer the Figure 1.1, for the tourist arrivals to Sri Lanka. Not only that, it's the third main largest foreign exchange earnings of the country, which accounts Rs. 598,356 million in year 2017 (SLTDA, 2017) Tourism industry only seconds to the earnings from foreign employment, textile and garment industry in Sri Lanka.

As the number of tourist arrivals increases, it records increase of the demand for domestic aviation also (CAASL, 2017). There is a direct relationship with the number of tourist arrivals and demand for domestic air travel too. Domestic aircraft movements and passengers carried is shown in Figure 1.2.

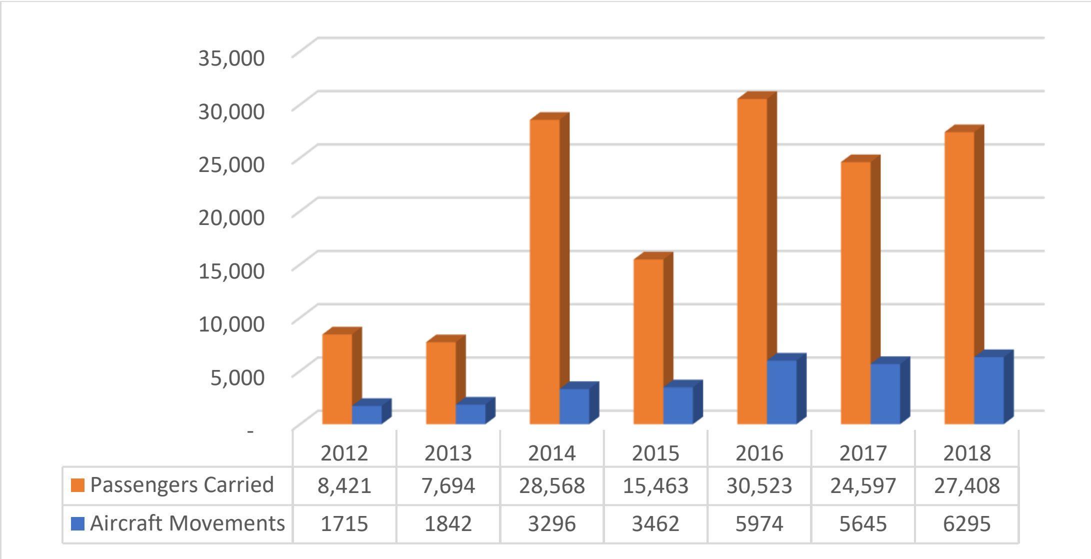


Figure 1.2: Domestic Passengers Carried & Aircraft Movements

Air connectivity or the air transportation plays a pivotal role in unlocking a country's long-term economic growth potential and has been recognized for doing so in recent times. To this end, among other advantages following are the benefits that can be achieved through the establishment of Domestic Aviation to the tourism industry as well as the country.

- Increase the tourist traffic by offering an air link at an affordable cost.

- Immediate connectivity to key tourist destinations in the country with the synchronisation of domestic flights with the arrival and departure of International flights.
- Significantly reduce the travel time (on road) enabling tourists to explore many destinations during their limited stay in Sri Lanka.
- Enable investment and infrastructure developments in rural areas of Sri Lanka which will result in enhanced standards of living.
- Provides new employment opportunities in the aviation and tourism industry.
- Contributes to sustainable development facilitating tourism and trade, generate economic growth, increased revenues from taxes and fosters the conservation of protected areas.
- Improve quality of life by broadening people's leisure and cultural experiences.

Cater to this increasing demand of the domestic aviation sector in Sri Lanka, air operators have to be prepared, well in advance for uninterrupted operations.

This research focused on development of aircraft spares and components consumption prediction model based on the regression analysis for the small air operators, such as domestic air operators in Sri Lanka. This Chapter provides an overview of the study. Research questions, research objectives and significance of the study detailed out in the Chapter followed by an overview of the research design. The Chapter concludes with a presenting the layout of this thesis.

1.1.1 Domestic Aviation Sector in Sri Lanka

There are 14 domestic land aerodromes all around the country except two international aerodromes, Bandaranaike International Airport, which is the main international airport in Sri Lanka and Mattala Rajapaksa International Airport, which is located in Southeast Sri Lanka. Not only that, there are sixteen (16) water aerodromes also located island wide as shown in the Table 1.1 (CAASL, 2019).

Bandaranaike International Airport, Mattala Rajapaksa International Airport, Colombo Airport - Rathmalana and Ampara Airport is operated by Airport and Aviation Sri Lanka Ltd., (AASL) under Civil Aviation Authority of Sri Lanka's standards and recommended practices. All the other land aerodromes are operated by Sri Lanka Air Force (SLAF). As per Air Operator Certificate (AOC) Registrations published by CAASL, there are eleven (11) AOC holders in the country (CAASL, 2019).

Table 1.1: Aerodromes in Sri Lanka

International Airports	Domestic Aerodromes				
	Land aerodromes				
Katunayake (CMB) VCBI	Ampara (ADP)/VCCG	Hingurakgoda (HIM)/VCCH	Iranativ (IRU)	Ratmlana (RML)/VCCC	Vanunia VCCV
	Anuradhapura (ACJ)/VCCA	Kankanturai (JAF)/VCCJ	Koggala (KCT)/VCCK	Sigirya (GIU)/VCCS	Weerawila (WRZ)/VCCW
	Batticaloa (BTC)/VCCB	Katukurunda (KTY)/VCCN	Puttlum VCCP	Trincomalee (TRR)/VCCT	
	Water Aerodromes				
Mattala (HRI) VCRI	Bentota River (BJT)	Kelaniya River (KEZ)	Polgolla Reservoir (KDZ)	Mahaweli (KDY)	
	Water's Edge (WRH)	Kondavttawan Tank (AFK)	Victoria Reservoir (KDW)	Dandugama (DGM)	
	Dambulla Oya (DBU)	Mawella Lagoon (DIW)	Castlerigh Reservoir (NUF)	NuwaraEliya (NUA)	
	Tissamaharama (TTW)	Pasikuda (PQD)	Arugambay (AYY)		

Source: (CAASL, 2019)

Out of all the above AOC holders, Cinnamon Air is the only premier domestic airline operating daily-scheduled flights out of Bandaranaike International Airport to some of the most exotic locations in the country. Cinnamon Air has scheduled its flight schedule in a way, which synchronized with the departures and arrivals of national carrier SriLakan Airlines, as well as all the major international airline services. All the Cinnamon Air scheduled flights are code-shared with SriLankan Airlines as well. The airline also offers charter services to and between all the county's aerodromes including water aerodromes in Sri Lanka. Cinnamon Air is based in Bandaranaike International Airport (BIA), Katunayake where it operates a dedicated domestic terminal next to the international terminal of BIA. Cinnamon Air, owned and operated by Saffron Aviation (Pvt) Ltd., is a joint venture between John Keells Holdings (JKH), MMBL Leisure Holdings, and Phoenix Ventures Limited. Cinnamon Air reported their 10,000th scheduled domestic passenger for the financial year 2017/18 on 23rd March 2018 (DailyFT, 2018). Cinnamon Air's fleet consists of three (03) Cessna 208 Series aircraft with eight (08) passenger seating capacity.

It is important to maintain the aircraft in an airworthy condition always, to provide an uninterrupted air transport operation. So that, aircraft maintenance is the key to the airworthy aircraft.

1.1.2 Aircraft Maintenance

There are lots of definitions for the 'aircraft maintenance'. In the overall, aircraft maintenance includes, performing tasks to ensure the continuing airworthiness of the aircraft, its components and systems, including overhaul, inspection, defect rectification, the embodiment of the required modifications, and compliance of the airworthiness directives.

Maintenance activities are the backbone of a successful and profitable air operator. The role of aircraft maintenance is to provide safety, airworthiness, on time aircraft for every day operations. The proper and efficient maintenance of the growing fleet of aircraft presents a unique challenge, which requires necessary capacity and technical competence. Aircraft maintenance must plan and perform according to the prescribed procedures and standards as per the Aircraft Maintenance Programme, which is approved by the national aviation authority. In Sri Lanka, aviation regulator is Civil Aviation Authority of Sri Lanka. The maintenance task standards specify in which time interval each task must be scheduled and how much time must be spent on each task are described in the AMP. The aircraft maintenance is categorized into two areas: line maintenance (consists of short-term checks and daily inspections) and base maintenance (regular checks: according to landing cycles or flight hours or calendar months of the aircraft, its components and systems).

Aircraft inspections and maintenance are performed periodically, pre-flight and post-flight. In addition to these checks, aircraft maintenance can take place due to an emergency breakdown found in the aircraft, aircraft component or aircraft system.

1. **Scheduled Aircraft Maintenance**
    - Line Maintenance Checks including pre-flight and post-flight inspections
    - Periodical Inspections such as A-Check, B-Check, C-Check and D-Check
2. **Unscheduled / Ad-hoc Aircraft Maintenance**
    - Ad-hoc repairs attended during the pre-flight and post-flight inspections
    - Aircraft on Ground (AOG) when critical part failed in airworthiness

Scheduled Maintenance Inspections are performed to ensure that the continuing airworthiness of the aircraft and its availability for the day to day operations. These maintenance tasks inspect and repair airframe, its components including engines, propellers, and aircraft systems as per component manufacturer's Maintenance Manual. Spares and components need the replacement are ordered well in advance and received at the maintenance facility prior to commencing the aircraft inspection.

