IMPACT OF
INFORMATION AND COMMUNICATION
ON
SPARE PARTS DELIVERY LEAD TIME
DURING AOG SITUATION
IN AVIATION INDUSTRY

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Research submitted in partial fulfilment of the requirements for the degree of Master of Business Administration in Supply Chain Management

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March 2018

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ABSTRACT

This research is carried out to study the **impact of information and communication on delivery lead time of aircraft spare parts during aircraft on ground (AOG) situation in aviation industry.** The industry operating cost is very high and includes labour, fuel, aircraft maintenance, spare parts and equipment, licensing, crew training, insurance and airport landing and parking fees. In addition to these costs, a very high cost causes to the operator when a scheduled flight cancelled and ground the aircraft due to a technical failure that emerge suddenly. Then the operator faces a challenge of supplying the required spare parts immediately to repair the aircraft and thereby spare parts delivery lead time becomes very critical in aviation supply chain management.

The problems that airline operators face with aircraft maintenance are; High cost of spare parts and life limited items are made to order with delivery lead time, Spares supply connect with multiple suppliers, Quality and safety conformity requirements, Regulatory obligations for transport/export/import, High dependency on logistics mode for transportation and Delivery lead time. Treuner during his survey on aviation and aerospace industry supply chain behavior has found that aviation industry supply chains are becoming more vulnerable than ever before due to globalization and complexity. He identifies main causes for the supply chain disruption are as resource constraints, communication and quality issue followed by suppliers and forwarders inefficiencies. (“Aviation and aerospace supply chains move eastwards,” n.d.). This lead to an industrial need to study the impact of communication flow on delivery lead time in supply chain management among other factors.

Previous research on impact of communication flow on delivery lead time could not find during the literature survey and identified the research gap need to fulfil for the industry. This research studies the flow of communication and information across the supply chain and their impact on spare parts delivery lead time at AOG situation under specific focus where the spare parts need to be procured and supplied and not found in stock inventory at the time AOG. The data was collected with respect to a small scale international air cargo operator in Sri Lanka. Learned experiences can be share with similar small-scale airline operators for the improvements in their supply chain management.

Chapter outline of this research includes, introduction to the industry, literature survey on communication and information sharing impact on delivery lead time in supply chain, research methodology, data analysis, results and observations and conclusion and recommendations.

Due to the complex nature of supply chain network and uncertainty involved in delivery lead time, PERT statistical tool was used as the research methodology. The research outcome identified the sequence of communication flow in the procurement process and the critical activities involved. It also shows that procurement process has four major time constraints that occur at external stakeholders in the upstream of the supply chain and has limited control to the operator; time taken for receiving quote from a supplier and order confirmation, payment to effect at supplier's bank, logistics arrangement and transportation. Handling of logistics and transport is complex and involved high risk of changes in flight schedules and cargo offloading which results in delivery delays. It was identified that activities most likely to make errors in communication are identification of correct part number by the engineer, communicating the part number to procurement, communication across supplier network to find the identical part number and communication between forwarder, airline and shipper on shipping instructions. Most common errors found are wrong part number or incomplete part number, supplier ship different part number instead the purchased part number, goods ship to different location without following delivery instructions and short deliveries.

Propose to re-structure the procurement process internal communications such that waiting time for internal response minimized by minimizing non-value activities and serial communications. Instead serial communication, parallel communications and use of ICT technology such as cloud computing systems are encouraged to use during approval obtaining and decision-making activities.

Key words: Information and communication, aircraft spare parts, delivery lead time, AOG situation, aviation procurement supply chain

ACKNOWLEDGEMENT

I am most grateful to my supervisor, Dr Varuna Adikariwattage, Senior Supervisor, Department of Transport and Logistics Management, University of Moratuwa for the guidance and support extended during my research. I also express my gratitude to Mr Chamath Nalaka, Research Assistant, Department of Transport and Logistics Management, University of Moratuwa for helping with data analysis and type setting, Course Director, Prof. Amal Kumarage and Research Coordinator Dr. Y M M S Bandara, Department of Transport and Logistics, University of Moratuwa for giving their generous support whenever needed.

I take this opportunity to thank Dr (Mrs) Chamini Kanatiwela de Silva, Clinical Trials Unit, Faculty of Medicine, University of Kelaniya for review the dissertation and valuable comments made for the improvements.

My special thanks go to Capt Mohamed Ameen, Flight Safety Expert, Bhutan Civil Aviation Authority and Mr Suranga Palliyaguruge, Head, Client Acquisition at Standard Chartered Bank for the pains taken to proof read this dissertation.

From bottom of my heart I thank the management of Fits Aviation Pvt Ltd, my employer who encouraged me for continuing higher studies and grant permission to use non-sensitive procurement related data wherever necessary for the case analysis.

Last, but not least I want to thank my parents, all friends and relatives not mentioned individually but who helped, encouraged and assist me in one way or other to complete this exercise satisfactorily.

LIST OF ACRONYMS

AOG	- Aircraft on Ground
AON	- Activity on Node
CAA	- Civil Aviation Authority
CASA	- Civil Aviation Safety Authority, Australia
CPM	- Critical Path Method
DHL	- Deutsche Post, (Dalsey Hillblom Lynn) Logistics Company
EASA	- European Aviation Safety Agency
EF	- Early Finish Time
ERP	- Enterprise Resource Planning
ES	- Early Start Time
ET	- Expected Time /Best Estimated Time
FAA	- Federal Aviation Administration
HAECO	- Hong Kong Aircraft Engineering Company Limited
IATA	– International Air Transport Association
ICAO	- International Civil Aviation Organization
ICT	- Information and Communication Technology
IPC	- Illustrated Parts Catalogue
IS	- Information Systems
JACAB	- Japan Civil Aviation Bureau
JIT	- Just in Time
LF	- Late Finish Time

LS	- Late Start Time
MRO	- Maintenance Repair Organization
MRP	- Material Requirement Planning
OEM	- Original Equipment Manufacturer
PERT	- Programme Evaluation Review Technique
POS	- Point of Sales
RFID	- Radio Frequency Identification Device
S	- Slack Time
SCM	- Supply Chain Management
SCOR	- Supply Chain Operating Reference
SME	- Small and Medium Enterprises
UPS	- United Parcel Services Inc, United States of America

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1 Introduction

1.1 Background

1.1.1 Aviation Industry

It involves air transportation of passengers and cargo around the world. Aviation industry is capital intensive and labour intensive. It involves high cash flow but, low profits. The demand is seasonal. Sustainability of aviation industry depends on the operating costs, government policies, economic factors and competition within the industry. Air transport needs substantial investment in infrastructure such as runways, air traffic control systems and airport terminals. It is further explained in Figure 1.1.

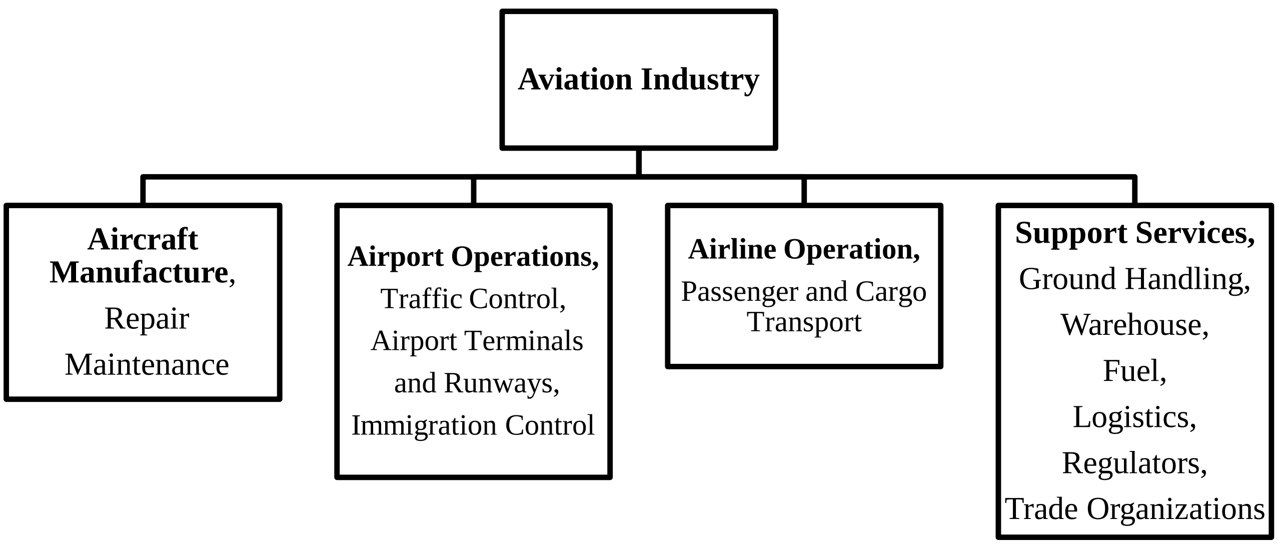


Figure 1.1 : Aviation Industry Classification

There are many economic and social benefits in air transport. According to IATA statistics, aviation industry supported more than 62.7 million jobs globally and generation of USD 2.7 trillion economic activities in 2014. Air transportation drives economic and social growth, connects people, countries and cultures, generates trade and tourism, provides access to global markets and contributes to sustainable development of the industry. Aviation further facilitates emergency delivery of medical supplies, organs for transplant and humanitarian aid relief which are essential for the livelihood. In 2014, approx. 3.6 billion passengers and 51.2 million tons of cargo had air transported across the world. (Benefits, Transport, & Findings, 2017). Air transportation can be international, regional or domestic.

Airlines have three types of aircraft. Passenger aircraft for dedicated passenger transport, freighter aircraft for dedicated cargo transport and combi aircraft for both passengers and cargo transport. Boeing and Airbus are the leading aircraft manufacturers in the world. They supply majority of commercial aircraft to the industry.

The industry has high operating costs including labour, fuel, aircraft maintenance, spare parts and equipment, licensing, crew training, insurance and airport landing and parking fees. Aircraft maintenance cost and aircraft on ground (AOG) cost are two critical factors that affect the revenue of the airline. Aircraft maintenance cost increases with AOG cost and as a result the delivery lead time of spare parts has a direct contribution to the AOG cost.

If an aircraft stay on ground due a technical failure, it has to be repaired immediately. Sometimes, required spare part could not be found at operators' spare parts inventory and need to be purchased and supplied. Therefore delivery lead time of spare parts is very critical in aviation industry and must kept duration at minimum. For this it is necessary to understand the variables that influence the delivery lead time and control them.

1.1.2 Aircraft Maintenance

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

i. Regular, scheduled maintenance
    - Line checks before flight and after flight
    - Periodical checks such as A check, B check, C check and D check

ii. Emergency, unscheduled maintenance.
    - Ad hoc repairs attended during pre-flight and post-flight inspections

- Aircraft On Ground (AOG) when critical part failed in airworthiness

Table 1.1 : Regular Maintenance Checks Carried Out for Aircraft (Source - Eurocotnrol by University of Westminister)

Check	Location	Description	Duration
Line	At gate	Daily (before the first flight or when in transit). Visual inspection; fluid levels; tires and brakes; emergency equipment	~1 hour
A	At gate	Routine light maintenance; engine inspection	~10 hours
B	At gate	Similar to A check but with different tasks (may occur between consecutive A checks)	~10 hours to ~1 day
C	Hangar	Structural inspection of airframe, opening access panels; routine and nonroutine maintenance; run-in tests	~3 days to ~1 week
D	Hangar	Major structural inspection of the airframe after paint removal; engines, landing gear, and flaps removed; instruments, electronic and electrical equipment removed; interior fittings removed; hydraulic and pneumatic components removed	~1 month

Scheduled maintenance checks are for ensuring continuous airworthiness and availability of aircraft for operation. These maintenance programmes inspect and repair airframes, engines and electronic systems as per manufacturer's operating manual. Components that require replacement are ordered in advance and received at maintenance site prior commencing the maintenance check.

Unscheduled, sudden emergency maintenance programmes are to fix a technical failure found in an operating aircraft. If the required component not found in the inventory, aircraft make ground until the repair attended. This is called aircraft on ground (AOG) and is a critical situation. It requires all efforts to make aircraft airworthy within the shortest possible time and continue operation. Therefore, delivery lead time is a critical factor in spare parts supply for an aircraft on ground.

If there is a delay in supply of spare parts, aircraft can be on ground for days or weeks. Then required to cancel scheduled flights, transfer cargo and passengers to another flight and crew will be idled until aircraft turn airworthy. This situation creates a huge cost to the operator. AOG cost to the operator includes flight cancellation or delay penalties to the airline, ground service charges for airports, parking fees for airports, payments to crew, loss of revenue, cost of the spare part and AOG logistics arrangements.

According to Skylink blog of Irfan Alam, when a small aircraft on ground, AOG cost will be more than USD 20,000 per day. It can be as high as USD 150,000 per day for larger aircraft. Further, AOG situation leads dissatisfaction to the customer and costs to the operator. ("How to Handle AOGs: An Airline's Perspective — Skylink," n.d.)

1.1.3 Classification of Aircraft Parts

Aircraft parts classify differently based on the purpose. (Systems, 2014)

International Air Transport Association inventory management classifies spare parts into 3 major categories and this is the generalized classification of aircraft spare parts. This classification is based on the repair and reuse capability. (IATA, 2015)

i. Rotables – have component maintenance manual
ii. Repairable – may not have component maintenance manual.
iii. Expendables – have manufacturer recommend parts list

Depend on the essentiality, same aircraft parts are grouped into 3 categories by the aircraft manufacturer; (Systems, 2014)

i. No Go – cannot fly without replacing the defective part. Critical and leads to AOG situations if part is not available in the inventory
ii. Go if – conditional operation, limited distance/hrs until the defective part is replaced
iii. Go – not critical but needs replacement during next maintenance check

Table 1.2 gives description of different types of classification adopted in aviation in classifying aircraft spare parts.

Table 1.2 : Aircraft Parts Classification (Source - Ramco Aircraft Parts Planning)

Classification Type	Classification	Usage in Material Planning
Spare Parts Class (SPC)	1- Expendable 2- Rotable 6- Repairable	• Ascertaining financial treatment to capitalize or to treat as inventory. • Setting up the scrap policies
Essentiality Code (ESS)	1- No-Go 2- Go-If 6- Go	• Ascertaining the quantity of spares to be positioned at the Line Stations • Entering into Pool Agreements through IATP or bilaterally
Restrictive Operations	• ETOPS • RVSM • Cargo	• Ascertaining the quantity of spares to be positioned at the Line Stations supporting restrictive operations
Regulatory Control	• HAZMAT • Electrostatic • Customs Bonded	• Ensuring regulatory compliance while receiving, transporting , moving, handling, stocking and exporting
Physical Nature	• Shelf Life	• Monitoring and disposing off the expired items • Monitoring and recertifying the Shelf life extendable items
Replacement Type	• SRU • LRU	• Ascertaining the spares to be positioned at the Line Stations

In aviation industry, aircraft maintenance is highly regulated for the safety reasons. Therefore, all aircraft spare parts need to be certified to be airworthy for use and all aircraft spare parts are purchased with airworthiness certificates. ICAO (International Civil Aviation Organization) sets global standards for aircraft maintenance and regulations are implemented through regional or national bodies such as FAA (Federal Aviation Administration) USA, EASA (European Aviation Safety Agency) Europe, CASA (Civil Aviation Safety Authority) Australia and JCAB (Civil Aviation Bureau of Japan). (Saúde, 2015). Some occasions OEM (Original Equipment Manufacturer) issues airworthiness compliance certificates. E.g. Nuts and Bolts, aviation lubricants, tires etc. have manufacturer certification. Therefore, during aircraft spare parts procurement, tag date and certification are essential criterion to check for quality and safety compliances.

Aircraft spare parts are identified by the manufacturer code and serial number. Manufacturer part number, its alternative part number and interchangeable relationships are described in IPC (illustrated parts catalogue) and maintenance manuals. It is vital to communicate the correct part number during maintenance and procurement activities to avoid inefficiencies in the downstream due to errors in the part number.

All international airlines and regional airlines maintain a stock of minimum essential components and tools at their base hub and few other maintenance hubs in frequent flying routes for the fleet maintenance. For example, American Airline has its maintenance bases at Tulsa International Airport, Dallas/Fort worth International Airport, Pittsburgh International Airport and LaGuardia Airport. (Baker, 2014). Similarly, Lufthansa airline has hubs at Frankfurt and Munich airports (Europe et al., 2010).

It is challenging to procure spare parts when aircraft on ground because, the part on demand need to be the same or interchangeable, conform to the aviation quality and safety norms and supply within a short delivery time.

1.1.4 Aircraft Parts Availability

Aircraft spare parts are quite expensive and “type” specific. They are manufactured and supplied to the aircraft assembly point from various original equipment manufacturers (OEM) located worldwide. Each OEM is specialized for one particular component and service area. As a result, spare parts supply chain is highly complex and has many suppliers connected to the supply chain. In some cases, suppliers’ connectivity extends to 3rd or 4th tier suppliers. Many aircraft parts are made-to-order and have a delivery lead time.

Involvement of many suppliers in component manufacture and their geographical locations across the world are well illustrated in figure 1.2 with Boeing 787 Dreamliner aircraft parts supply. (“Supply Chain Management: Boeing’s outsourcing flaws,” n.d.). This shows the interdependency of supplier and manufacturers and complexity of the Boeing aircraft manufacture supply chain.

Similarly, Boeing 747-8 aircraft manufactured in 2012, has approximately 6 million individual components and they are manufactured in nearly 30 countries by 550 separate suppliers. Airbus's A400M military transport aircraft has component production in nearly 10 countries. (Mayer, 2014)

It is critical to have support from each and every supplier for an aircraft to successfully and timely assemble and deliver. Therefore aviation supply chain need to be managed efficiently and effectively.

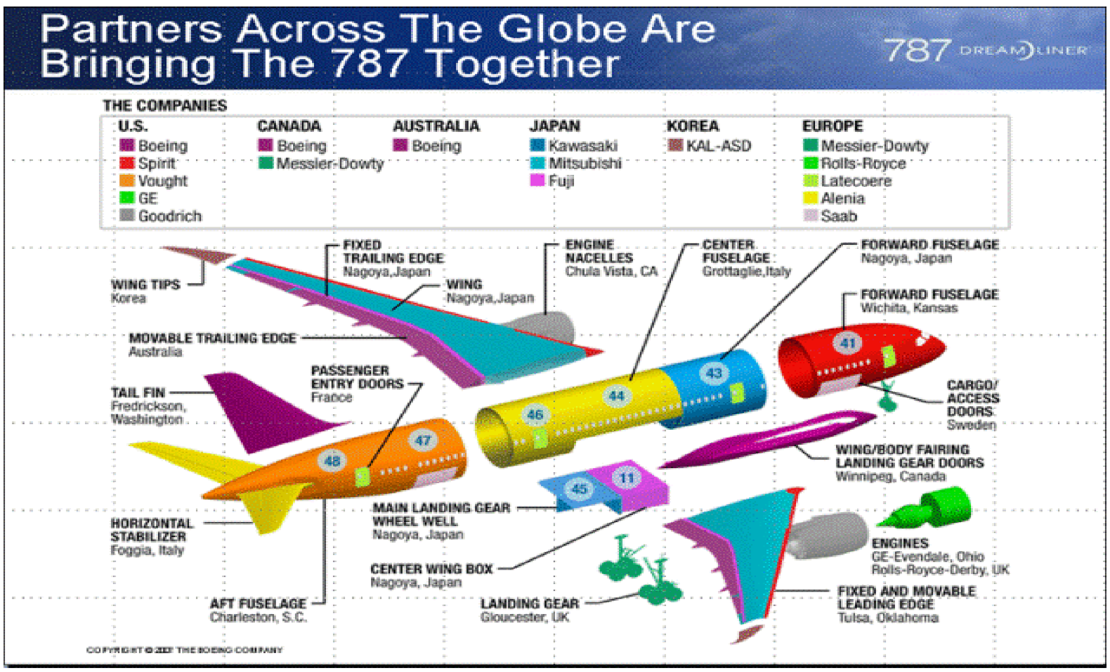


Figure 1.2 : Boeing Partners across the Globe for Parts Supply (Source -Boeing's Outsourcing Flaws, 2013)

Supply chain management becomes a prime requirement in aviation industry due to

- Globalization of suppliers
- Compliance requirements
- Technological advancements
- Necessity of effective communication and coordination

Raza (2015) shows the importance of understanding the processes and concepts of supply chain management to know, how the system support the organization sustainability, development and global expansion. Three crucial flows in the supply chain are; flow of information, finance and products across the chain from upstream to downstream to fulfil customer requirements.

Raza identifies 4 main entities in aviation industry. They are

- Demand entity – passengers, travel agents, owners and shippers of cargo, forwarding agents etc.
- Supply entity – airport, ground handling services, regulators, aircraft manufacturers
- Inside entity – government and political organizations
- Outside entity – climate, geographical locations

These entities influence each other and to run aviation system smoothly, each entity should collaborate with each other.

Airline industry is unique with 4 market characters. (Gu, Zhang, & Li, 2015)

- Global need for parts
- Demand unpredictability
- Traceability of parts for safety reasons
- High cost of not having parts (AOG situation)

This characterization, well describes the key challenges that to be addressed in aviation supply chain management.

“PWC” white paper shows that, successful spare parts planning and forecasting needs more effective collaboration and sharing of information across the supply chain. It has identified that key information that necessary to share across the supply chain are; fleet data, engineering change orders, parts reliability, service bulletins, demand aggregation, spares planning bill of material, software, monthly sales, inventory, operations planning and procurement release time fences. (Unknown et al., 2013)

Delivery lead time of aircraft spare parts is a critical factor to avoid aircraft on ground situation. As a mitigation step, major airlines sign contracts with maintenance repair organizations (MRO) and transfer the responsibility to MRO for holding stocks, carrying out repair maintenance services and provide technical assistance as and when required. These service contracts help airlines to have access to spare parts and repair activities within a short time and in turn manage to keep the aircraft's airworthiness turnaround time at a minimum. E.g. Delta Airline, Southwest Airlines, Qatar Airways and Cathay Pacific have service contracts with MRO facilities such as Delta TecOps, Lufthansa Technik and Hong Kong Aircraft Engineering Co Ltd. ("Aircraft MRO & Engine Maintenance Repair & Overhaul Engineering Services | Delta TechOps," n.d.) ("Lufthansa Technik - Lufthansa Technik AG," n.d.)

Spare parts pooling is another popular method adopted in aviation to increase accessibility for spare parts and reduce delivery lead time. Component pooling is a successful system for airlines which hold similar types of aircraft in the fleet. In the pool inventory management system, MRO will maintain the inventory of minimum equipment list of spare parts and other components which are frequently demanded for exchange or purchase for aircraft repair maintenance. Spare parts pooling system facilitates, supply of spares on time for aircraft repair, reduce the risk of aircraft ground due to non-availability of critical components, avoid delivery delays and reduce the inventory holding cost. This is called vendor managed inventory system in supply chain management. ("Aircraft Spare Parts Pooling: Art Or Science?," n.d.)

Airlines also enter into contracts and partnerships to get the optimum services at minimal cost. Alliances help sharing of resources among airlines. As a result, during an emergency, airlines have an opportunity to borrow spare parts from another airline that has similar type of aircraft in the fleet and minimize risk of aircraft on ground due to non-availability of spare parts. E.g. Lufthansa Technik has set up "Aero-Xchange" market place, an airline industry online trading exchange that offers industry specific goods and services for Star Alliance partners. (Sigala, 2005)

Aircraft manufacturers such as Boeing and Airbus enter into contracts with suppliers for their components design, manufacture and delivery in order to manage their supply chains. E.g. Airbus have service contracts with Zodiac, Thales Avionics, Diehl Air Cabins, Crane Aerospace and Siemens for design, manufacture and supply of spare parts, components and interiors for Airbus aircraft types. (Airbus, 2015). This is one of the new trends in managing aircraft manufacture supply chain efficiently with a low operating cost. (Tang, Zimmerman, & Nelson, 2009)

Aircraft manufacture also emphasis the criticalness of delivery lead time of spare parts for aircraft assembly enable delivering the aircraft to the airline on agreed date.

Small airline operators are more vulnerable to situations where aircraft is on ground for longer period of time until required spare parts are supplied. Sometimes the operator might have to wait until the components are repaired and receive at stores. Small airlines have less bargaining power with suppliers. Direct access to MRO is limited due to little revenue the supplier can generate by working with small airlines. As a result, access to correct spare part on emergency situation becomes limited and expensive. Small airline operators often depend on service of an intermediate broker or MRO nominated workshops. Therefore, small airline operators need to find ways to manage the risk of spare parts availability at an AOG situation to avoid spare parts delivery delays. One of the strategies is to have PBH (parts by the hour) contracts with MRO nominated workshops located nearby the airline base hub.

Experience shows that delivery lead time of aircraft spares depends on many factors. They are effective communication, right information sharing, availability of correct spare part, geographical location, transport connectivity, international regulations and efficiency of the suppliers and forwarders.

The highest attention in aviation industry is to avoid aircraft on ground. Therefore, it is essential to have faster delivery modes and free access to spare parts.

Problems that airline operators face with aircraft maintenance are;

- High cost of spare parts and life limited items are made to order
- Spares supply connect with multiple suppliers
- Quality and safety conformity requirements
- Regulatory obligations for transport/export/import
- High dependency on logistics mode for transportation
- Delivery lead time

This report will discuss the impact of communication errors on delivery lead time of spare parts at AOG situation in aviation industry under the sub headings

Chapter 1 – Introduction

Chapter 2 – Literature Review

Chapter 3 – Research Methodology

Chapter 4 – Data Analysis and Observations

Chapter 5 – Discussion of Results

Chapter 6 – Conclusion and Recommendations

1.2 Statement of the problem

Aircraft are operated on published scheduled times. If an aircraft is found with a technical fault, scheduled flight needs to be canceled or delayed until the problem is fixed. Then the aircraft remain on ground. This is an unexpected technical failure and affects the flight operation. For this emergency repair, it needs access to spare parts immediately. If the required spare parts are not found in the inventory, it has to be purchased and supplied.

Supplying aircraft spare parts under AOG situation is a challenge due to;

- Quality and safety conformity requirements to be fulfilled for airworthiness
- Limited accessibility for made to order and life limit components
- High cost to the operator
- Unpredictable nature of logistics and transport facilitators
- Global distribution of spare parts
- International transport regulations
- Customs formalities and documentation

As a result, supply of spare parts will have a delivery lead time all the time and managing this lead time is essential for an AOG situation.

Communication plays a key role in procurement process and timely communication of correct information across the supply chain among the airline operator, suppliers and carriers, is very important to understand in order to plan the shortest possible delivery lead time.

Aviation industry records major losses to aircraft manufacturers due to the interruptions occurred in their supply chain. E.g.

1. Boeing made loss in billions due to delay in delivering aircraft spares on time for assembling Boeing 787 new design. (Denning, 2013)
2. Airbus experienced similar situation with Airbus customers due to delay in supply of
    a. Groundbreaking Pratt &Whitney-geared turbofan engine for A329 neo single aisle aircraft
    b. Cabin equipment from Zodiac of France for A350 twin-aisle model. ("Airbus and Boeing put pressure on supply chain," n.d.)

Treuner, Hubner and Baur share their survey findings on aviation and aerospace industry supply chain behaviour. ("Aviation and aerospace supply chains move eastwards," n.d.)

- Aviation and aerospace industry supply chains have become global, highly complex and more vulnerable to disruptions than ever before
- Main causes for the supply chain disruptions are resource constraints, communication and quality issues followed by suppliers' insolvency and environmental events

Therefore, it is an industrial need to explore the impact of communication flow on delivery lead time among other factors.

Previous studies on aviation spare parts delivery lead time management was not found during the literature survey. Instead, came across research that have introduced various aircraft spare parts inventory management models to minimize AOG situations.

- Model with predicts the impending demand of spare parts based on the installed parts failure distribution against the flying hours or number of landings (Gu et al., 2015)
- Dynamic prediction model as a preventive maintenance action (Fritzsche & Lasch, 2012)

There is a research gap in studies on impact of communication errors on spare parts delivery lead time in aviation industry.

Hence, my research problem of study is "***Impact of information and communication flow on spare parts delivery lead time at AOG situations in aviation supply chain".***

1.3 Research Objectives

The research objectives are to map the communication network in aviation spare parts procurement process and identify the critical links in communication network. Then

- To identify the sources of communication errors within critical components of the communication flow
- To determine an order of priority among the key factors causing communication errors.

1.4 Scope of the Research

Topic in focus – Impact of information and communication on the spare parts delivery lead time at AOG situation in aviation industry.

The area in focus – In this research, flow of communication and information across the supply chain and impact of communication errors on the spare parts delivery lead time at AOG situation were studied. Specific focus is given on the supply chain of parts need to be procured that are not available in the airline inventory at the time AOG.

The study was carried out in view of improving the supply chain performance and thereby, reduce the operational cost to the operator.

Data collection – Data was collected with respect to a small scale international cargo airline operator in Sri Lanka.
Internal stakeholders – employees
External stakeholders – suppliers, forwarders, airlines, regulatory bodies

1.5 Limitations of the Research

Research is focused on the information and communication flow across the supply chain during AOG situation and its impact for the delivery lead time.