Unscheduled, sudden emergency maintenance inspections are to fix technical failures found in an operating aircraft, aircraft component(s) or aircraft system(s). During the inspection, if found any failures or defects of components or systems and the failed during functional checks, needs to be replaced. If the required aircraft spare or component not found in the Aircraft Parts Store, that aircraft need to be grounded until the repair attended if the defective component or the system is not listed in the Minimum Equipment List (MEL), which is approved by the Civil Aviation Authority of Sri Lanka. This is called aircraft on ground (AOG) situation, and it is a critical situation. It requires all efforts to make the aircraft airworthy within the shortest possible time to continue its operations.

Aircraft component maintenance is also categorized mainly in to three categories, such as hard time components, on-condition components and condition monitoring components. Normally, hard time and on-condition components maintenance is directly involved with preventing failures, but condition monitoring is not. It's based on the preventive action only if necessary (Ghobbar & Friend, 2003). Component maintenance is described in Table 1.2.

Table 1.2: Component Maintenance

Hard-time	Hard Time components maintenance included in the preventive maintenance process to recognized deterioration of a component. And taking back to the satisfactory level by performing the maintenance tasks as per the manufacturer's instructions. This maintenance is based on the component life which is calculated based on the calendar time, operating cycles or landings. Maintenance actions includes servicing, functional tests, overhaul, or replacement of the part.
On-condition	On-condition maintenance is also included in the preventive maintenance. Periodic checks are involved in this process. Sometimes item has to be checked as per the given standard to determine whether it can continue in service till the next scheduled inspection. These checks confirm that item can continue in the operations till the next inspection without fail during the flight. These time periods can be adjusted as per the operators experience in more frequently without compromising the manufacture's standards.
Condition-monitoring	Condition-monitoring is not involved with any preventive maintenance activity, not included in both hard-time and on-condition items, some of the information monitored on the item. This is carried out by taking physical measures on as per the

	standards mentioned in the Maintenance Manual. For an example, weariness measurements of the brake liner.

Source: (Ghobbar & Friend, 2003)

Some airlines maintain flyaway kits, which includes important items that have a high chance of becoming faulty based on their past maintenance experience. Not only that, some airlines get in to partnerships with other airlines operating the same types of aircraft fleets for part exchange, this may include the part pooling as well.

Cannibalization is another option, which is robbing a unit from an aircraft grounded for maintenance if available (Alam, 2016). But in Sri Lankan context, these options will be very limited, because limited number of the same types of aircraft are operating in the Sri Lankan aerospace. Airlines like SriLankan Airlines, which operates in international and large network can managed AOGs' with above-mentioned options. So that it is important to plan and storing critical aircraft spares and components in required amounts in the Aircraft Parts Store, especially for the scheduled domestic air operation.

If there is a delay in the supply of spare parts, aircraft may be grounded (AOG) for days or weeks. It may lead to cancellation of scheduled flights, transfer cargo and passengers to another flight, over utilization of other aircraft in the fleet, flight crew may be idled until aircraft returned to service with airworthy condition. This situation creates a huge cost to the air operator. AOG cost to the operator includes flight cancellation or delay penalties to the airline, customer dissatisfaction, loss of brand reputation, ground service charges at airports, parking charges at airports, payments to flight crew, loss of revenue, the cost of spares and components, AOG logistics arrangements, etc.

Other than SriLankan Air Lines, all the other domestic air operators are facing lots of difficulties specially in AOG spares shipments, due to prevailing import approval requirements, Customs clearance delays, information unavailability in the supply chain, improper communication, etc. These kinds of delays are mostly common in domestic aviation industry. This is badly affected to the schedule air operators.

1.1.3 Aircraft Parts Classification

Compared to other transportation modes in aviation is so unique due to four (04) main market feathers such as, the global need of parts, demand for parts are highly unpredictable, parts traceability due to safety reasons and huge costs when not having a part (Gu, Zhang, & Li, 2015). In general, spares are classified in to four main categories, which describes in Table 1.3.

Table 1.3: Aircraft Spares Classification

Rotables	Rotables are more complex components and can be repaired unlimited times. In normal conditions item scaping is not involved. All the rotables are having a unique serial number and parts exchange is involved during the maintenance.
Repairables	Repairable items are the items, which can be economically, as well are technically feasible to repair. In this case, item serialization is not heavily involved. Items can be repaired for limitedly and at the end, item will be scrapped.
Expendables	After the useful life, if it is found unserviceable, item will be scrapped. One to one replacement is taking place. Expendable cannot be repaired. Most of the time these items are standard spares.
Consumables	Consumables are the items which are used at once, such as raw materials, chemical items, paint oil and lubricants, etc. at the application,

Source: (Gu, Zhang, & Li, 2015)

International Civil Aviation Organization (ICAO) sets the standards and recommended practices for civil aircraft maintenance and those are adopted by each national aviation authorities and imposed them through Implementing Standards, Aviation Safety

Notices and National Aviation Regulations. Civil aircraft maintenance is highly regulated by the aviation regulatory authorities due to safety and airworthy concerns. Therefore, all the aircraft spare parts come with an airworthiness approval tag or release certificate issued by the appropriately approved organization. Prior installation on the aircraft, it's important to verify its accuracy and the authenticity of the release certification.

In United State of America, approved aircraft parts are issued with Federal Aviation Administration (FAA) Form 8130-3, European Aviation Safety Agency (EASA) approved parts are comes with the EASA Form-1, CASA (Civil Aviation Safety Authority, Australia comes with the CASA Form-1. In Sri Lankan certified aircraft spares comes with CAASL Form 1. In general OEM (Original Equipment Manufacturer) issues airworthiness compliance certificates. E.g. hardware, aviation lubricants, etc. have manufacturer's certification or the Certificate of Conformance, which confirms that it meets a minimum set of regulatory, technical and safety requirements. Therefore, during aircraft spare parts receiving inspection, Airworthiness Tag, Authorized Release Certificate, or the Certificate of Conformance is essential criterion to confirm the quality, and the regulatory compliances.

All the aircraft related parts and components are listed in the aircraft Illustrated Parts Catalogue (IPC), on the ATA Chapter wise. This standard numbering system was introduced by the Air Transport Association of America in 1956. All the aircraft spares are identified with the manufacturers code or the part number. For the major and critical parts, unique serial number also included to trace the history of that aircraft spare. So that it's so important to order and receive the correct part number to the aircraft stores as well as should be issued to the aircraft maintenance as well.

Most of the aircraft spares are quite expensive and aircraft type specific. Various spares are supplied to the aircraft manufacturer from the worldwide locations. So that aircraft spares supply chain is so complex and extended up to third and fourth tier suppliers as well. Some aircraft components are make-to-order and comes with considerable lead time to the aircraft manufacturer, upon that delivery lead time also has to be added to receive it to the end user.

Delivery lead time of aircraft spare parts is so critical factor in a situation. To avoid such lead time delays, major airlines sign agreements with maintenance repair organizations (MRO) and transfer the responsibility to the MRO for holding aircraft spares stocks, carrying out repair maintenance services and provide technical assistance as and when required. These service agreements help airlines to have access to spare parts and repair activities within a shortened time period and in cut down the repair turnaround time as well. Air France Industries, KLM Engineering and Maintenance, British Airways Engineering, AAR Corporation, Air China and Ameco Beijing, Delta TechOps, GE Aviation, are some of the so-called MROs' in world.

Air operators like Cinnamon Air, is more vulnerable to situations where aircraft is on AOG for a longer period of time until required spare parts are supplied with. Sometimes the operator might have to wait until the components are repaired and receive back to the stores due to lack of part exchanges available. Not only that, small airlines have less bargaining power with suppliers as well. Direct access to MRO is limited due to little revenue and the limited size of the fleet. As a result, access to the correct spare part on an emergency situation becomes limited and expensive. Small air operators often depend on service of an intermediate broker or MRO nominated workshops. Therefore, small air operators need to find various ways to manage the risk of spare parts availability during the aircraft on ground situation to avoid spare parts delivery delays. The highest attention in aviation industry is to avoid AOG situations. Therefore, it is essential to have faster delivery modes and free access to spare parts.

Considering the above, all the air operators used to maintain enough stocks of the frequently used aircraft spares for uninterrupted operations due to avoid spares stock-out situations.

1.1.4 Aircraft Spares Ordering Process of Cinnamon Air

As descried in the Aircraft Parts Classification in Chapter 1.1.3, all the aircraft spares and components are coming with the relevant certification and all most all the aircraft spares are imported from world-wide suppliers. Aircraft Spares ordering process starts in two ways. Cinnamon Air's inventory ordering procedure is shown in the following Figure 1.3.

Firstly, when there is an unavailable aircraft spare(s) or component(s) requested by the Aircraft Maintenance Staff at the Parts Store. Secondly, a new spare(s) or component(s) ordered by the Aircraft Maintenance Staff, which is not available in the Parts Store for a future scheduled aircraft maintenance task or defect rectification activity. If the requested part is required for the ongoing inspection, and not available in the Parts Stores, and also the part is a no-go item, aircraft may have to be grounded (AOG) as well, until the part receive to the Aircraft Parts Store.