Assumptions made are;

1. All suppliers are equally capable and efficient in spare parts supply
2. Purchase spare parts at market price, not bargained for AOG situations
3. Spare parts conformed to the quality and safety requirements
4. Information transfer happens instantaneously
5. Spares purchased from farthest locations such as North America

The data collected for the research is based on the small-scale cargo airline. Thus, data collected will be limited to the type of fleet and operations involved in the above context.

Opportunity to study aviation supply chain practices for replenishing orders and spares demand for scheduled maintenance are restricted. But, it can be carried out in future as an extension of the research for performance improvement in aviation supply chain management.

1.6 Significance of the Study

Aviation is time bound service industry. Lead time is important in aviation in all aspects. Passenger transport, cargo transport, delivery of new aircraft, fleet management and receive spares after repair maintenance. In aviation industry, it is essential to avoid occasions of an aircraft on ground due to technical failure.

Operating an airline is high capital intensive and small operators run business with many difficulties such as;

- Lack of economies of scale in fleet management
- Old aircraft difficult to find spare parts, some modified aircraft components are obsolete and have maintenance difficulties
- Hanger and airport facilities to be rented on demand
- Lack of government support for private operators

Research findings will be important for any airline to improve efficiency of communication between supplier and customer to reduce supply chain interruptions.

When identify the best methods of information sharing during procurement, we can reduce the time taken for order processing as well as order delivery. If supplier understands the product requirement of the customer correctly within the 1^{st} email communication of RFQ then, order can be finalized in next communication. This will save time for both vendor and buyer. If logistical information is clearly understood, forwarder can ship the goods earlier and meet the delivery deadlines without a difficulty.

This research will be done for the benefit of a small-scale cargo airline operator to reduce operational expenses due to spare parts delivery delays due to AOG situation. Learned experience can be shared with similar small-scale airline operators for improvements in their supply chain.

Since there were no literature survey found on impact of communication errors in delivery lead time of aircraft spare parts, this research study will be able to fill that knowledge gap.

2 Literature Review

This chapter discusses the impact of information and communication on the delivery lead time in supply chain management. Literature was reviewed under

I. **SME (small and medium enterprises) operational performance, manufacturing and retail supply chain inventory management**
   - Impact of information and communication on principal – agent setup in SCM
   - Value of information sharing on inventory management
   - Types of information required for sharing
   - Communication through information sharing

II. **Application of advanced information and communication technology in medical supplies as emergency logistics solutions**
   - RFID technology for real time data access in inventory management
   - Charter airline service for blood, organ and vaccines transport
   - Drones used to deliver medicines for remote, difficult to access areas

III. **Aviation industry spare parts procurement and inventory management systems used to minimize AOG risk**
   - Factors influencing supply chain management
   - Inventory management models
   - Collaborative supply chain management
   - E-procurement
   - Contribution from 3D printing technology

Findings from scholar articles and case studies are listed under this section.

Since the research methodology is based on PERT analysis, PERT statistical tool and its application in finding the critical path, estimating project lead time and optimization of supply chain processes are also discussed here.

Findings of literature review has be taken as guidelines for designing my research project.

2.1 Supply Chain Management in General

Tatoglu and his team provide a comparative analysis of the impact of supply chain management and information systems practices on operational performance of small and medium sized enterprises operating in Turkey and Bulgaria. They empirically identify the dimensions of SCM and IS practices and related enabling and inhibiting factors. Then using multiple regression analysis to estimate the impact of SCM-IS practices on operational performance of SME. (E Tatoglu, Bayraktar, Golgeci, & Koh, 2016)

They measured mean, standard deviation and t-value of variables. Variables are classified into groups under SCM practices, IS practices, enablers and inhibitors. Variables include; close partnership with customers and suppliers, E procurement, MRP and ERP systems, financial support, infrastructure, delivery lead time, forecasting and extent of support from suppliers.

Research findings shows that;

1. Effectiveness of implementation of SCM-IS practices depends of infrastructure facilities
2. SCM and IS practices are inextricably intertwined, thus need integrative approach for SCM and IS practices
3. Use of IS applications improve operational performance and help building closer partnership among customers and suppliers.

Fiala (Fiala, 2005) describes supply chain as a system that consists of suppliers, manufacturers, distributors, retailers and customers where they are interconnected by flow of material, finance, information and decisions. He further says supply chain management benefits from several different disciplines such as marketing, information systems, economics, system dynamics, logistics, operations management and operations research. Supply chain partnership leads increase in information flow, reduce uncertainty and growth in profits.

Figure 2.1 explains the information sharing model proposed by Fiala for communication between manufacturers and retailers. Information asymmetry is identified as a source of inefficiency in the supply chain. This model consists of three inter-related network structures; production net, Petri net and neutral net. Production net captures information flows among agents. Petri net coordinates asynchronous events in the production network. Neutral net serves as an instrument for inductive learning.

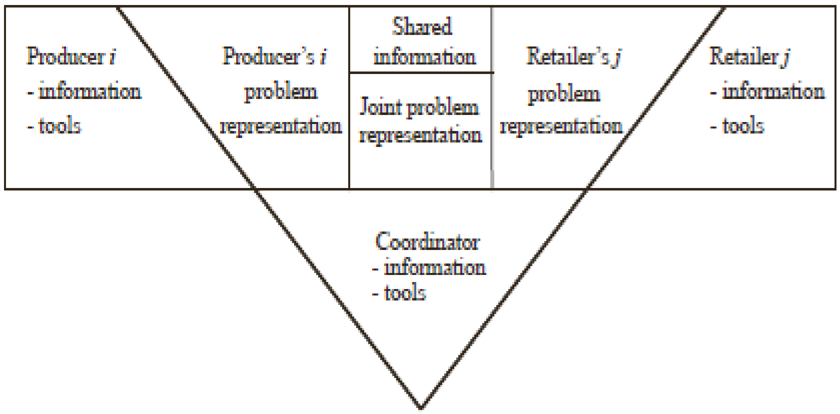


Figure 2.1 : Communication through information sharing (Source: P Fiala/Omega 33 (2005))

As per the model, two phase interactive approach helps solving cooperative decision making. For solving cooperative decision-making problem needs to find ideal solution for individual agent and find the consensus for all the agents. Free communication among agents give synergic effect in a conflict resolution. The model shows the importance of information sharing in problem solving and finding a consensus solution for all the agents.

Cachon and Fisher (Cachon & Fisher, 2000) reveal their study on the supply chain inventory management and the value of shared information. When applying information technology to logistics and inventory management, they have found substantial savings from lead time and batch size reduction. However, the study could not find much benefit from sharing full information of retailer's demand with supplier. This study was carried out for retailer market and demand information has little value to supplier in deciding his batch size in production. Information were shared only at two levels; traditional information and full information. Traditional information shared with supplier could only receive retailers' orders where as full information shared with supplier has access to the retailers' inventory data.

Lee (H. Lee, So, & Tang, 2000) in his analysis of value in information sharing identifies three benefits to the manufacturer; reduction in cost, inventory and lead time. Successful stories of information shared in vendor managed inventory programmes or continuous replenishment programmes found in companies such as Campbell Soup and Barilla S.P.A. Replenishing orders are made according to the demand information and inventory information shared. Retailers encourage their manufacturers to participate in vendor management inventory programmes so that manufacturer monitors the retailer's inventory and schedule replenishment deliveries to the retailer. A centralized inventory control system benefits from information sharing.

Lee and Whang (H. L. H. Lee & Whang, 2000) in their article of "Information Sharing in a Supply Chain" discuss

1. Different types of information frequently shared across supply chains among the stakeholders
2. Models of information sharing
3. Challenges faced by sharing information along the supply chain

They have found that inventory level, sales data, order status for tracking, sales forecast, product/delivery schedule and order information as the most frequently shared information in the supply chain.

Examples for successful stories;

- Sharing of inventory information - Procter & Gamble and Wal-Mart practice vendor managed inventory systems at their suppliers' premises and replenish orders supplied to the retailer as per the pre-agreed replenishing guidelines.
- Sharing of point of sales data – Seven Eleven, Japan and McDonald's, Japan do sales forecast and plan production using POS data.
- Horizontal information of information - Japan semiconductor manufacturers share information with his competitors from Korea, USA and Europe to jointly monitor their inventory levels to mitigate chronic problems associated with business cycle.

Studies has found that information sharing in a principal – agent setting in supply chain transaction can influence the coordination. This has allowed less informed party to punish or reward the more informed party in supply chain coordination. The research identifies two positive effects;

information sharing reduce the influence results from information deficits and communication can limit the out-of-equilibrium behaviour. (Inderfurth, Sadrieh, & Voigt, 2013)

2.2 Emergency Logistics Solutions

Modern health care industry is looking for methods to overcome inefficiencies and bottlenecks in the supply chain and improve accessibility for medical equipment and medicines in short time. Emerging new strategies include; RFID technology for inventory visibility improving, virtual centralization of supply chain and vendor managed inventory for improving corporation in hospitals and controlling costs and supply utilization management for reducing wastes, value mismatch, misuse through standardization. (Mathew, John, Kumar, & Management, n.d.)

It is difficult to predict the demand for medicines accurately due to lack of accurate data on consumption and lack of standard nomenclature for medical products and preferences of medical practitioners.

There is a necessity of improving the information and communication systems to support rapid replenishment and implement JIT and stockless approach. ("Pull" type inventory management system). With RFID technology, real time information on delivery time supports JIT supplies. Health care industry is interdependent and needs to address the whole supply chain to obtain the efficiency.

Some freight forwarder with airlines have developed specialized emergency logistics services for health sector to transport blood and blood related products, organs and tissues, medical devices and personalized medicines on demand. These logistics solutions provide same day, customized and specialty services at a premium price. They have dedicated, specially trained experts to work exclusively with hospitals, blood banks, laboratories and medical processing centers to supply services when needed. Advanced ICT tools are used for communication and information sharing to facilitate real time data to the customer as well as supplier. ("Organs & Tissue - Quick Specialized Healthcare Logistics," n.d.)

E.g.

a) Quick International has a service contract with America's top blood banks to collect samples from 35 blood donating centers across the US, get them tested at one of the 3 laboratories for infectious disease and distribute to the US hospitals daily basis for life saving. Comprehensive planning and management is important to minimize service inefficiencies.
b) During a major snowstorm in Northeast of US, Quick International has successfully delivered twenty consignments of time and temperature sensitive donor tissues to a processing center in Northeast of USA. Forwarder closely worked with the tissue processor and airlines and set up protocols for re-routing and re-icing to maintain the temperature and meet delivery deadlines. These donor tissues were collected from various locations in US such as Hawaii, California, Texas and Boston and delivered to the East Coast of US. They had set up contingency plans with facilitators and proactively prepared to adopt to the situation when needed during the snowstorm. Tissue processor, donors and facilitators were kept updated with necessary information and communication. ("Delivery of Time- and Temperature Sensitive Donor Tissue During a Major Snowstorm - Quick Specialized Healthcare Logistics," n.d.).
c) Importance of timely communication and accuracy of shared information is well demonstrated in cord blood transportation. Cord blood require immediate pick up from hospitals and transport to the laboratories under controlled temperature. Cord blood is crucial for treatment against life threatening diseases. During the transportation of samples, clients need to have accurate visibility of the inbound shipment to advice staff for preparation for testing. Advanced IT systems are used to monitor real time shipment data and bar code scanning facility is used at the laboratory to enhance chain of custody upon delivery of samples. ("Cord Blood Company - Quick Specialized Healthcare Logistics," n.d.)

UPS (United Parcel Service Inc.) has begun testing drones for emergency deliveries of medical supplies to rural areas to overcome access barriers and delivery lead time. They delivered a package from Beverly to Children's Island in North America. UPS is further planning to use drones in Rwanda to transport life-saving blood supplies and vaccines. This is an example of application of technological advancements in supply chain management. ("UPS is testing drones for delivering medical supplies - Business Insider," n.d.)

2.3 Aviation Industry Spare Parts Inventory Management

Treuner's survey findings claim that 91% of the disruptions of aviation industry supply chain occurs in the upstream of chain and outside the direct control of the focal company. Communication, resources constraints, environmental factors, product quality, suppliers' insolvency and freight forwarders are identified as the major contributing factors for supply chain interruptions. ("Aviation and aerospace supply chains move eastwards," n.d.)

He proposes adoption of a risk sharing model to reduce supply chain interruptions. This model helps the airline operator to prepare for emergencies. It contains the impact of materialized risks. Since aviation is capital intensive industry, 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. Supply chain risk mitigation involves either avoidance, removal of the risk, modifying the likelihood or consequence and sharing the risk with other parties. When adopting supply chain risk sharing model it is essential to communicate and consult the stakeholders in whole supply chain on regular basis for the success.

There is a growing demand for planning, security, global spare parts support and 24 hrs x 7 days service availability in aviation industry, to ensure aircraft fleet in operation are, fully airworthy and reliable to fly at any given time. Airline operators and their supply chain networks in the aviation industry are confronted with challenges; timely delivery of correct spare parts to the station, keep the inventory cost at lowest possible, shortage of urgently needed spare parts and guarantee reliability of aircraft fleet airworthiness.

Due to the globalization and complex nature of aviation industry supply chain, they are more vulnerable for disruptions and operational loses. (Mocenco, 2014).

Examples are quoted from Boeing and Airbus, key players in the aircraft manufacture.

- Airbus in 2006, faced delivery delay during manufacture of A380 due to harness supplies disruption.

- Boeing in 2007, had similar experience during manufacture of B787 due to quality failure in fasteners received from one of their suppliers.

Gu and Li (Gu et al., 2015) in their research article, "Efficient Aircraft Spare Parts Inventory Management" says that, in airline industry 13% of the operating cost, contributes from aircraft maintenance cost. Operator has to deal with the operating cost as well as the customer satisfaction. The article emphasizes the importance of aircraft maintenance planning to keep the operation cost at a minimum while making the customer happy.

They proposed an efficient inventory management model to improve service level and reduce total cost. Variables selected were spare parts demand, quantity and time. This model predicts impending demand based on installed parts failure distribution. It is assumed that lifetime of parts and total number of failures are non-correlated, number of failures within given period follows a probability density function. Also assumed that the lifetime of operating parts is independent with an identical probability density function. Sometimes flying hours consider as a major factor in the demand forecast calculation and use mean time between removal/overhaul to forecast a failure rate.

Fritzsche (Fritzsche & Lasch, 2012) in his research paper emphasizes the necessity of preventive maintenance actions with prognostics to reduce the downtime in airline operation and reduce penalty cost for unscheduled maintenance and delay time. The researcher recommends a dynamic prediction model as a decision support, for maintenance method selection considering the requirements of an entire airline network. Proposed preventive model has 3 levels; airport level, reparation level and logistics level. During the research, long range networks of 4 selected airlines operations were observed. The airlines modeled are Qantas Airline, Virgin Airline, Korean Airline and Thai Airways with 45 aircraft.

Simulation study results shows that total cost of an airline can be significantly reduced under well-chosen maintenance strategy, the constant interchange of information between three levels and elaborated forecast. It also proves that, proper coordination and interchange of correct information, the key variables in the aviation industry supply chain.

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.

Today with the advancement in information technology, we have the ability to share the real-time demand and supply data across the supply chain, amongst the stakeholders.

Information and communication technology (ICT) tools are extensively used in supply chain management to reduce inefficiencies. Collaborative supply chain management involves exchanging and integrating information, tactical decision making, planning, forecasting, distribution and product designing. It has several benefits such as reduce process costs, inventory levels, production cost, increase responsiveness, improve customer satisfaction and better understanding of the needs of end customer and competitiveness amongst partners. Collaborative supply chain management process can also categorize in to 5 major processes under SCOR model (supply chain operating reference); plan, source, make, deliver and return and describe inter-company activities. (Sigala, 2005)

Airlines engage in collaborative procurement processes for two reasons;

a. Achieve economies of scale and scope of procurement – reduce costs, negotiate better purchase deals and delivery lead time regarding aircraft maintenance and supply of spares
b. Optimize the utilization of resources – exchange and swap resources with network airlines

Joint purchase of Airbus aircraft by Star Alliance partners is an example for joint purchase under collaborative supply chain management. Aero-Xchange is a leading e-market place designed by Lufthansa for purchase of aircraft spare parts and components for Star Alliance airlines. Resource management systems such as crew management systems, technical documentation management systems, maintenance control systems and e-procurement systems are integrated with other operational support systems of alliance partners to minimize the AOG situations and service disruptions while enhancing fleet and staff utilization. (Sigala, 2005)

With the developments of information and communication technology, e-market places have boomed up and compete each other along the aviation supply chain. E.g. www.PartsBase.com, www.exostar.com and www.airparts.com.

Vendor managed inventory system example from DHL supply chain solutions, who has entered into long term contract with Cathay Pacific airways and Cathay Dragon Airways to provide land transport, warehousing and inventory management of 80,000 aviation specific spare parts, components and equipment to ensure smooth operation of both airlines. Through this contract, it is expected synergizing core capabilities of airline management by Cathay Pacific, aircraft maintenance by HAECO and MRO supply chain management by DHL to obtain the best results. DHL has also signed a contract with Etihad Airways Engineering, the MRO to outsource Etihad Airways internal logistics functions. In this case DHL supply chain will manage stores, local transport movement and associated supply chain planning at Etihad Airways Engineering hub at Abu Dhabi International Airport. In turn, DHL will use Etihad Airways Engineering services to maintain parts of DHL fleet. (“MRO & Support : DHL wins two new MRO logistics contracts,” n.d.)

It is important to know about the organizations that involved in develop, implement and regulate Aviation industry operation. There are 3 main bodies that monitor and regulate aviation operation, namely;

ICAO – International Civil Aviation Organization, UN specialized agency, works with its 191 members who are airlines, states and industry groups. Key responsibilities are to develop and implement international civil aviation standards, recommended practices and policies in support of safety, capacity and efficiency, security and facilities, economic development and environmental protection for the aviation sector. Regulates operation of airports, aircraft, passengers, cargo and routes. (International Civil Aviation Organization, n.d.)

IATA – International Air Transport Association is the subordinate body that implement policies and standards established by ICAO. Mission of the agency is to represent, lead and serve the airline industry. IATA represents 256 airlines over 117 countries. Ensure safety and security of aircraft, passenger, cargo, mail and crew. (“IATA - About Us,” n.d.)

CAA – Civil Aviation Authority is a local authority that supervise the conformity of airline operation with the IATA standards and policies within the country or state. Building airports, runways, air traffic services and area control as per local government rules and regulations and ICAO standards. (“National aviation authority - Wikipedia,” n.d.)

The additive manufacturing technology is becoming popular in aviation and aerospace industry for manufacturing spare parts. Current applications are such that, manufacture of 3D printed fuel nozzles for General Electric’s advanced LEAP jet engines, introduction of over 1000 of 3D printed parts in Airbus 350 model and NASA is planning to use 3D printed materials for operation in space. 3D printing technology also known as additive manufacturing. (Kuckelhaus & 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

Boeing plans to use 3D printed titanium aluminium alloys in the newly designed 787 aircraft. (“Boeing Set to Use 3D Printed Titanium Parts for 787 - 3D Printing,” n.d.). It will reduce the weight of the aircraft part and improve the fuel efficiency.

There are specialty logistics agents who provide same day or next day AOG transport solutions for airline operators. Forwarding agent have contracts with airlines for on board courier and AOG transport facilities for aircraft parts. Some agents provide extended AOG service facilities such as aircraft parts exchange and loan facility. In this exercise, timely communication of right information is very important to obtain on time delivery of aircraft parts. ("AOG Loan-Borrow Recovery | Sterling Courier," n.d.)

2.4 PERT Statistical Tool Applications in Supply Chain Management

PERT (programme evaluation review technique) is one of the standard methods of network analysis. This project management technique was developed in 1950s by US Navy for planning and control of the Polaris missiles programme (*Series of management.*, n.d.). Since then the PERT model became popular in planning, scheduling and controlling complex projects. PERT analysis is used to manage complex actions having stochastic nature. It is assumed that duration of sub activities as random variables and follow probability distribution. Aim of the PERT model is to help arrange activities and sub activities of the project in such a manner that they conform to the deadline of the project completion with high probability. Understand the risks and critical activities. Identify the critical path, availability of opportunities for resources sharing and changing of start time for non-critical activities.

Willard Fazar, head of Programme Evaluation Branch of the US Navy has well summarized the features of PERT. He says, "Through an electronic computer, the PERT technique processes data representing the major, finite events essential to achieve end-objectives; the interdependence of those events; and estimates of time and range of time necessary to complete each activity between two successive events.

The technique is a management control tool that sizes up the outlook for meeting objectives on time; highlights danger signals requiring management decisions; reveals and defines both methodicalness and slack in the flow plan or the network of sequential activities that must be performed to meet objectives; compares current expectations with scheduled completion dates and computes the probability for meeting scheduled dates; and simulates the effects of options for decision – before decision" ("Everything You Need To Know About PERT in Project Management," n.d.)

Main elements in PERT analysis.

1. Activities and events that involved in the project
2. Estimated time for each activity

3. PERT diagram to indicating sequence of the activities
4. Critical path
5. Lags and slacks
6. Gantt chart for visual depiction of the project progress

In PERT analysis, for a given project, determine the probability of any given activity to be successfully completed within three time estimates/variables.

1. Optimistic time – time required when activity execution goes extremely well
2. Most likely time – time required when activity execution is normal
3. Pessimistic time – time required when everything goes bad

These time estimates/variables are used in a weighted average assuming probability distribution. This weighted average forms the expected time for a given task. Expected time also represent the mean of the probability distribution. ("Statistical Modeling in Supply Chain Continued: When should we incorporate uncertainty into project schedule estimates?," n.d.)

$$\text{Expected Time (Mean)} = \frac{(\text{Optimistic time} + 4 \text{ x Most likely time} + \text{Pessimistic time})}{6}$$

Equation 2.1 : Equation for Expected Task Completion Time in PERT Analysis

Benefits of PERT model;

- Focus on the relationship between the time each activity takes, cost for each activity and expected time and cost for completion of the project.
- Calculate expected project completion time
- Probability of completion before a specific date
- Identify critical part activities which has direct impact on completion time of the project
- Identify the activities that have slack time which can share resources to critical path activities to meet the scheduled delivery target
- Activity start and end dates
- Helpful for implementing "what if" scenarios

Limitations of PERT model; ("Pros and Cons of Program Evaluation Review Technique (PERT)," n.d.)

- Analysis process is subjective in nature. Charts cannot accurately estimate cost and time
- Labour intensive in nature and expensive
- Requires detailed research and study of the comments from many people and project activities
- Is a time focused method and has limitation in determining labour and material requirements

According to the literature review, PERT model has been a research tool in academic research and in real life business applications. First, the concept of PERT in purchasing appears in Rago (1968) in which purchasing functions were studied using a PERT network chart. This chart was used to identify the purchasing functions with has constraints, necessity of more time or detailed information to commence the next activity to improve efficiency of the purchasing process.

Applications of PERT analysis in real life summarize with following examples;

I. PERT can be used for risk analysis, to identify potential opportunities and difficulties for the activities and calculate the worst-case scenario.

II. Feasibility study was carried out using network analysis, PERT and CPM methods for construction of a new branch of a company. Project had two options, either to put up the office at a shopping center or at city center. Decision was made based on the PERT analysis, the time taken for construction of new office and the risks involved. ("Statistical Modeling in Supply Chain Continued: When should we incorporate uncertainty into project schedule estimates?," n.d.)

III. For logistics projects such as construction of warehouse PERT analysis and Gantt Charts are used to control the project. Gantt chart illustrates the logistics project schedule whereas PERT diagrams are used for finding the relationship and inter-dependency of activities, critical path for the project completion and bottle necks of the project which cause delay the date of completion. (Management, 2011)

IV. Boeing used PERT model for control the defect analysis and ensure all changes are done in time for Boeing 787 manufacture. Project scheduling and communication managed through network analysis. ("Boeing Case Study | Operations Management | Supply Chain," n.d.)

V. PERT analysis used in clinical laboratory research and development project of monitoring transcutaneous ρCO_2 for premature infants who had respiratory diseases, for identification of critical path bottlenecks and optimization of labour resource allocation. (Kost, 1986)

Findings from literature review summarizes that;

a) 90% of disruption in aviation supply chain occurs in the upstream of the chain, outside the direct control of the focal company
b) Researchers identify communication, product quality, freight forwarder, supplier inefficiencies, recourses constraints and environmental factors as the major causes for supply chain disruptions
c) Globalization creates complexity to the supply chain and become more vulnerable for disruptions
d) AOG situations can minimize by adopting efficient inventory management systems
e) Information and communication technology tools are extensively used in supply chain management to reduce inefficiencies, control and monitor emergency medical supplies
f) RFID technology used in medical supplies for JIT (just in time) inventory management systems to obtain real time information across the supply chain. Thereby improve the efficiency of the emergency medical supply chain
g) Information sharing and communication increases relationship and trust between supplier and customer and thereby improve efficiencies
h) Information sharing across the supply chain offers three benefits to the stakeholders; reduction in cost, reduction in lead time and reduction in inventory
i) PERT statistical tool has been used in research studies, mega projects, aviation, clinical laboratory tests and supply chain management to identify bottle necks, sequence of activities, plan resources allocation and estimate total cycle time

3 Research Methodology

This chapter elaborate the research design, the justification, possible methods available for analysis and the reasons for using the one selected.

When aircraft are scheduled for transportation of cargo or cargo and passengers, sometimes there can be flight cancelations or delays due to a sudden technical failure occur in the aircraft. Then the aircraft make ground for repair maintenance and spare parts to be supplied with immediate effect. If the part is not found in the inventory, it has to purchase and supply. Therefore, in an AOG situation, delivery lead time becomes critical. Transportation, communication and information become contributing factors for the delivery lead time. Therefore, these factors need to be managed efficiently and effectively to avoid delivery delays.

Literature review done in Chapter 2, shows that many research have been done to improve overall performance of the supply chain by improving communication and information sharing. Literature survey could not capture any research carried out to reduce delivery lead time of aircraft spare parts in airline industry that can be taken as a guideline for this study.

Few researches were found which have studied methods of reducing delivery lead time in supply chain management, but they are for manufacturing sector to reduce production cycle time not related to the current research topic; delivery lead time of spare part.

1. Pulp and paper manufacturing company worked to reduce the production cycle from 4 weeks to 1 week by improving consistency in production process. Lot size was reduced according to the actual customer demand. Supply chain participants were encouraged to work together to exchange information and thereby contribute to improve the market mediation. Customer's demand information was transferred to manufacturers immediately and production was done just sufficient to fulfil the market demand. Example for Juts in Time (JIT) supply chain. (Treville, Shapiro, & Hameri, 2004). This is good for retail market supplies where the demand can be forecasted.

2. A research study was found on supply of theater medical devises. In this research, internal factors that leads to delays in delivery time was studied using cause and effect, Ishikawa

diagrams. The approach was to control the manufacturing delays and improve supply of medical devices. Value stream mapping technique was adopted to determine the gaps in the process and efficiency in order processing flow. Contribution of raw material suppliers and customer to the delivery lead time delays were studied under a risk management scheme. (Kamaleswaran & Ramachandram, 2015). Though the customer demand is unpredictable as in the case of aviation AOG situations, study was confined to internal factors improvement in view of reducing lead time. But value chain mapping they adopted to eliminate non-value creating process is a valuable tool to use in aviation procurement process mapping to identify bottlenecks as well as non-value steps involved in procurement process to reduce the delivery lead time.

Literature survey identifies PERT statistical tool as an effective technique for analysis of complex network of activities.

1. Iwona in his project report, defines logistics projects as a complex, special and consists of unique set of activities which determines by cost, time and scope in supply chain to be managed. He discusses the controlling of logistics projects and tools that can be adopted in controlling logistics processes. Further he identifies controlling of logistics projects as controlling subsystem of the enterprise which by coordinating the planning, control, collection and processing of information, ensures the project objectives were achieved, necessary corrective actions were timely taken for deviation observed and evaluate what remains to be done. Propose sue of PERT method to estimate the total duration of the logistics project and analyze critical and non-critical activities. Gantt charts were recommended for illustration of control of the work in progress of the projects. (Management, 2011). This research paper lays ground for the current research work which uses PERT analysis as statistical tool to identify the critical activities involved in procurement logistics project in aviation supply chain management.

2. In history, PERT has been used for improving purchasing process. (Rago, 1968). PERT has been helpful in mapping the purchasing functions and identify the processes that need to be improved.

3. Boeing has adopted PERT for control of defect analysis during the manufacturing of Boeing 787 Dreamliner aircraft to ensure defects are competed on time. (“Boeing Case Study | Operations Management | Supply Chain,” n.d.)

Specific objective of current study is to analyze the impact of information and communication errors on spare parts deliver lead time in aviation industry. Lead time is critical airline when their aircraft is on ground due to unscheduled repair. Procurement process in aviation supply chain is complex due to globalization of suppliers, uncertainty of demand time and spare part, quality conformity and international transport regulations. It involves number of sequential activities in the procurement process of spares parts.