Then quotations will be requested from the pre-approved suppliers. All the air operators are having their own Quality Management System, which is approved by the national aviation authority. As per the Quality Management System procedures, upon the satisfactory facility audit or an email audit, Head of the Quality Assurance of the air operator is approved that supplier or the facility for the audited purpose. Only approved suppliers are audited annually by the Head of the Quality Assurance.

Received quotations, reviewed by the Head of Aircraft Maintenance & Engineering and send for the Chief Executive Officer's approval for the payment approval. Then Head of Procurement and Stores raise the Purchase Order and send to the supper to confirm the order. At the same time spares importation approval process is also started. Initial approval should be granted from Civil Aviation Authority of Sri Lanka (CAASL) and for that, relevant from the Illustrated Parts Catalogue (IPC) of the requested spares, copy of the Pro-forma Invoice of the intended purchase should be submitted with a covering letter. Upon the receipt of the Purchase Order, supplier issue the Pro-forma Invoice. By experience, that approval normally takes two (02) to five (05) working days.

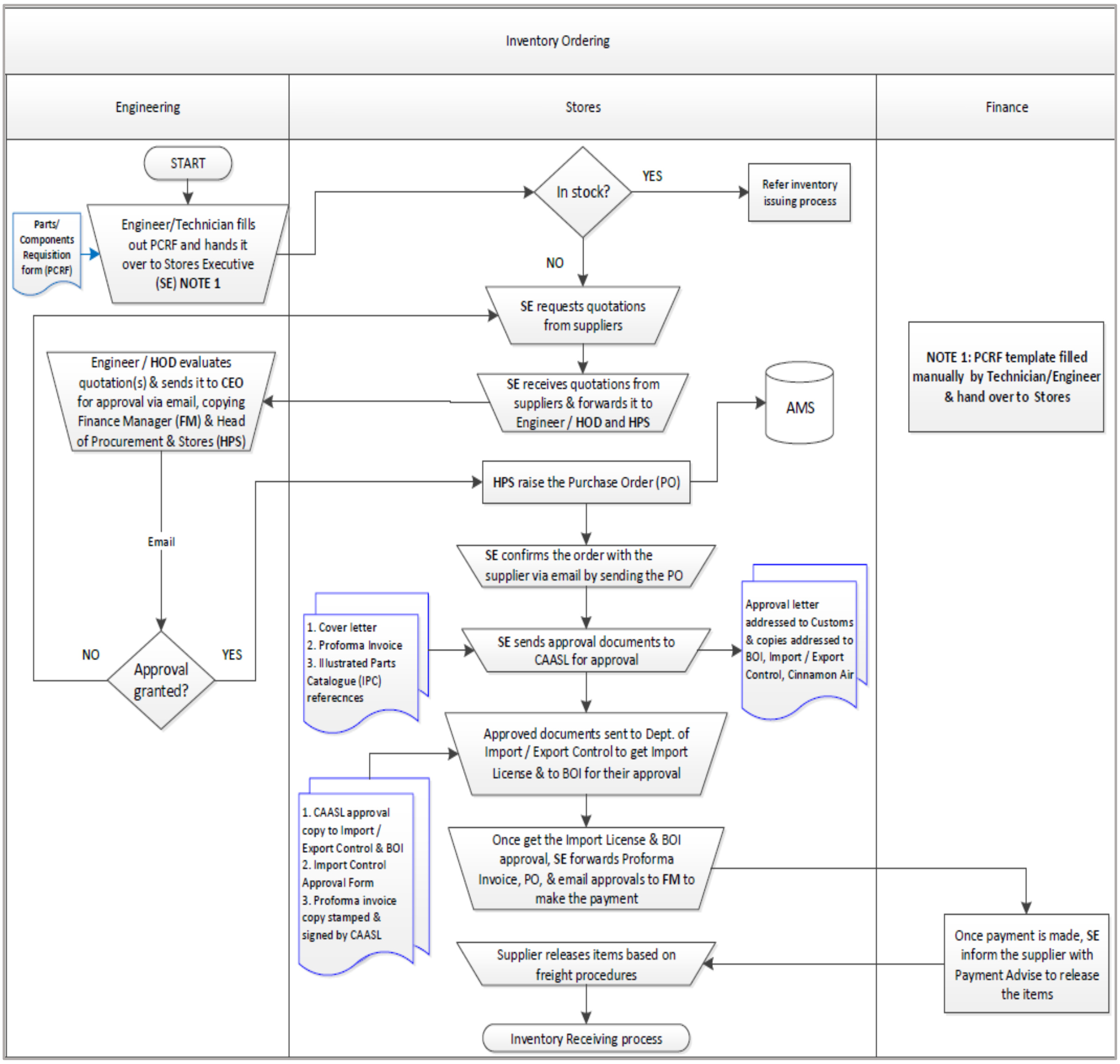


Figure 1.3: Cinnamon Air Inventory Ordering Process

Once received CAASL approval, Board of Investment (BOI) for tax exemptions and Department of Import and Export Control for Import Licence are applied with covering letters and the respective CAASL approval letter copy.

BOI approval normally takes three (03) to five (05) working days and Import Licence is also takes the similar time period in normal circumstances. Based on the importation item, additional approvals also may be required. For Telecommunication related aircraft avionics spares; Telecommunication and Regulatory Commission of Sri Lanka approval, for oil and lubricant items; Ministry of Petroleum Resources Development, for seat and upholstery leather importation; Department of Animal Production and Health are required.

Once received all the required approvals, payment will be processed mostly on wire transfer to reduce the time consumed. Upon the cleared payments, ordered spares will be shipped by the supplier as per shipping instructions given in the Purchase Order. Most of the time aircraft spares shipments are sending on airfreight and currier services such as DHL Express, Fedex Express and UPS to reduce the transit time.

After receiving the shipment to destination airport or seaport in Sri Lanka, Customs clearance process will be taking place. For Sri Lanka Customs clearance, above mentioned pre-importation approvals are required and needs to pay applicable duties and taxes. Additional penalties may be applied, if there are any discrepancies of the shipment with the pre-approved paper work. In normal circumstances, Customs clearance process also takes two (02) to five (05) working days.

Considering the above, minimum five (07) working days are required only for the approval process excluding shipment packing, handling and transit times to Sri Lanka.

1.2 Research Problem

Delays in aircraft spares shipments create huge capital losses to the air operators including flight delays, cancellations, customer dissatisfaction, the loss of brand reputation, over utilization of other aircraft in the fleet, etc. On the other hand, aircraft parts are expensive and excess inventory is an additional cost to the air operator. Some of the aircraft materials like sealants and lubricants come with a shorter shelf life like three (03) to six (06) months. Not only that, some of the parts are ‘Make to Order’ and delivery lead time is associated with parts ordering.

So that, it is very vital to predict the demand of aircraft spares required for future maintenance and repair activities and stock them in right quantities of an air operator for uninterrupted operations, as well as to reduce the excess inventory cost including inventory holding cost, inventory obsolesce cost, etc. Planned inventories can be consolidated and it reduces the shipping cost. All most all the domestic airlines in Sri Lanka do not follow a systematic approach to predict the consumption of aircraft spares and make the scientific decisions on aircraft maintenance resources to take the maximum outcome to improve maintenance capabilities. Here, the research interest arises to introduce a mathematical model to predict the consumption of aircraft spares for small air operators such as domestic air operators in Sri Lanka.

Hence, my research problem of study is ***"How to predict the aircraft spares consumption of small air operators".***

1.3 Research Objectives

Research objectives of this research are listed below.

1. Study the importance of aircraft spares consumption prediction.

2. Study on the existing methods of aircraft spares consumption prediction in practice to identify the most suitable method to develop a mathematical model to predict the aircraft spares consumption for small air operators like domestic air operators in Sri Lanka.

3. Develop a mathematical model to predict the consumption of aircraft spares for the small air operators such as the domestic air operators in Sri Lanka.

4. Analyse the developed model and modify it, based on the analysis results to improve the prediction accuracy.

5. Provide recommendations to the domestic air operators in Sri Lanka on the aircraft spares prediction and the optimum inventory levels to minimize the operating cost.

1.4 Scope of the Research

This research focussed to develop a mathematical model to predict the aircraft spares consumption for the small air operators such as domestic air operators in Sri Lanka. Mathematical model developed, based on the Sri Lanka's premier domestic airline, Cinnamon Air's condition monitoring aircraft spares consumption details from 2015 to 2018 time period, which operates Cessna 208 series aircraft.

Out of the condition monitoring spares, for this research is only focussed on the air line's Main Wheels consumption of the above-mentioned four (04) years' time period due to frequent Main Wheels changes and higher costs associated with the replacements.

2. LITERATURE REVIEW

Chapter 1 introduced the topic of this research giving its objectives and general layout of the thesis. This Chapter discussed on the importance of the aircraft spares inventory management and technology enhancements of the aircraft spares. As the most important part of this Chapter, it is discussed on the existing literature on the aircraft spares prediction models, which were developed to predict the aircraft spares consumption to identify the most suitable method to develop a mathematical model for small air operators like domestic air operators in Sri Lanka.

2.1 Aircraft Spares Consumption Prediction and its Importance

All most all the worldwide air operators used to store aircraft spares. At the same time, they face lots of issues related to the aircraft spares availability as well. The higher costs of spares and components, items with limited shelf life, spares supply connect with multiple suppliers, quality and safety conformity requirements, regulatory obligations for transportation and importation to the country, high dependency on logistics modes for transportation and delivery lead time are some of the problems that aircraft operators faced with aircraft maintenance daily related to aircraft spares. It is well-known that the cost of the aircraft spares and components only seconds to the cost of fuel. So that, effective management of civil aircraft spares, components are significantly important to the cost-effective operation of aeroplane (Li, Zhang, Yan, & Peng, 2015). Spare parts are significantly influenced to all types of aircraft maintenance tasks, and unavailability of spares may cause excessive aircraft downtime costs, idling air operator's manpower cost, etc. (Hassan, Khan, & Hasan, 2012).

Treuner and his team, founded with a survey that key issues in aviation spares supply chain are the resource constraints, communication and quality issues, followed by suppliers' insolvency and inevitable environmental events (Treuner, Hübner, Baur, Prof. Dr. Stephan M. , & Zürich, 2014). They proposed adoption of a risk sharing model to reduce supply chain interruptions. That model helps the airline operators to prepare for emergencies. It contains the impact of materialized risks. Since aviation is one of the higher capital-intensive industries, it is also important to have high commitment from senior management in the organization to create efficient production process and resilient supply chain to drive financial performance.

As per Gu, Li and Zhang, out of the airline operating costs about 13% is for the aircraft maintenance and that can be reduced through proper maintenance planning (Gu, Zhang, & Li, 2015). While having these costs, airlines also have to satisfy their customers too. So that aircraft maintenance planning plays the key role of both. The well-planned maintenance programme helps the airline to effectively avoid flight delays and cancellations, which leads to the customer satisfaction too. Also, it helps to improve the competitiveness in the industry. Same as in all the industries, in airline also excess aircraft spares inventories lead to a additional holding costs and obstructs cash flows, while insufficient inventories caused for costly flight delays and cancellations. It is important to maintain adequate levels of inventories of spares for the smoother airline operation.

Fritzsche and Lasch highlight the importance of the increasing interest in optimal maintenance strategies due to increasing costs, with quality improved spares, and huge pressure on planners to reduce the spares inventories (Fritzsche & Lasch, 2012). They also emphasize the necessity of preventive (scheduled) maintenance. Not only that, reduced network complexity also helps for enormous total cost savings on scheduled maintenance. Fritzsche's dynamic predication model assures following benefits for the airlines;

- Maintenance performed only when system needs maintenance. Results in longer maintenance free operating periods and decrease in down time costs
- When airline has the ability to plan the maintenance, inventory can be managed better with planned quantity of spares to retain and locations to store.
- Airlines can improve availability of aircraft for the operation
- Prevention of catastrophic and expensive failures such as engine breakdowns during a flight

- Through the preventive model, fixed maintenance intervals are transferred to variable intervals so that unnecessary services are avoided. This results in decreasing downtime, delay time and cancellation of machines and thereby increase airline efficiency and image.

2.2 Technology Enhancements and Aircraft Spares

With new technology enhancements, the additive manufacturing technology is becoming more famous in aircraft spares manufacturing industry for manufacturing aircraft components. Current applications are such that, manufacturing of 3D printed fuel nozzles for General Electric's advanced LEAP jet engines, introduction of over 1000 of 3D printed parts in Airbus A350 model and NASA is planning to use 3D printed materials for operation in space. 3D printing technology also known as additive manufacturing (Kückelhaus & Yee, 2016).

Advantages of additive manufacturing are;

- Reduce number of production steps and able to customize products
- Faster delivery time and on-demand production
- Lower logistics and production costs
- Higher sustainability

Lots of studies shown that maintaining an aircraft spares inventory accounts nearly 10% of the aircraft overall operating cost. Excess spares inventory impedes the cash flows and inadequate inventory resulting the expensive flight delays and cancellations, resultant for adverse impacts on airline performance. So that, optimal aircraft spares inventory is so critical for air operator's optimum usage of each aircraft in the fleet and reducing its over-all operating cost.

2.3 Demand Prediction Models used for Aircraft Spares

Demand for air transport is varying daily, weekly, monthly, seasonally and created peaks in most attracted time periods. Most of the air operators are trying their level best to capture these demands. In general, aircraft maintenance, most of the spare's lifetimes are unpredictable. So that, demand for the aircraft spares are forecasting based on the future flight schedules, scheduled maintenance activities, maintenance contract information, etc. Not only that, aircraft spares usage patterns are also vary based with the past flying hours as well as past demand information. Not only that, air operator's fund allocation for the aircraft spares also matters in the spares forecasting process.

Thirteen (13) forecasting methods are analysed in the Ghobbar and Friend's research (Ghobbar & Friend, 2003), which are currently in practice with the air operators for the aircraft spares consumption prediction. Those methods are listed in Table 2.1.

Table 2.1: Forecasting Methods of Aircraft Spares

Model Name	Description
Additive Winter	Seasonal Demand patterns are captured in this model
Multiplicative Winter	Used for the seasonality which is increased with the time
Seasonal Regression Model	Is used in time series for modelling data with seasonal effects.
Component service life (Replacement)	Replacement time limits are forecasted based on the usage, flying time, landing cycles or calendar months
Weighted calculation of demand rates	Based on the past experience, weights are allocated for the demand patterns identified.
Weighted regression demand forecasters	Moving Regression methods are used for the forecasting based on the flying time
Croston	Used for the intermittent demand forecasting.
Single exponential smoothing	Used for the low and intermittent demand forecasting.
Exponentially weighted moving average	Used for time series data related forecasting, which shows a linear pattern.
Trend adjusted exponential smoothing	Used for time series data related forecasting, which shows a linear trend.

Weighted moving averages	With past experience, weights are assigned for the moving average
Double exponential smoothing	Used for time series data related forecasting, which shows a linear trend.
Adaptive-response-rate single exponential smoothing	Proposed changes are made to predict systems that change the prevalence system and maintain a degree of reaction based on the value of a detection signal.

Source: (Ghobbar & Friend, 2003)

2.3.1 Intermittent Demand Prediction of Repairable Spares

Demand prediction of the aircraft spares one of the is most vital activities in aircraft maintenance management, including planning required inventory levels. This is most critical for the airlines as well as Maintenance and Repair Organizations (MRO) also. Forecasting the short-term spares requirements to the most possible accurate levels, is the most critical tasks for the all most all the airlines worldwide. Expensive aircraft parts and components including aircraft engines, propellers, avionics components, repair overhaul or exchange costs, contributes a larger portion of the investments of the air operators as well. Unavailability of these expensive, low in demand spares in the parts store may cause for the expensive AOG situations (Ghobbar & Friend, 2003).

Determination of requires inventory levels should base on the Aircraft Maintenance Programme, there the inspection schedules and frequencies are listed. Out of there, some of them are intermittent, due to the demand pattern of the aviation industry. Single exponential smoothing method and Croston methods are widely used for the intermittent and low demanded aircraft spares forecasting (Ghobbar & Friend, 2003). Single exponential smoothing method is the most commonly in practice for the intermittent demand prediction. In the Craston Method, wide range of simulated conditions are used.

2.3.1 Artificial Neural Network Model

In 2006, Ahmed Z. Al-Garni and the team developed a model using both artificial neural network and Weibull regression model to identify the failure rate of the De Havilland Dash - 8 aircraft tires. They have input the independent variables for the neural network model and outcome is the failure rate of the aircraft tires. They have used six (06) years past tire consumption data of the De Havilland Dash - 8 for model development and validation. Developed model was validated using the Weibull regression model and results shown that the failure rate, which was predicted by the artificial neural network is almost similar to the actual data available. As per the research, artificial neural network model predations are more accurate that the Weibull regression model results for this case (Al-Garni, Jamal, Ahmad, Al-Garni, & Tozan, 2006).

2.3.2 Double level combination approach using five direct forecasting methods

To forecast the repairable aircraft spares, a model was introduced by Guo and the team proposed a double level combination forecasting method. They have initially analysed the contributing factors for the repairable spares' demand. At the next stage they have used five (05) direct forecasting methods combination to introduce the double-level combination model. The five direct forecasting methods are the genetic neural network model, grey model and the three types of exponential smoothing models. Here they have used low level forecasting methods of demand forecasting and absolute errors of the respective method. Then the top-level combination method, developed using direct forecast method's demand forecast and absolute error calculation and the weighted coefficients calculated from the low-level forecasting method (Guo, Diao, Zhao, Wang, & Sun, 2017). The developed model takes only forty (40) seconds to compute the forecast of the demand of the restrictive repairable spare part. They have concluded, with developed model is more accurate for the demand forecasting for the repairable aircraft spares.