With literature survey, it was learnt that PERT is an effective technique that has been tried and tested for analyzing such complex networks of activity flow. Therefore, PERT method is used as the tool for analyzing the sequence of communication flow in the procurement process and determining the critical activities involved.

3.1 Theoretical Framework

a) PERT Analysis

PERT is a management control tool for meeting objectives on time for a given project, highlights bottlenecks that require management decision and map the sequence of activities in the network enabling compare the current expectation with scheduled completion dates. Often used for complex projects where variables are stochastic in nature.

PERT defines four types of estimated times for an activity to include uncertainty about duration in scheduling. ; (“Statistical Modeling in Supply Chain Continued: When should we incorporate uncertainty into project schedule estimates?,” n.d.)

O: Optimistic time; minimum possible time required for an activity to accomplish, assume everything happens favourable and better than normal situation

P: Pessimistic time; maximum possible time required for an activity to accomplish, assume everything goes wrong in the process

M: Most likely time; best estimated time required for an activity to accomplish, assume everything proceeds as normal

ET: Best estimation of time required for an activity;

$$ET = \frac{P + 4 * M + O}{6}$$

Equation 3.1 : Equation for best estimation of time requirement for an activity in PERT analysis

$$Variance = \{(P - O)|6\}^2$$

Equation 3.2 : Equation for estimation of variance in time for activities in PERT analysis

TCT : Total cycle time; time requried for completion of the total project (Lead Time)

$\sum_{i=1}^{n} ETi$ i – No of activities to perform for completion of the projcet

Equation 3.3 : Equation for estimation of Total Cycle Time for activities in PERT analysis

Critical Path = longest duration of time in the PERT network and consists activities that cannot be delayed without affecting the total cycle time.

To model the communication flow using the PERT method following methodology was adopted.

- Activities in the communication flow from defect identification to receiving parts was listed.
- Individuals responsible for handling (generating and receiving) information under each activity is listed
- A matrix was developed with activity as the Y axis and the individual responsible as the X axis. Each cell in the matrix represents an activity in the information flow.
- Sequence of activities and activity durations are determined
- Based on the above information, the information flow will be modeled using the PERT method and critical activities were identified using critical path method.

3.2 Conceptual Framework

This research was focused on determining the impact of communication and information on delivery lead time in aviation supply chain. A case, considering spare parts purchase and supply to the work site for an AOG repair at a small airline operator was modeled. Figure 3.1 illustrates the approach used for the case study.

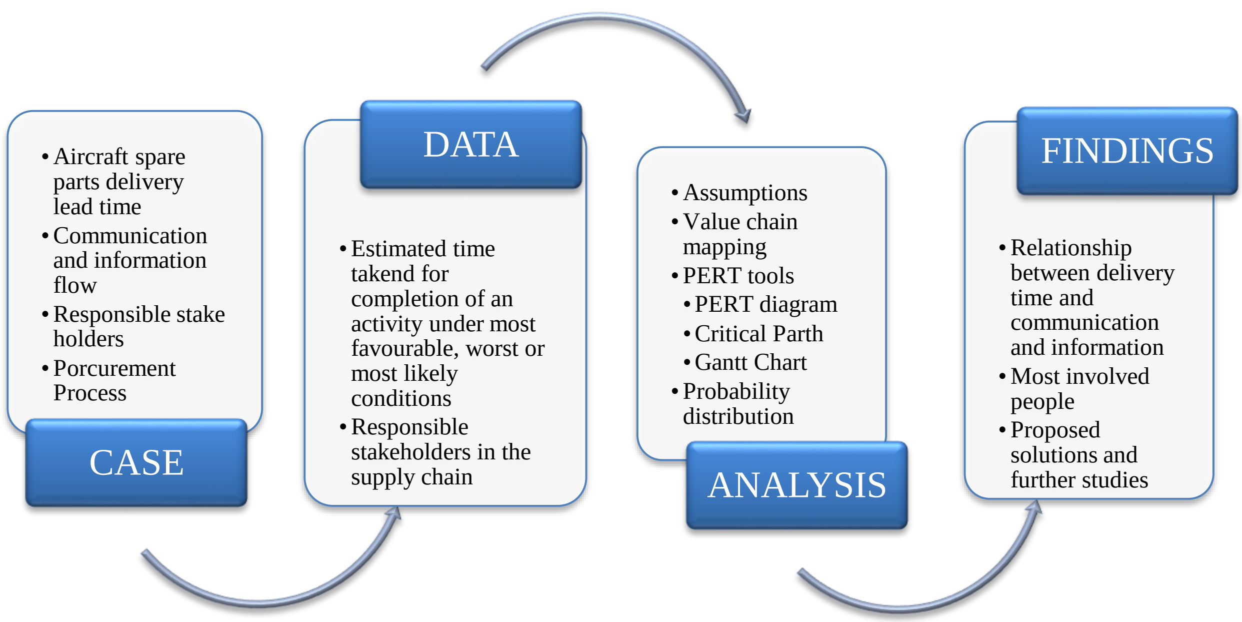


Figure 3.1 : Conceptual framework for the case study

3.3 Assumptions

To apply the PERT method and model the information flow of this study, following assumptions are made.

1. Communication of procurement functions defined as activities, denote by "Nodes" in PERT diagram. Flow of communication indicated by vector with an "Arrow" for the forward direction.
2. Start is the point that any person receiving the information, End is the point that person releases the information onwards.
3. Anytime taken for processing is Activity Duration

4. Anytime between releases of information from one person to receiving by the other is a lag time (e.g. time zone difference, work hours difference, etc.)
5. Delays due to communication errors are only considered. Hence other criterions of accepting a particular part (e.g. product quality and standards) are assumed to be adequate

3.4 Data Collection

Actual data was selectively collected from Fits Aviation Pvt Ltd, a small scale international cargo airline operator in Sri Lanka. The fleet consists of high variation in aircraft types but few number of aircraft.

Data sample consists of qualitative data such as information, communication as well as quantitative data such as time and cost.

Data exchange occur between one to one, one to many, many to one or many to many people during activities. These data were extracted from spare parts purchase history records, email communications with stakeholders, engineering log books, vendor payment records.

Time estimations were calculated basis on the average time taken for each activity.

Information shared during communication includes;

- Spare part number, parts catalogue, quality certificates
- Lead time and location
- Quotations, purchase orders, invoices, packing lists
- Mode of transport and status of transport
- Air way bill/courier tracking/ bill of lading
- Payment advice
- Customs entry, authority approvals

4 Data Analysis and Observations

4.1 Engineering procurement procedure

Engineering procurement includes, aircraft spare parts purchase and coordinate getting repaired components at MRO workshops and return. Categories of spare parts procure includes; rotables, repairables and expendables as referred in Chapter 1 under subheading 1.1.3. Service requests are made from engineering department to procurement and then suppliers are contacted accordingly. Prior to purchasing, suitability of components and price are evaluated and then approvals from quality department and operations are received.

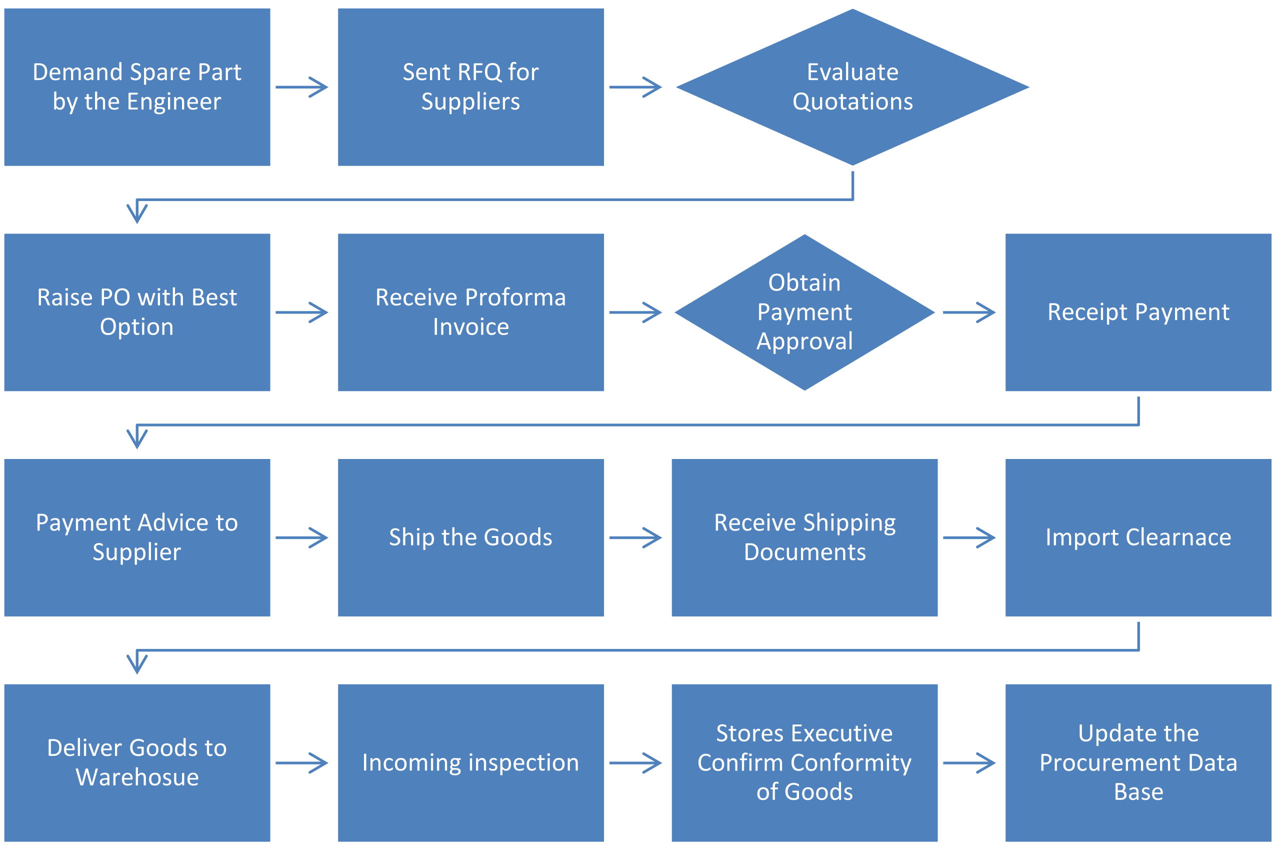
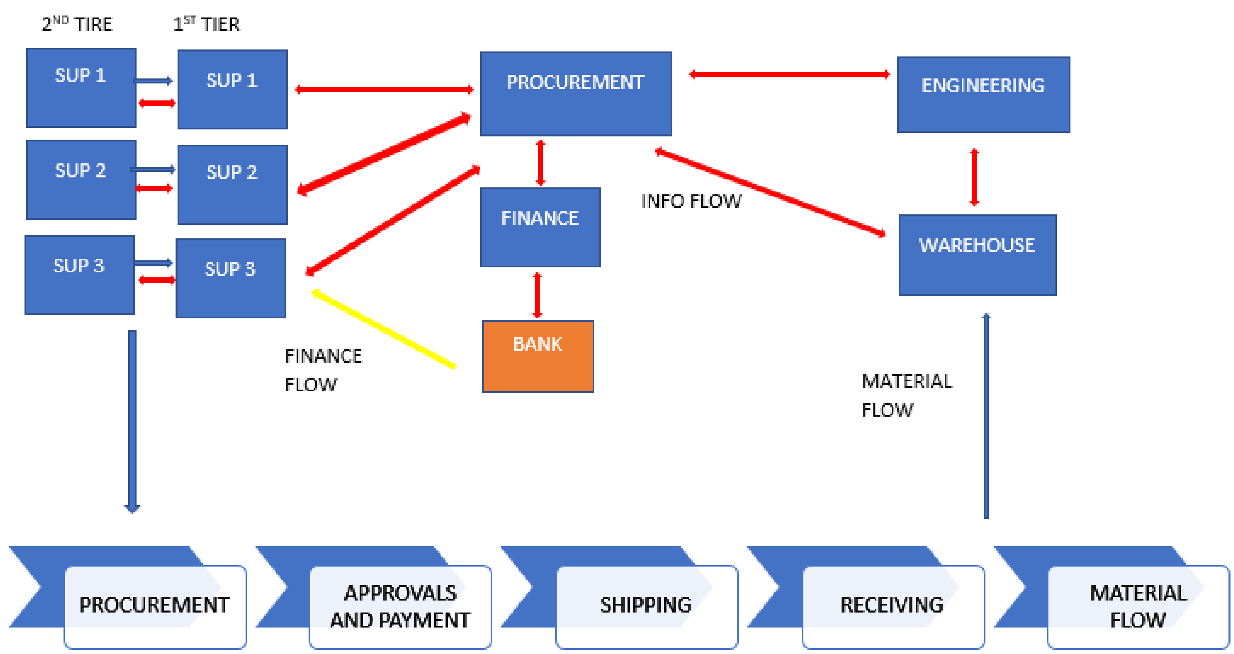


Figure 4.1 : Fits Aviation Aircraft Spares Procurement Procedure

Logistic services are obtained from agents who have service contracts with the company and provide inwards and outwards logistics services through courier services, air freight solutions and hand carry service is obtained based on the urgency of the spare part at line station. Procurement procedure can be summarized as in figure 4.1. Sequence of activities and decision-making points are presented according to the current practice.

4.2 Value chain of procurement process

Value chain of the procurement process mapped and illustrated in figure 4.2. Most of the time purchases are made from traders since operators having small fleet have difficulty in access to the OEM or MRO facilities. Therefore, supplier network extends from 1st level to 2nd level in some cases such as in repairing avionics, breaks and wheels.



Legend

	Information flow
	Material flow
	Financial flow

Figure 4.2 : Fits Aviation procurement value chain

4.3 Communication flow matrix

Communication flow across the supply chain with responsible stakeholders for each activity was described in the matrix illustrated in table 4.1. Total procurement process until receiving goods at the aircraft maintenance site was described with 20 key communication activities.

Expected time for each activity was calculated using PERT formula. Best time, worst time and most likely time intervals were taken from the past records of operator considering AOG repair maintenance spare parts deliveries made during the past two years, 2016 and 2017. Best time denoted when spare parts are available at 1^{st} tire supplier and supplier locate in an area accessibility and transport connectivity is high. Worst time is the longest time that could take to find and transport part when purchased from 2^{nd} tire located in a remote area and limited access. Most likely time represent when part is drop shipped but from an easy access location. In addition to the precedence and successor communication for each activity, their relationships are also identified.