2.3.4 Weibull Distribution

In 2016, Lowas and Ciarallo done a study on the reasons for the lumpy demand for aircraft spares, and identification of the opportunities on the spares' regulatory related demands. This study was done using Weibull distribution considering the typical failure distribution of aircraft spares. There, they have identified the typical aircraft spares failure frequencies using Weibull model parameters and used these parameters to perform a Monte Carlo simulation notional for aircraft components in aircraft fleet sizes and operations (Lowas III & Ciarallo, 2016). There they have tried to discuss mainly on the lumpy nature of demand for the aircraft spares.

As per the study they have concluded that, the lumpiness of the aircraft spares should be forecasted based on the aircraft spares and components wear out characteristics, size of the fleet, aircraft fleet's purchasing period.

2.3.3 Linier Regression Model

Yang, Sun and Guo highlighted the importance of aero-material consumption prediction and the scientific decision making, with that aircraft maintenance capabilities improved (Yang, Sun, & Guo, 2018). They have discussed the parameter estimation and model test method as well, using the liner regression analysis. There, they have introduced a linier model for the non linier problems. In this model they have analysed five (05) years aircraft tire consumption data and aircraft landing cycles. Regression analysis was followed by a residual plot analysis and also with a comparative analysis on the predicted results as well.

2.4 Summary of the Literature Review

To achieve the first objective of this research literature survey was carried out to identify the importance of aircraft spares consumption prediction. When aircraft are in continuing operations, aircraft should be maintained in timely manner with the pre-allocated time intervals as per the Approved Aircraft Maintenance Programme. For the scheduled maintenance inspections, required replacement due hard time aircraft spares are known, and those spares are ordered and get down well in advance in required quantities. Not only that, sometimes there can be flight delays and cancelations due to a sudden technical failure occur in the aircraft. Then the aircraft needs to be grounded for repair maintenance and spare parts to be supplied with immediate effect. For that, emergency needed spares are also listed in the Manufactures Maintenance Manuals and should be stored for the continuous operations. During scheduled inspections, if there are any replacement due condition monitoring spares such as main and nose wheels, brake units, etc. are found, they need to be replaced and should be available in the Parts Store. If the part is not found in the Aircraft Parts Store, it has to purchase and supply to the aircraft maintenance crew. Until that required part receives to the stores, aircraft has to be grounded. So that it is important to predict the required spares consumption based on the forecasted flight operations.

Second objective of this research was achieved by reviving the existing research on the aircraft spares consumption prediction. Many researches have been done on the development of aircraft spares prediction models and consumption predations, etc. using various mathematical approaches.

Literature survey could not capture any research carried out on any of the domestic air operator's aircraft spares consumption prediction model development in Sri Lankan contest, even for a small air operator in the global context as well. As per the ICAO definition, small air operators are the air taxis and commercial business operators, that provide commercial air transport services with less than five (05) aircraft in the fleet. So that, it is important to develop a method to predict the aircraft spares consumption of small air operators as well. This Research will fill that gap of the aircraft spares consumption prediction model for the small air operator such as domestic airlines in Sri Lanka.

3. RESEARCH METHODOLOGY

Previous Chapter discussed on the literature done on this study. This Chapter elaborated on the research design with the justifications, possible methods available for analysis and the reasons for using the one selected. The research methodology provided an overview of the research design, and how to achieve the research objectives listed in Chapter 1.

3.1 Research Approach

To achieve the first two (02) objective of this research, literature survey was carried out in Chapter 2 of this research on the importance identification on aircraft spares consumption prediction and study on the previously developed aircraft spares prediction model development and what kinds of the theoretical approaches used in those methods.

Third objective: to develop a mathematical model to predict consumption of aircraft spares for the small air operators such as domestic air operators in Sri Lanka, data collection was carried out, and it is discussed in Chapter 3.2 of this research. Collected data was analyzed using two (02) regression methods. First one was linier regression and second one was Poisson Regression analysis. Based on the analysis results model was developed using Poisson Regression Analysis to predict the aircraft spares consumption of the small air operators such as domestic air lines in Sri Lanka. At the same time, model was modified using analyzed results to achieve the forth objective.

Finally, to achieve the fifth objective of this research, some recommendations were proposed to the domestic air operators to minimize their operating cost while having the optimum inventory levels.

3.2 Data Collection

Actual data was selectively collected from Saffron Aviation Pvt Ltd, which is the operating company of Cinnamon Air, premier domestic airline. For the model development and analysis, previous four (04) years from year 2015 to year 2018 data, including monthly aircraft flying time and monthly landing cycles was collected from the Cinnamon Air, Aircraft Maintenance Management Database. For that, Monthly Aircraft Flying Report was used. At the same time, respective month wise Aircraft Main Wheel consumption data also was collected from the Cinnamon Air's Inventory Management Database. That was derived from the Monthly Inventory Consumption Report.

Collected primary data was converted in to the meaningful manner for the data analysis, monthly wise aircraft Main Wheel consumption, with the aircraft flying time and respective landing cycles was listed accordingly.

3.3 Data Analysis and Discussion

Collected data was analyzed using following two methods, linier regression analysis and Poisson Regression analysis to develop the model for the aircraft spares prediction model for the small air operators such as domestic air lines in Sri Lanka to achieve the third objective of this research.

3.2.1 Linear Regression Model

Linear regression is a basic and widely used for predictive analysis. Concept of the Simple linier regression is to develop a model between two variables, which are one independent variable and other is dependent variable on the independent and fit experimental data set to a simple linear equation to experimental data.

Simple linier regression model is:

$$y = a + bx$$

Where 'y' is the dependent or the forecast variable and 'x' is the independent or the explanatory variable. Here 'a' and 'b' are the coefficients. For the estimating parameters of the model 'a' and 'b' least square method can be adopted. Supposing that 'n' pairs of data that predict the dependent variable 'y' and the dependent variable 'x'; *(x, y) (I = 1, 2, ……., n).* Assuming the linier relationship between *'y'* and 'x', above linier regression equation can be used.

Using the least square method;

$$b = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \overline{y})}{\sum_{i=1}^{n} (x_i - \overline{x})^2}$$

$$\text{a} = \bar{y} + b\bar{x}$$

Where $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$; $\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$

After the linier regression model is established, model needs to be tested. Here, as commonly used standard deviation and correlation coeffect test are used for the testing the developed model.

To testing the accuracy if the regression prediction model, standard deviation test, where standard deviation '*s'*.

$$s = \sqrt{\frac{1}{n-2}(y_i - \acute{y_i})^2}$$

Where $\acute{y_i}$ is the actual value of the predicted or the estimated value.

Here, standard deviation 's' represents the average error between the predicted value and the actual value. So that, the smaller the value of the 's', the better. In general following require should be meet.

$$\frac{s}{y} < 10\% \sim 15\%$$

To test the significance of the liner correlation between independent and dependent variables, correlation coefficient test is used. Correlation coefficient 'r' is calculated as follows.

$$r = \sqrt{1 - \frac{\sum_{i=1}^{n}(y_i - \acute{y}_i)^2}{\sum_{i=1}^{n}(y_i - \overline{y})^2}}$$

In general, when 'r' is closer to 1, the relationship between 'y' and 'x' can be described with linier regression model. The test is carried out using critical coefficient test $r_{\propto}$, where the significant level α = 0.05.

3.2.2 Poisson Regression Model

Poisson Regression or the log-linear model also similar to the multiple regression, except that the dependent variable 'y' consists of 'count data' given one or more independent variables and follows a Poisson distribution. Hence, possible values of the 'y' should be nonnegative integers 0, 1, 2, ….., n. Here, it is assumed that the larger counts are rare. In the Poisson Regression is has a unique feature that the, mean and variance are equal. The probability function for the Poisson distribution represented as follows,

$$P\,(Y = y \mid \mu) = \frac{\mu^y}{y!}\; e^{-\mu}$$

The above equation gives the probability of observing a given value, y, of variable Y that is distributed as a Poisson distribution with parameter μ. For the count variable Y, μ is the arithmetic mean number of incidents that occur in a specific time interval; the Poisson distribution would yield the probability of 0, 1, 2, . . . incidents given the mean μ of the distribution. The probability of the specific count also based on the variance of number of counts. Poisson distribution is specified by only one parameter μ, which equals to both mean and variance.

The logarithm of the expected count is assumed to be a linear function of some predictors in Poisson Regression.

$$\ln(\mu_i) = b_0 + b_1 x_1 + b_2 x_2 + \ldots + b_k x_k$$

Where μ_i is the predicted count on the outcome variable given the specific values on the predictors x_1, x_2, x_3, ……… x_k. Recall that 'ln' refers to the natural logarithm, b_0 is the intercept. And b_1 is the regression coefficient for the first predictor, x_1.

4. DATA ANALYSIS & DISCUSSION

In the first phase literature survey is presented to have an understanding about the industry practices and methods previously introduced related to this research area. Then the research methodology is presented, how this research was done and in the next phase in this Chapter discussed the research findings, analysis, outcomes of the research. As described in the previous Chapter, from year 2015 to year 2018 monthly wise aircraft flying time, number of landing cycles and Main Wheel Consumption details of Cinnamon Air of the Cessna 208 aircraft are shown in the following Table 4.1.