The case study narrows down to the operation of aircraft in Indian Subcontinent and Central Asia. The aircraft in concerned is a McDonnell Douglas MD82 type twin engine, narrow body aircraft. Very few operators found in the Asian region who has this type of aircraft in their fleet. Opportunities for spare parts pooling or borrowing parts on PHB systems (parts per hourly basis) are very much limited. Some airline operators in United States of America still use this type of aircraft for domestic transport services and found serviceable parts as removed from teardown aircrafts in North America. As a result, quite often spare parts are purchased from suppliers in North America. However, during major repairs or modifications, technical supports are received from OEM’s such as Boeing for airframe, Meggitt for wheels and break systems and Pratt & Whitney for engines.

Legend for the Communication Matrix

Task – Main activities numbered in chronological order and number with a letter indicates the sub activities of a main activity.

Task Description – Considering an AOG situation, activity breakdown from identification of the technical fault, request spares, purchase and supply and repair the aircraft.

Person Responsible - Person who initiate communication for the activity in concern

Code – Notation of an English letter is given to each person involved in the communication network

Activity (AON) – Communication flow from predecessor to successor

E.g. AB = communication flow from engineer to planning officer

Expt Time (Duration) – PERT equation

(Best time + 4 * Most like time + Worst time)/6 = Expected time or the Estimated time

Table 4.1 : Communication flow matrix (part 1)

COMMUNICATION FLOW MATRIX

Task	Task Description	Person(s) Responsible	Code	Activity (AON)	Best Time, Hr	Worse Time, Hr	Most Like, Hr	Expt Time, Hr (Duration)		Variance	Standard Dev. Hr	Previous Task	Predecessor	Precedence Relationship	Successor	Successor Relationship
1a	Identify fault and inform to Planning Officer	Engineer	A	AB	1.00	1.75	1.38	1.56		0.016	0.125	Start	Start		BP	FS
1b	Inform to HOE	Engineer	A	AE	0.25	0.50	0.38	0.44	2.00	0.002	0.042	Start	Start	FS dummy	End	FS
2a	Check the inventory	Planning Officer	B	BP	0.50	0.75	0.63	0.69		0.002	0.042	1a	AB	FS	PB	FS
2b	Stores response to Planning Officer	Stores Officer	P	PB	0.25	0.50	0.38	0.44		0.002	0.042	2a	BP	FS	PA	FS
2c	Status update/item release	Stores Officer	P	PA	0.50	1.00	0.75	0.88	2.00	0.007	0.083	2b	PB	FS	AB	FS
3	Aircraft repair/status update	Engineer	A	AB	2.00	4.00	3.00	3.50		0.111	0.333	2c	PA	FS	End	
4	Demand spare parts	Planning Officer	B	BC	0.50	2.50	1.50	2.00		0.111	0.333	2b	PB	FS	BC	FS
5	Send RFQ to suppliers	Procurement Officer	C.	CD	0.50	1.50	1.00	1.25		0.028	0.167	4	BC	FS	CD	FS
6	Receive quotes	Supplier	D	DC	2.00	16.00	9.00	12.50		5.444	2.333	5	CD	FS	DC	FS
7a	Quality conformity approval req	Procurement Officer	C	CF	0.50	1.00	0.75	0.88		0.007	0.083	6	DC	FS	CF	FS
7b	Feedback from quality	HOQ	F	FC	0.75	1.25	1.00	1.13	2.00	0.007	0.083	7a	CF	FS	FC	FS
8	Place the order with supplier	Procurement Officer	C	CD	0.50	1.50	1.00	1.25		0.028	0.167	7b	FC	FS	CD	FS
9	Receive order confirmation/invoice	Supplier	D	DC	6.00	14.00	10.00	12.00		1.778	1.333	8	CD	FS	CE, CJ, CK	FS
10a	Payment approval - HOE	Procurement Officer	C	CE	0.25	0.50	0.38	0.44		0.002	0.042	9	DC	FS	EC	FS
10b	Receive approval	HOE	E	EC	0.50	0.75	0.63	0.69	2.00	0.002	0.042	10a	CE	FS	CG	FS
11a	Approval req from CAA	Procurement Officer	C	CK	0.50	1.00	0.75	0.88		0.007	0.083	9	DC	FS	KC	FS
11b	Approval req from BOI	Procurement Officer	C	CJ	0.50	1.00	0.75	0.88	36.00	0.007	0.083	9	DC	FS	JC	FS
10c	Payment approval - DCEO	Procurement Officer	C	CG	0.25	0.50	0.38	0.44		0.002	0.042	10b	EC	FS	GC	FS
10d	Receive approval	DCEO	G	GC	0.25	0.50	0.38	0.44		0.002	0.042	10c	CG	FS	CH	FS
12a	Payment request from FM	Procurement Officer	C	CH	0.50	1.00	0.75	0.88	30.00	0.007	0.083	10d	GC	FS	HI	FS
11c	Receive approval	CAA	K	KC	8.00	12.50	10.25	11.38		0.563	0.750	11a	CK	FS	CL	FS
11d	Receive approval	BOI	J	JC	8.00	12.50	10.25	11.38		0.563	0.750	11b	CJ	FS	CL	FS
11e	Approval requ	Procurement Officer	C	CL	0.50	1.00	0.75	0.88		0.007	0.083	11c, 11d	KC, JC	FS	LC	FS
11f	Receive approval	IC	L	LC	6.50	12.00	9.25	10.63		0.840	0.917	11e	CL	FS	CD	FS
12b	Payment request to bank	Finance Manager	H	HI	1.00	7.50	4.25	5.88		1.174	1.083	12a	CH	FS	IH	FS
12c	Payment advice	Bank	I	IH	12.00	24.00	18.00	21.00		4.000	2.000	12b	HI	FS	HC	FS
12d	Payment advice to procurement	Finance Manager	H	HC	1.50	2.50	2.00	2.25		0.028	0.167	12c	IH	FS	CD	FS
13a	Inform payment details and forwarder to supplier	Procurement Officer	C	CD	0.50	1.00	0.75	0.88		0.007	0.083	12d, 11f	HC, LC	FS	CM	FS
13b	Inform shipment details to forwarder	Procurement Officer	C	CM	0.50	1.00	0.75	0.88		0.007	0.083	13a	CD	FS	MD	FS

Table 4.2 : Communication flow matrix (part 2)

Task	Task Description	Person(s) Responsible	Code	Activity (AON)	Best Time, Hr	Worse Time, Hr	Most Like, Hr	Expt Time, Hr (Duration)		Variance	Standard Dev. Hr	Previous Task	Predecessor	Precedence Relationship	Successor	Successor Relationship
13c	Forwarder contact supplier	Forwarder	M	MD	2.00	4.00	3.00	3.50		0.111	0.333	13b	CM	FS	DC-CD	FS
13d	Send invoice and packing list, check accuracy	Supplier	D	DC-CD	3.00	6.00	4.50	5.25		0.250	0.500	13c	MD	FS	DM	FS
13e	Share cargo details and shipping doc	Supplier	D	DM	3.00	6.00	4.50	5.25		0.250	0.500	13d	DC-CD	FS	MQ	FS
13f	contact carrier and space booking	Forwarder	M	MQ	4.00	5.00	4.50	4.75		0.028	0.167	13e	DM	FS	QM	FS
13g	Booking confirmation			QM	4.00	5.00	4.50	4.75		0.028	0.167	13f	MQ	FS	MD	FS
13h	Cargo picked up	Forwarder	M	MD	2.50	5.50	4.00	4.75	30.00	0.250	0.500	13g	QM	FS	MQ	FS
14a	Cargo handover to carrier	Forwarder	M	MQ	1.00	3.00	2.00	2.50		0.111	0.333	13h	MD	FS	QM	FS
14b	Issue AWB	Carrier	Q	QM	0.50	1.00	0.75	0.88		0.007	0.083	14a	MQ	FS	QC	FS
14c	share the AWB with customer	Forwarder	M	MC	1.00	1.50	1.25	1.38		0.007	0.083	14b	QM	FS	QC	FS
14d	Cargo transit, arrive and notice to customer	Carrier	Q	QC	34.00	54.00	44.00	49.00	48.00	11.111	3.333	14b	QM	FS	CN	FS
15a	Advice customs broker with shipping docs & approvals	Procurement Officer	C	CN	0.50	1.00	0.75	0.88		0.007	0.083	14d	QC	FS	NQ	FS
15b	Contact carrier for shipping documents	Customs Broker	N	NQ	0.50	1.00	0.75	0.88		0.007	0.083	15a	CN	FS	QN	FS
15c	Collect shipping documents from carrier	Customs Broker	N	QN	1.00	4.00	2.50	3.25	5.00	0.250	0.500	15b	NQ	FS	NG	FS
16a	Prepare cusdec, request pay order approval	Customs Broker	N	NG	2.00	3.00	2.50	2.75		0.028	0.167	15c	QN	FS	GN	FS
16b	Approval for duty	DCEO	G	GN	0.50	1.00	0.75	0.88		0.007	0.083	16a	NG	FS	NH	FS
16c	Pay order request	Customs Broker	N	NH	0.50	1.00	0.75	0.88	9.00	0.007	0.083	16b	GN	FS	HI,NL	FS
17a	ICL debit	Customs Broker	N	NL	1.00	2.00	1.50	1.75	16.00	0.028	0.167	16c	NH	FS	LN	FS
16d	Pay order advice	Finance Manager	H	HI	1.00	1.50	1.25	1.38		0.007	0.083	16c	NH	FS	IH	FS
16e	Pay order	Bank	I	IH	2.00	3.00	2.50	2.75		0.028	0.167	16d	HI	FS	HN	FS
16f	Pay order to customs broker	Finance Manager	H	HN	0.50	1.00	0.75	0.88		0.007	0.083	16e	IH	FS	NO	FS
17b	Pay duty to customs	Customs Broker	N	NO	1.00	2.00	1.50	1.75		0.028	0.167	16f	HN	FS	ON	FS
17c	payment receipt	Bank	I	ON	0.25	0.50	0.38	0.44		0.002	0.042	17b	NO	FS	NO	FS
17d	IDC debit note	IC	L	LN	2.00	4.00	3.00	3.50		0.111	0.333	17a	NL	FS	NO	FS
17e	Forward cusdec for approval	Customs Broker	N	NO	1.00	2.00	1.50	1.75		0.028	0.167	17c, 17d	ON, LN	FS	JN	FS
17f	BOI approval	BOI	J	JN	1.00	2.00	1.50	1.75		0.028	0.167	17e	NO	FS	NO	FS
17g	Request customs verification	Customs Broker	N	NO	1.75	2.00	1.88	1.94		0.002	0.042	17f	JN	FS	ON	FS
17h	Customs verification	Customs	O	ON	2.00	3.50	2.75	3.13		0.063	0.250	17g	NO	FS	NP	FS
18	Goods released and deliver to warehouse	Customs Broker	N	NP	0.75	1.75	1.25	1.50	1.50	0.028	0.167	17h	ON	FS	PA	FS
19a	Inform engineer for quality inspection	Stores Officer	P	PA	0.25	0.50	0.38	0.44		0.002	0.042	18	NP	FS	AP	FS
19b	Quality approval	Engineer	A	AP	1.00	2.00	1.50	1.75		0.028	0.167	19a	PA	FS	PA	FS
19c	Update inventory and release spare parts	Stores Officer	P	PA	0.25	1.00	0.63	0.81	3.00	0.016	0.125	19b	AP	FS	AB	FS
20a	Attend repair and status update to Planning Officer	Engineer	A	AB	2.50	6.00	4.25	5.13		0.340	0.583	19c	PA	FS	AE	FS
20b	Status update to HOE	Engineer	A	AE	0.05	0.15	0.10	0.13	5.25	0.000	0.017	20a	AB	FS	End	
									191.75			End				
								days	8							

4.4 PERT diagrams and Critical Path

Activity diagrams drawn for the communication flow during procurement process.

Under optimistic condition, procurement process communication activities drawn for AOG situation where the spare part found in the inventory. Figure 4.3

Under best estimated time, where the spare part to be purchased and supply, procurement process communications categorized into five major activities and drawn the PERT diagrams for each major activity with their sub activities.

I. Order placing – start the project and map sub activities until order was placed. Figure 4.4
II. Approvals and payment – once order placed, continue the activities for approvals and payment process. Figure 4.5
III. Inwards clearance – after payment arranged, goods shipped from supplier, arrived in Colombo and arrange inward clearance. Figure 4.6
IV. Goods received – clear the import goods and deliver to warehouse. Figure 4.7
V. Aircraft repair – received goods verified for quality conformity, issued to engineers, repair and make the aircraft airworthy. Figure 4.8

Early start (ES), early finish (EF), late start (LS), late finish (LF) times were calculated using forward pass and backward pass along the network.

If duration or the estimated, expected time indicated by t,

$EF = ES + t$ and $LS = LF – t$

If slack is denoted by S,

$S = LS – ES$ or $S = LF - EF$

Slack is the maximum time that an event can be delayed without delaying the total project completion time. Slack was calculated to each activity identify the critical path. Activities on the critical path have zero slack. (Krajewski, Ritzman, & Malhotra, 2013)

Legend for the PERT activity diagram

ES – Early Start time	Duration, Hrs (Est. Time)	EF – Early Finish time
Activity – Communication Flow		
LS – Late Start time	Slack	LF – Late Finish time

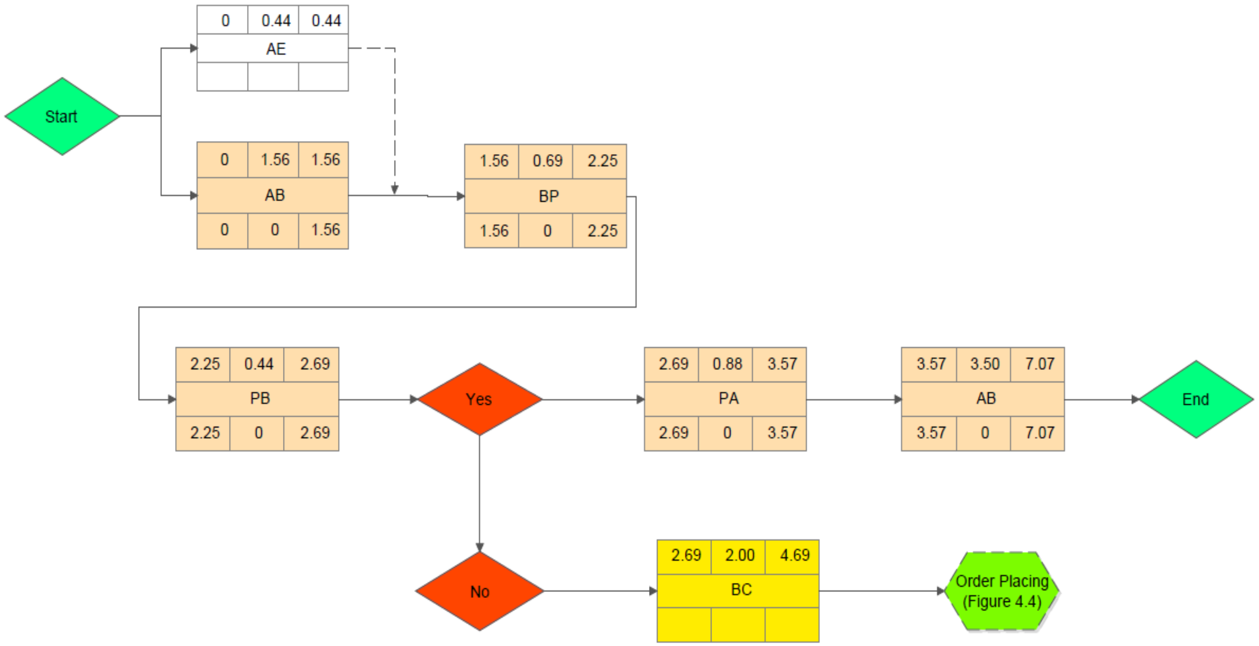


Figure 4.3 : Activity diagram for aircraft repair under perfect conditions

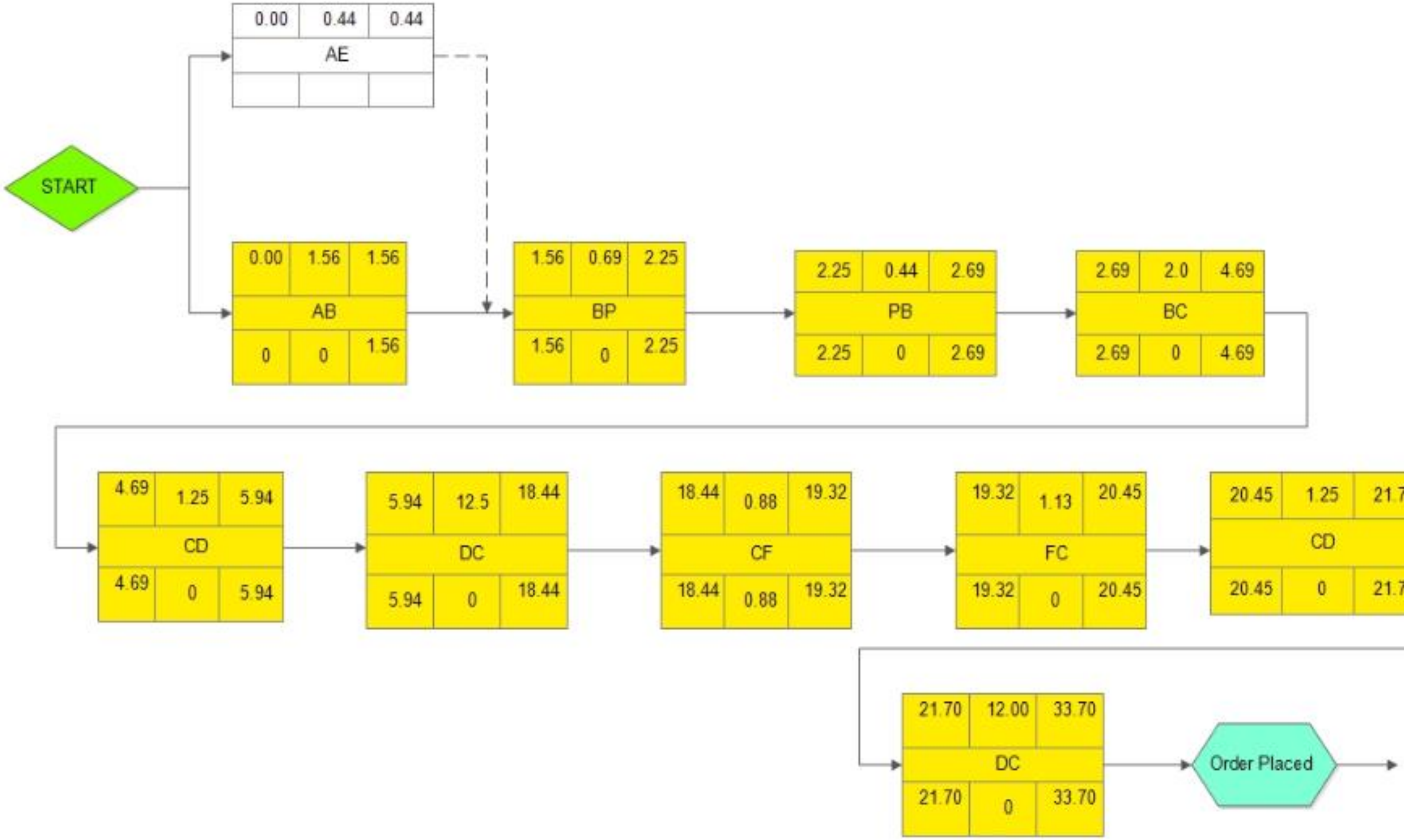


Figure 4.4 : Activity diagram for order placing – Project start

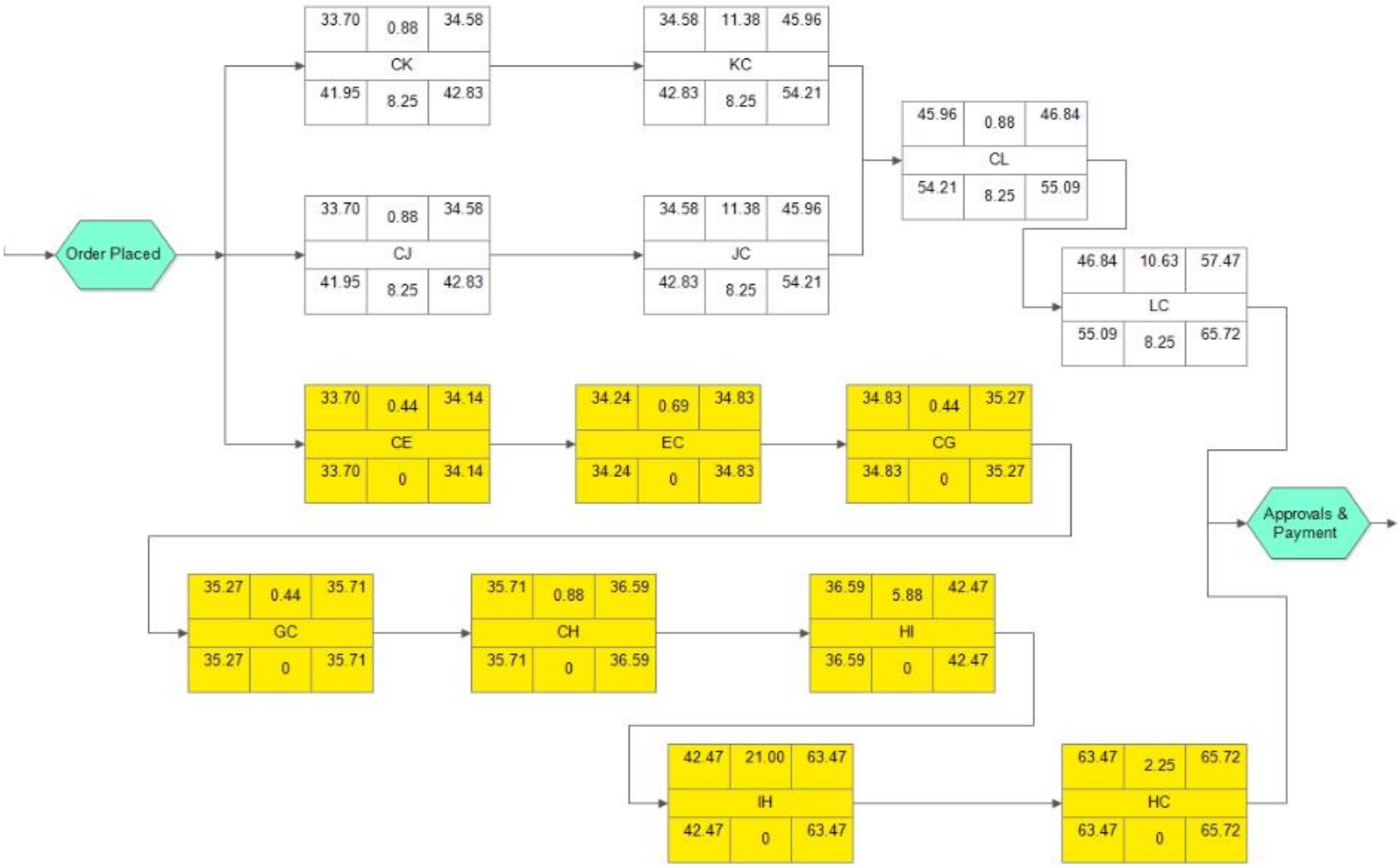


Figure 4.5 : Activity diagram for approvals and payment

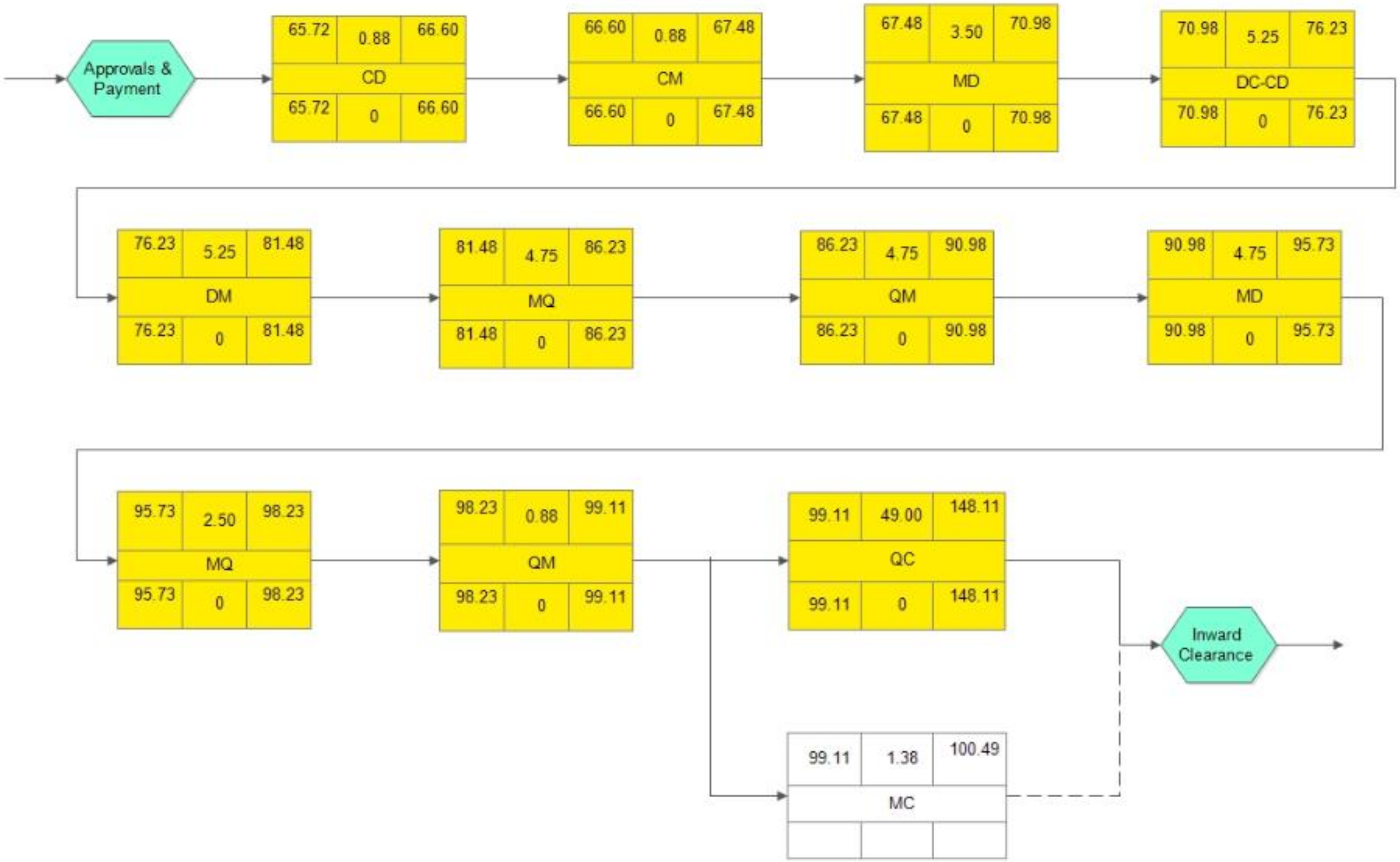


Figure 4.6 : Activity diagram for inward clearance

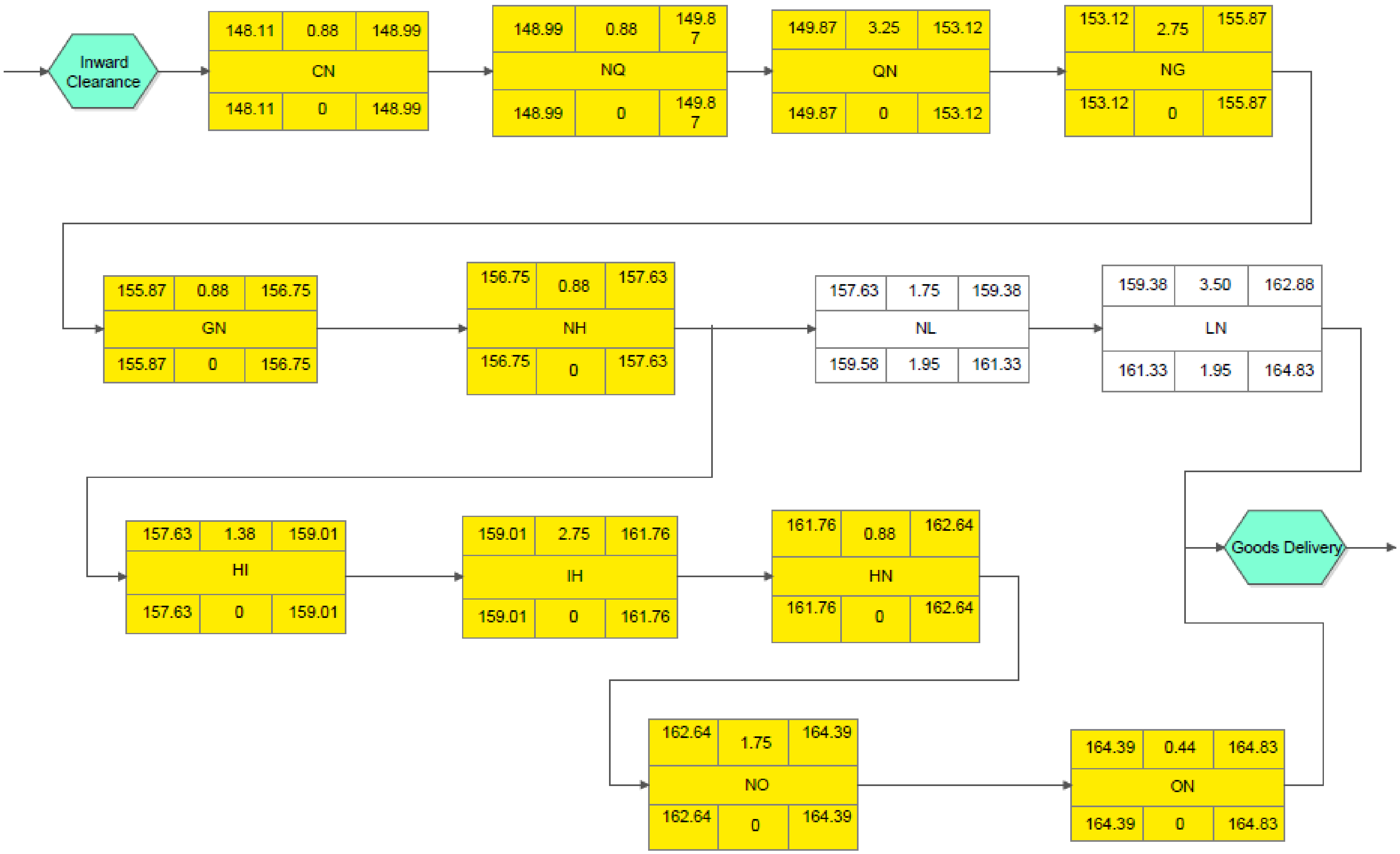


Figure 4.7 : Activity diagram for goods delivery

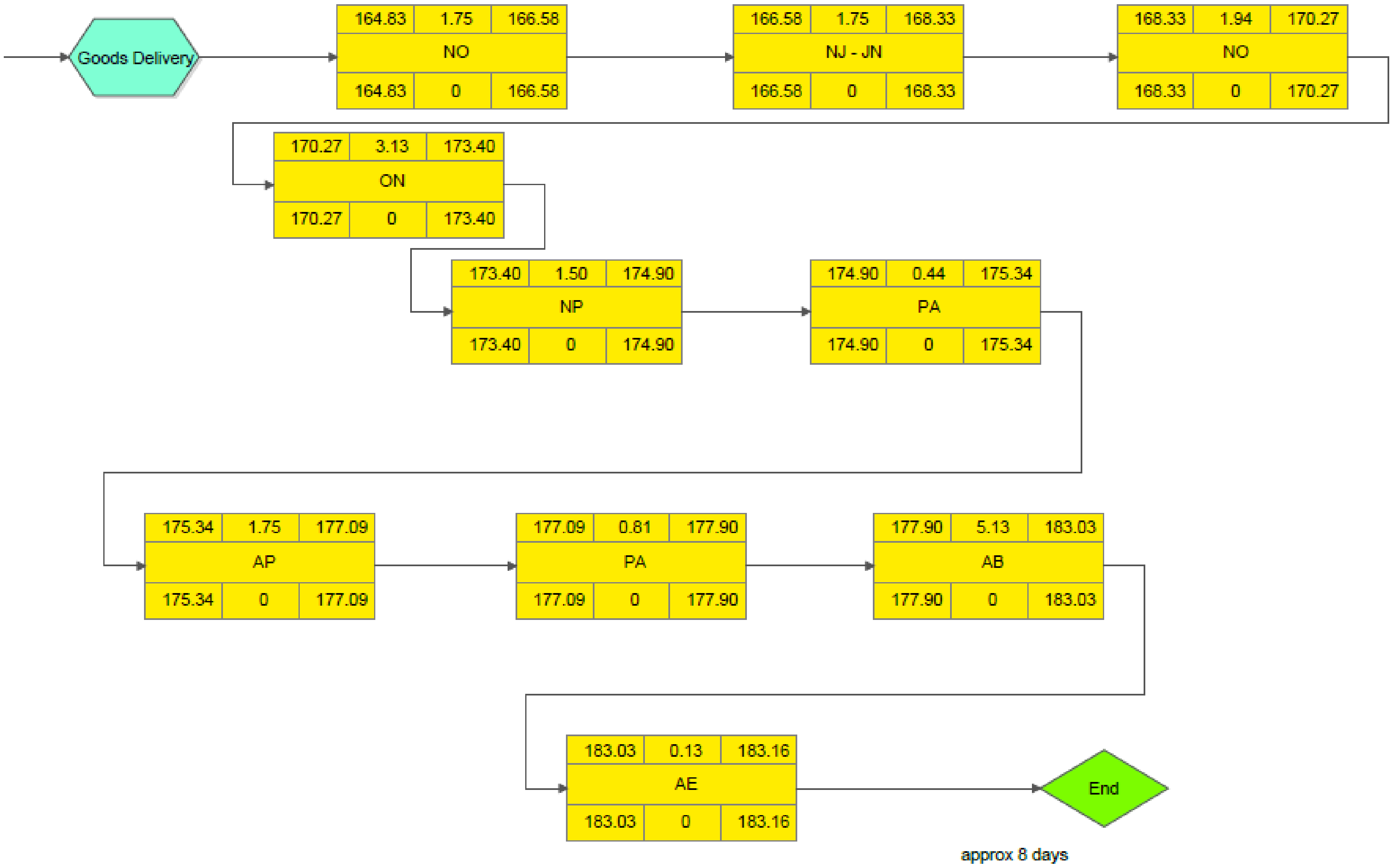


Figure 4.8 : Activity diagram for aircraft repair – Project completion

In the above illustrated PERT diagrams, critical path was identified by activities having zero slack time and those activities marked in yellow in the network diagram.

50 critical communications involved in the procurement process and it takes 7 days and 14 hours to search, purchase and supply a spare part. Most strenuous activities are the communication activities involved with supplier for order confirmation, payment process, logistics arrangement and transport.

Communication activity is denoted by two alphabetical letters and each letter denoted the stakeholder responsible for that particular communication. For example, ‘AB’ is used to indicate the communication activity and information transaction from A, the engineer to B, the planning officer.

4.5 Gantt chart for Critical Path

Gantt chart drawn for the activities in the critical path shows that relationship between two adjacent activities within the chain is finish to start. All activities are sequential and need wait the predecessor activity to finish to start the successor activity.

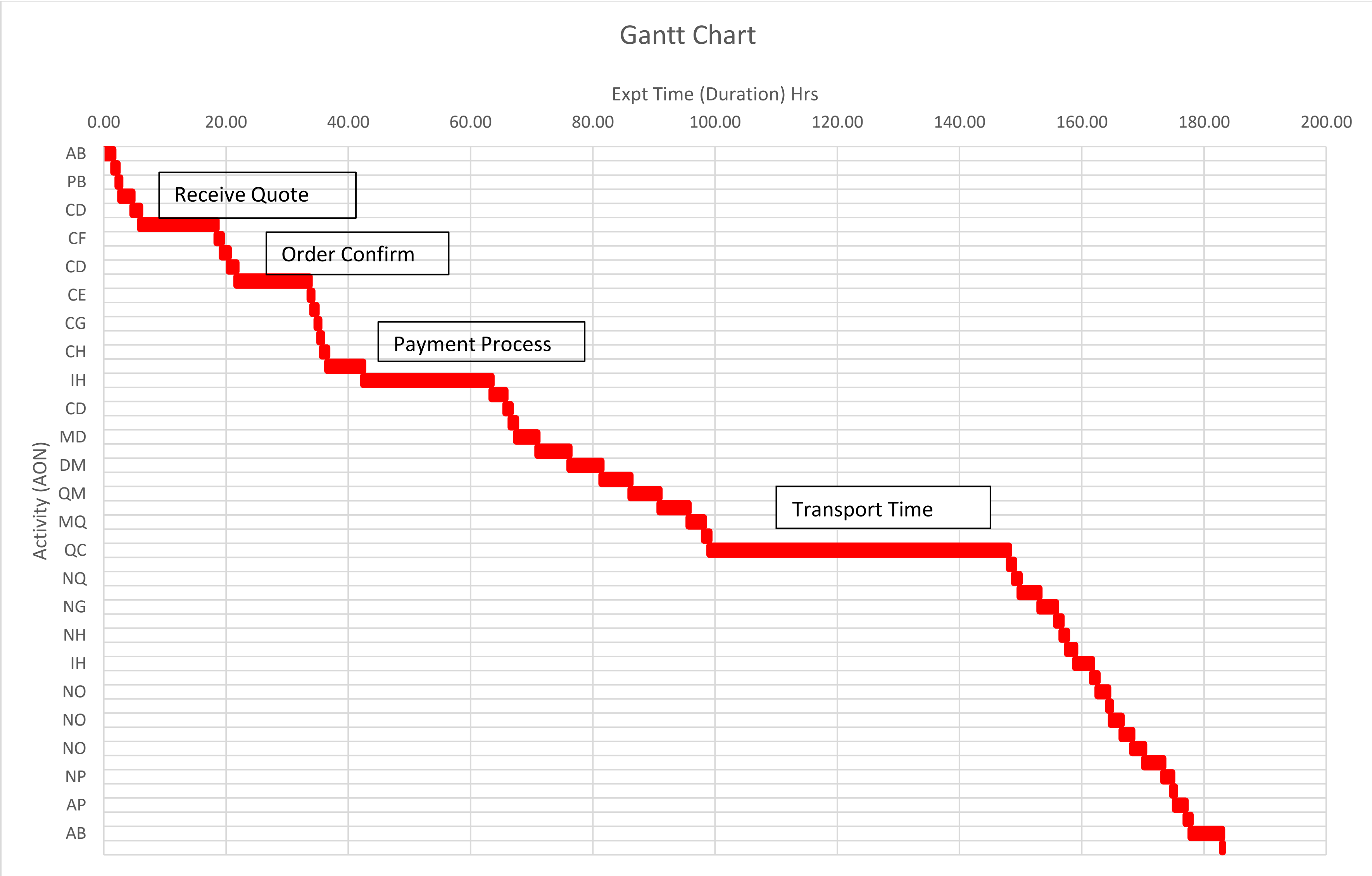


Figure 4.9 : Gantt chart for spare parts procurement critical part

4.6 Sources of communication and information shared

To identify the best mode of communication and most important information types, mapped the activities, information shared and communication flow and the results tabulated in Table 4.2. Stakeholder(s) that initiate the activity was considered as the owner of the communication activity and communication flow between owner and the other stakeholders plotted with communication medium and information types shared. Key variables communicated was identified and listed in the matrix. With the help of data in table 4.2 summarizes the findings as follows;

Mostly communicated information are

- Part number and IPC (illustrated parts catalogue)
- Quality, warranty, certification
- Lead time
- Price
- Supplier bank details
- Country of origin and country of shipping