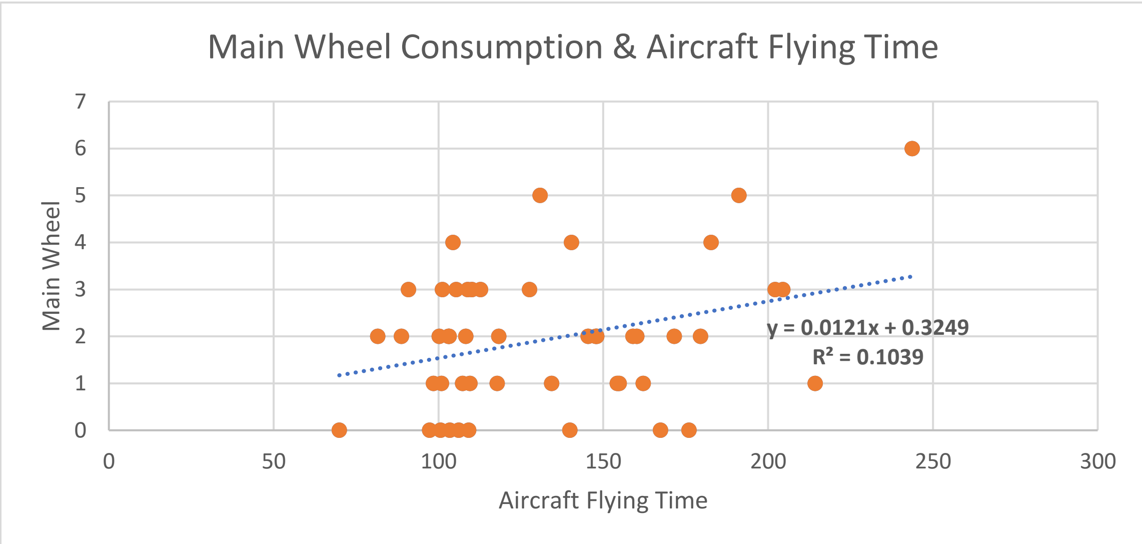
Table 4.1 Main Wheel Consumption 2015 - 2018

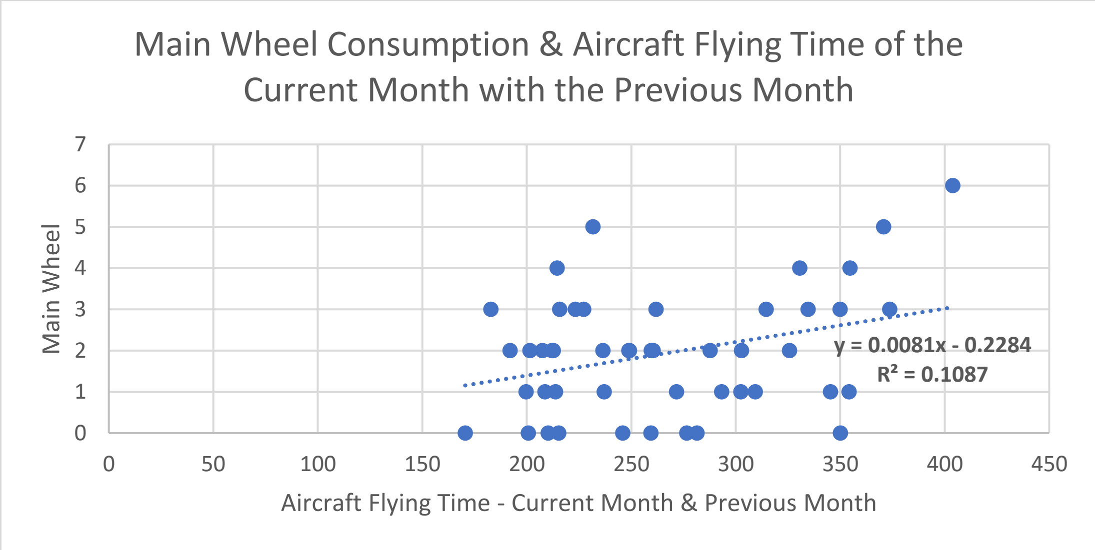
Month	Flying Time	Landings	Main Wheel Consumption	Month	Flying Time	Landings	Main Wheel Consumption
Jan - 15	81.6	176	2	Jan - 17	134.3	291	1
Feb - 15	101.2	213	3	Feb - 17	127.6	292	3
Mar - 15	98.5	211	1	Mar - 17	109.5	250	1
Apr - 15	103.0	232	2	Apr - 17	162.1	372	1
May - 15	112.8	245	3	May - 17	97.3	210	0
Jun - 15	100.9	233	1	Jun - 17	103.4	209	0
Jul - 15	130.8	272	5	Jul - 17	145.4	285	2
Aug - 15	118.3	238	2	Aug - 17	204.5	385	3
Sep - 15	108.9	227	3	Sep - 17	110.1	220	3
Oct - 15	103.2	201	2	Oct - 17	104.4	230	4
Nov - 15	88.8	183	2	Nov - 17	108.3	255	2
Dec - 15	147.7	324	2	Dec - 17	179.5	401	2
Jan - 16	154.8	334	1	Jan - 18	191.2	423	5
Feb - 16	148.0	351	2	Feb - 18	154.2	363	1
Mar-16	182.7	397	4	Mar - 18	171.5	395	2
Apr - 16	167.4	366	0	Apr - 18	202.1	417	3
May - 16	109.2	212	0	May - 18	107.3	222	1
Jun - 16	106.1	196	0	Jun - 18	100.2	198	2
Jul - 16	139.9	266	0	Jul -18	160.2	310	2
Aug - 16	214.3	399	1	Aug - 18	243.7	423	6
Sep - 16	140.3	282	4	Sep - 18	90.9	179	3

Oct-16	69.9	162	0	Oct-18	117.8	224	1
Nov-16	100.6	222	0	Nov-18	105.4	218	3
Dec-16	159.0	358	2	Dec-18	176.0	366	0

4.1 Scatter Plots

As the initial step of the analysis, monthly Main Wheel consumption was Scatter Plotted against the Aircraft Flying Time with main wheel consumption, aircraft flying time of the current month and previous month with main wheel consumption and aircraft flying time of the current month and previous two months with main wheel consumption (as shown in Figure 4.1) to see the correlation against the Aircraft Flying and Main Wheel consumption.





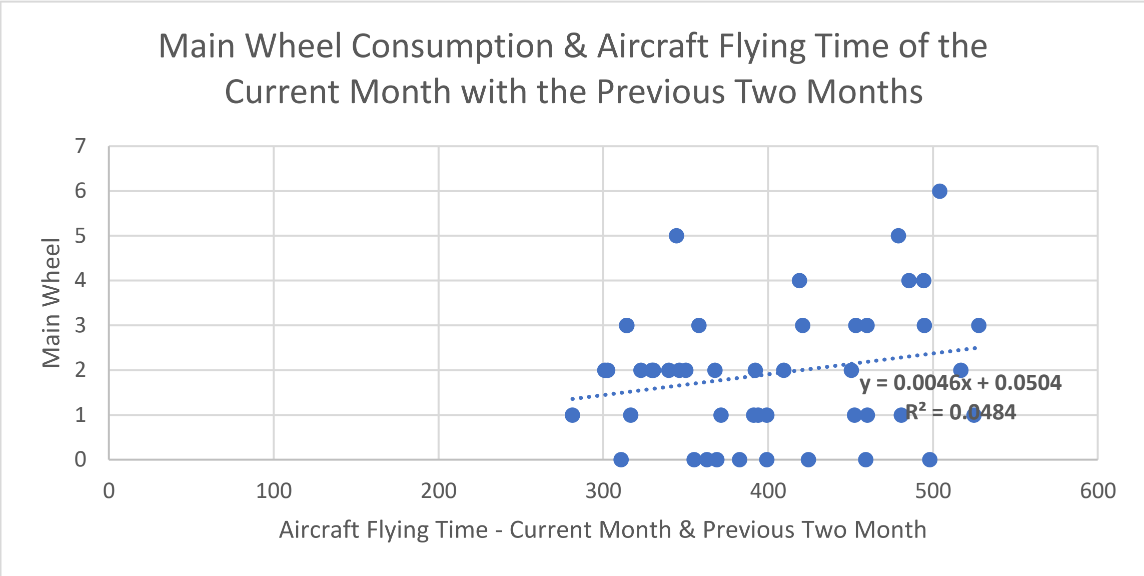
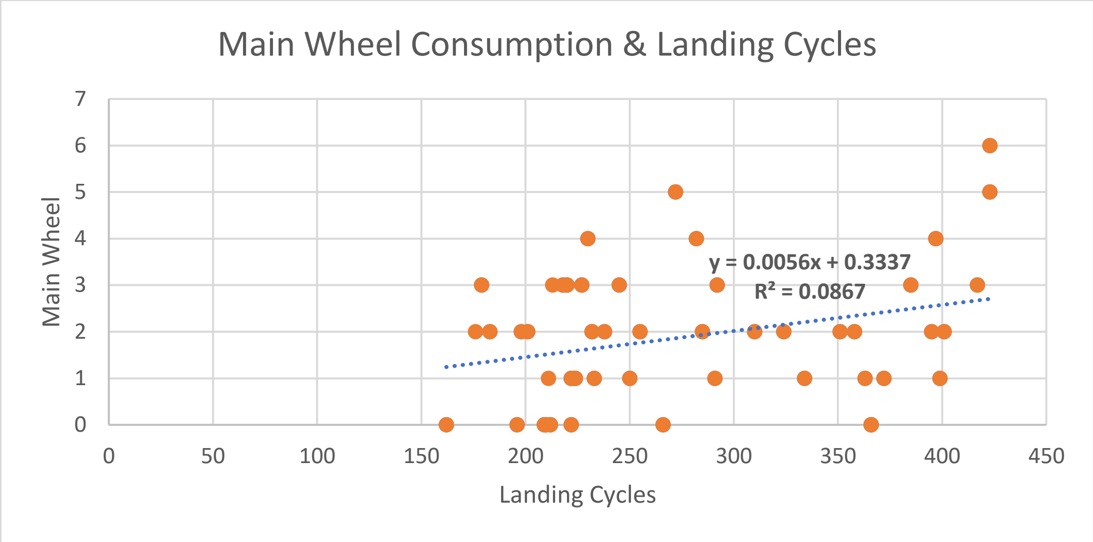
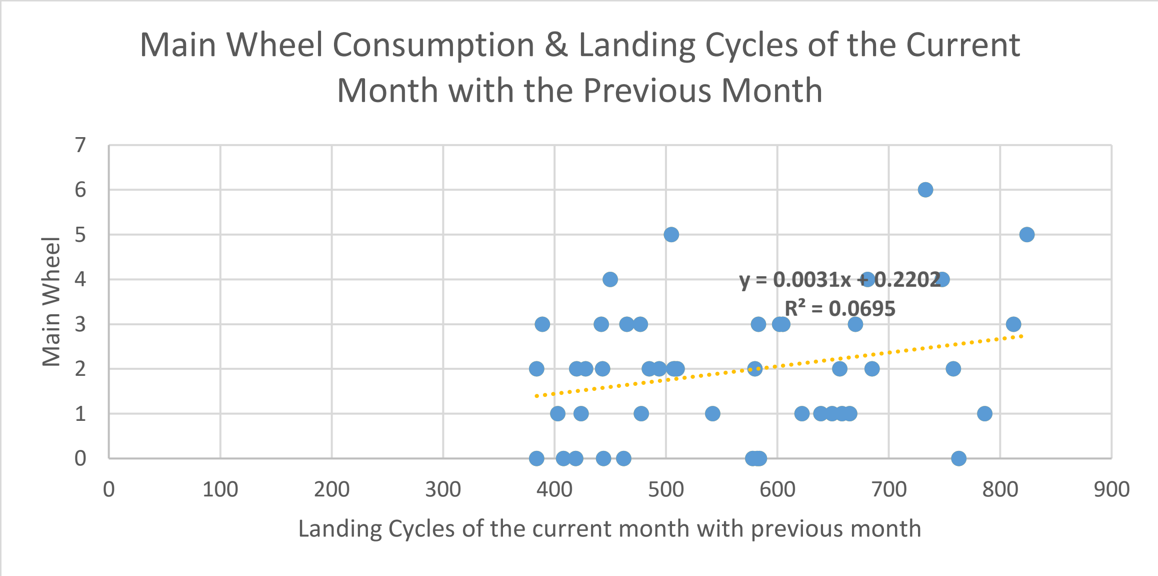


Figure 4.1: Main Wheel Consumption and Aircraft Flying Time

Then, to see the correlation between Landing Cycles and the Main Wheel consumption was scatter plotted. Monthly landing cycles with wheel consumption, current month landing cycles and previous month landing cycles with main wheel consumption and current month landing cycles and previous two (02) months landing cycles with main wheel consumption shown in Figure 4.2.


Main Wheel Consumption & Landing Cycles
Main Wheel
Landing Cycles
y = 0.0056x + 0.3337
R² = 0.0867
0
1
2
3
4
5
6
7
0
50
100
150
200
250
300
350
400
450


Main Wheel Consumption & Landing Cycles of the Current Month with the Previous Month
Main Wheel
Landing Cycles of the current month with previous month
y = 0.0031x + 0.2202
R² = 0.0695
0
1
2
3
4
5
6
7
0
100
200
300
400
500
600
700
800
900

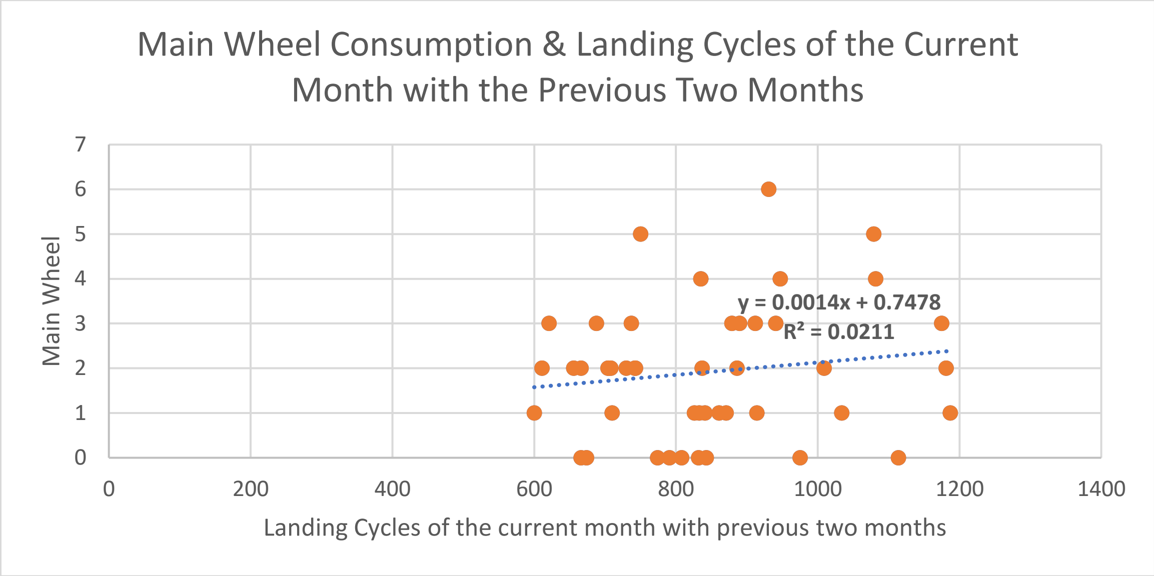


Figure 4.2: Aircraft Flying Time and Landing Cycles

By reviewing the above Scatter Plots, it is confirmed that the more correlation exists in between aircraft Main Wheel Consumption and Aircraft Flying Time. So that, further analysis was carried out on the aircraft flying time and aircraft Main Wheel consumption using linier regression.

4.2 Linier Regression Analysis

As the next step, the Linear Regression Analysis was carried out monthly Aircraft Flying Time and the Main Wheel consumption using Microsoft Excel and results are shown in the fowling Table 4.2, assuming that the Main Wheel consumption is normally distributed.

Table 4.2: Regression Analysis - Aircraft Flying Time & Main Wheel Consumption

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.322361
R Square	0.103917
Adjusted R Square	0.084437
Standard Error	1.401369
Observations	48

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	10.4761	10.4761	5.334511	0.025448
Residual	46	90.3364	1.963835		
Total	47	100.8125			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.324885	0.726914	0.446937	0.657018	-1.13832	1.788088	-1.13832	1.788088
X Variable 1	0.012104	0.005241	2.309656	0.025448	0.001555	0.022654	0.001555	0.022654

From the regression analysis results it's shown that the relationship is significant (0.025 < 0.05). Since the R^2 value is 0.1039, further analysis was carried out to see whether there is an improvement on the results by adding the previous month flying time to the current month flying time. Results are shown in the Table 4.3.

Results showing that by adding previous month flying time to the current month, relationship is still significant and also getting little improved (R^2 value get improved up to 0.1087. since the R^2 value is shown a lesser value nearly 10.39%, the dependant variable, which is Main Wheel Consumption is not entirely depending on the Aircraft

Flying Time. There may be other variables affect to the Main Wheel consumption which is not captured in this research.

Table 4.3: Regression Analysis - Previous Month Flying Time with Current Month Flying Time & Main Wheel Consumption

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.329707
R Square	0.108707
Adjusted R Square	0.0889
Standard Error	1.413034
Observations	47

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	10.95855	10.95855	5.488426	0.023624
Residual	45	89.84996	1.996666		
Total	46	100.8085			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.22839	0.946654	-0.24126	0.810451	-2.13505	1.678271	-2.13505	1.678271
X Variable 1	0.008118	0.003465	2.342739	0.023624	0.001139	0.015097	0.001139	0.015097

Further analysis was carried out using the quarterly aircraft flying time and quality aircraft Main Wheel consumption. regression analysis details shown in the Table 4.4.

Table 4.4: Regression Analysis - Quarterly Aircraft Flying Time and Quarterly Main Wheel Consumption

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.382536
R Square	0.146334
Adjusted R Square	0.085357
Standard Error	2.884343
Observations	16

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	19.96538	19.96538	2.399848	0.143652
Residual	14	116.4721	8.319437		
Total	15	136.4375			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.64236	4.228663	-0.15191	0.881428	-9.71194	8.427217	-9.71194	8.427217
X Variable 1	0.01615	0.010425	1.549144	0.143652	-0.00621	0.03851	-0.00621	0.03851

From the results it’s confirmed that the relationship is not significant (0.14 > 0.05). So that, further analysis was carried out with rolling aircraft flying time with previous month, previous two months and the respective rolling Main Wheel consumption. Results are summarised in the following Table 4.5.

Table 4.5: Regression Analysis Results - With Rolling Aircraft Time and Main Wheel Consumption

	Significance F Value	**Respective R^2 Value**
With previous month rolling	0.0288	0.1017
With previous two (02) months rolling	0.1276	0.0519

Even though the relationship is significant (0.0288 < 0.05) with the past month rolling Aircraft Flying Time and rolling Main Wheel consumption, there is no strong dependence on the aircraft flying time and the Main Wheel consumption, since R^2 value is 0.1017.

Considering all the outcomes of the above, it’s confirmed that relationship with the Aircraft Flying Time and Main Wheel consumption is significant. But the relationship may be a non linier relationship. So that, further analysis was carried out using Poisson Regression Analysis, since the Main Wheel is consist with count data.

4.3 Poisson Regression Analysis

Further analysis was carried out using Poisson Regression, which is used for the dependent variable which consists of 'count data' given one or more independent variables. Here, analysis was carried out based on the following assumptions.

- Dependent variable is consisting with count data, which is the Main Wheel consumption.
- One or more independent variable, which can be measured in continuous, ordinal, or nominal scale. All the cases Air Time related variable is acting as the independent variable, and it is continuous.
- Observations consist with independent observations, which means that each observation is independent of the other observations, one observation cannot provide any information on another observation. In all these cases observations are independent.
- The data distribution counts follow a Poisson distribution.
- The mean and the variation of this model are identical.

As the initial step, to see whether data set represented a Poisson distribution, one sample Kolmogorov-Smirnov test was carried out. Test results represented in Table 4.6.

Table 4.6: One-Sample Kolmogorov-Smirnov Test

		MainWheelAssy
N		48
Poisson Parameter[a,b]	Mean	1.94
Most Extreme Differences	Absolute	.043
	Positive	.043
	Negative	-.027
Kolmogorov-Smirnov Z		.301
Asymp. Sig. (2-tailed)		1.000

a. Test distribution is Poisson.

b. Calculated from data.

Since, Asymp. Sig = 1.000 it I proven that the data set is having a Poisson distribution. Then, Poisson Regression Analysis was carried in several cases, Air Time as the independent variable and Main Wheel consumption as the dependent variable. Analysis results presented in below Table 4.7.

Table 4.7: Poisson Regression Analysis Results

Case No	Description	Significant	Coefficient	P	Pearson Chi-Square
1	Monthly air time and Main Wheel consumption	Yes	1.006	0.024	0.992
2	Monthly air time with previous month air time and Main Wheel consumption	Yes	1.004	0.019	1.017
3	Monthly air time with previous two months air time and Main Wheel consumption	No	-	0.114	-
4	Monthly air time with previous three months air time and Main Wheel consumption	No	-	0.939	-
5	Quarterly air time with quarterly Main Wheel consumption	No	-	0.065	-
6	Monthly air time with previous month air time and Monthly Main Wheel consumption with previous month Main Wheel consumption rolling	Yes	1.003	.020	1.101
7	Monthly air time with previous two months air time and Monthly Main Wheel consumption with previous two months Main Wheel consumption rolling	No	-	0.084	-

Above seven (07) cases analysed using IBM SPSS Statics software and it is proven that the relationship is significant in the Case numbers 1, 2 and 3. Out of the significant cases, Case 1 relationship is having a good fitness. Case 1 results discussed in detail.

Case 1, which the Poisson Regression was carried out with the monthly Air Time and monthly Main Wheel consumption. Omnibus Test Results shown in Table 4.8.

Table 4.8: Omnibus Test Results

Omnibus Test[a]

Likelihood Ratio Chi-Square	df	Sig.
5.103	1	.024

Dependent Variable: Main_Wheel

Model: (Intercept), Air_Time

a. Compares the fitted model against the intercept-only model.

Results shown that the *p*-value of 0.024 (i.e. $p = 0.024$), indicating a statistically significant overall model. Next parameter estimation was carried out, and results shown in Table 4.9.

Table 4.9: Parameter Estimates Results

Parameter Estimates

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test			Exp(B)	95% Wald Confidence Interval for Exp(B)	
			Lower	Upper	Wald Chi-Square	df	Sig.		Lower	Upper
(Intercept)	-.130	.3686	-.852	.592	.124	1	.724	.878	.426	1.808
Air_Time	.006	.0025	.001	.011	5.359	1	.021	1.006	1.001	1.011
(Scale)	1[a]									

Dependent Variable: Main_Wheel

Model: (Intercept), Air_Time

a. Fixed at the displayed value.

Table 4.9 provides both the coefficient estimates shown in the 'B' column of the Poisson Regression and the exponentiated values of the coefficients shown in the 'Exp(B)' column. Here, the estimated coefficient value is 0.006. So that, when expected Main Wheel consumption is E, and Air Time is T;

$$\boldsymbol{E = e^{0.006T}}$$

Using above model, expected value calculated and results shown in the Table 4.10.

Table 4.10: Expected Main Wheel Consumption

Month	Air Time	Actual Main Wheel Consumption	Expected Main Wheel Consumption	Month	Flying Time	Actual Main Wheel Consumption	Expected Main Wheel Consumption
Jan-15	81.6	2	2	Jan-17	134.3	1	2
Feb-15	101.2	3	2	Feb-17	127.6	3	2
Mar-15	98.5	1	2	Mar-17	109.5	1	2
Apr-15	103.0	2	2	Apr-17	162.1	1	3
May-15	112.8	3	2	May-17	97.3	0	2
Jun-15	100.9	1	2	Jun-17	103.4	0	2
Jul-15	130.8	5	2	Jul-17	145.4	2	2
Aug-15	118.3	2	2	Aug-17	204.5	3	3
Sep-15	108.9	3	2	Sep-17	110.1	3	2
Oct-15	103.2	2	2	Oct-17	104.4	4	2
Nov-15	88.8	2	2	Nov-17	108.3	2	2
Dec-15	147.7	2	2	Dec-17	179.5	2	3
Jan-16	154.8	1	3	Jan-18	191.2	5	3
Feb-16	148.0	2	2	Feb-18	154.2	1	3
Mar-16	182.7	4	3	Mar-18	171.5	2	3
Apr-16	167.4	0	3	Apr-18	202.1	3	3
May-16	109.2	0	2	May-18	107.3	1	2
Jun-16	106.1	0	2	Jun-18	100.2	2	2
Jul-16	139.9	0	2	Jul-18	160.2	2	3
Aug-16	214.3	1	4	Aug-18	243.7	6	4
Sep-16	140.3	4	2	Sep-18	90.9	3	2
Oct-16	69.9	0	2	Oct-18	117.8	1	2
Nov-16	100.6	0	2	Nov-18	105.4	3	2
Dec-16	159.0	2	3	Dec-18	176.0	0	3

Then based on selected three (03) probability levels (50%, 70% and 90%), required Main Wheels Consumption Estimation Decision Model developed, which is shown in Table 4.11. As per the required aircraft availability and the probability level defined in the model, Aircraft Parts Store can maintain the required Main Wheel quantities.

Table 4.11: Main Wheel Consumption Estimation Decision Model

Forecasted Air Time for the Period	**Probability Level**		
	50%	**70%**	**90%**
10.0	0	1	2
20.0	0	1	2
30.0	0	1	2
40.0	0	1	2
50.0	0	1	2
60.0	0	1	2
70.0	0	1	2
80.0	0	1	2
90.0	1	1	3
100.0	1	1	3
110.0	1	2	3
120.0	1	2	3
130.0	1	2	3
140.0	1	2	4
150.0	1	2	4
160.0	1	2	4
170.0	2	3	4
180.0	2	3	4
190.0	2	3	5
200.0	2	3	5

If the cost of grounding the aircraft by not having required Main Wheel in the Aircraft Store is lesser than the cost of cancellation or delaying the flight, based on the decision model, required Main Wheels has to be maintained to avoiding the aircraft grounding times by not having a Main Wheel for replacement.

5. RECOMMENDATIONS & CONCLUSION

Firstly, with the linier regression analysis it is proven that the relationship between the Air Time and aircraft Main Wheel consumption is significant. Secondly, with the Poisson Regression analysis it is proven that there is a good fitness with the Air Time and the Main Wheel consumption.

Estimation was carried out and Decision Model was developed using Poisson Regression Analysis, that can be used as a decision tool for the small air operators such as domestic air operators in Sri Lanka for their consumption prediction, rather doing a rough estimation without any scientific backing.

There may be other factors, which haven't captured in this research, such as pilot behaviour on the aircraft landing, take off and taxing, runway surface condition, age of the tires used for the Main Wheels, aircraft operating payload, etc. Further research can be carried out by integrating the above factors.

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