Main sources of communication identified are

- Emails
- Tech log book entries
- Verbal messages
- Documents – catalogues, certificates, Purchase Order, Invoice, Packing List, Air Way Bill, Wire Transfer receipt

Table 4.3 : Sources of communication used for information sharing (part 1)

Activities, Information Shared and Communication Flow

Activity	Owner	Information Communicated	Communication Tools Used	To Whom Communicated	Flow of Communication	Order of Communication	Variables
1. Identify technical failure	Engineer (A)	Identify the fault, U/S component, PN to replace	Email (Unformatted), Technical log book, Verbal	B,E	(A,B) (A,E)	(A,B) (A,E)	Part number
2. Check inventory	Planning officer (B)	PN	Verbal	P, A, E	(B,P) (P,A) (P,B) (B,E)	1. (B,P) 2.(P,A) (P,B) 3. (B,E)	Part number
3. Repair the aircraft	Engineer (A)	aircraft airworthiness	verbal, log book	B,E	(A,B) (A,E)	(A,B) (A,E)	airworthiness
4. If no stocks, demand spares	Planning officer (B)	PN, Alt PN, qty, condition, req date, IPC	Email (tablutated)	C	(B,C)	(B,C)	Part number, Qty, Price, Quality, delivery date
5. Send RFQ	Procurement officer (C)	PN, Alt PN, qty, condition, req date, IPC, payment term, warranty	Email (tablutated)	D	(C,D)	(C,D)	Part number, Qty, Price, Quality, delivery date, warranty
6. Receive quotations	Supplier (D)	PN, Alt PN, qty, quality, lead time, price	Email/Formatted quote	C	(D,C)	(D,C)	Part number, Qty, Price, Quality, lead time, supplier, location, payment terms, warranty

Table 4.4 : Sources of communication used for information sharing (part 2)

Activities, Information Shared and Communication Flow

Activity	Owner	Information Communicated	Communication Tools Used	To Whom Communicated	Flow of Communication	Order of Communication	Variables
7. Conformity approval	Proc Officer (C)	Quotation Summary	Email (tablutated)	F	(C,F) (F,C)	1. (C,F) 2. (F,C)	Part number, Qty, Price, Quality, lead time, supplier, location, payment, warranty
8. Place the order	Proc Officer (C)	PO with shipping instructions, forwarder	Email/Formatted PO	D	(C,D)	(C,D)	PN, Qty, price, quality, warranty, shipping method, delivery address
9. Order acknowledge	Supplier (D)	Invoice, order acknowledgement	Email/ Formatted OC	C	(D,C)	(D,C)	PN, qty, price, quality, warranty, beneficiary bank details
10. Payment approval	Proc Officer (C)	approval request for invoice & PO	Email/(Formatted)	E, G, H	(C,E) (E,C) (C,G) (G,C) (C,H)	1. (C,E) (E,C) 2. (C,G) (G,C) 3. (C, H)	PN, qty, price, beneficiary ank details
11. Import approvals	Proc Officer (C)	PN, Qty, Con, COO, COE, price, supplier, TDS	Letter (formatted)	J, K, L	(C,J) (J,C)(C,K) (K,C) (C,L) (L,C)	1. (C,J) (C,K) 2. (J,C) (K,C) 3. (C,L) (L,C)	PN, qty, cond, price, COO, COE,
12. Process payment	Finance Mgr (H)	invoice, wire transfer advice	Letter (formatted)	I, H	(H,I) (I,H) (H,C)	1. (H,I) (I,H) 2. (H,C)	Beneficiary bank, Remitter bank, invoice value, currency

Table 4.5 : Sources of communication used for information sharing (part 3)

Activities, Information Shared and Communication Flow

Activity	Owner	Information Communicated	Communication Tools Used	To Whom Communicated	Flow of Communication	Order of Communication	Variables
13. Logistics arrangment	Proc Officer (C)	TT advice, Forwarder, Shipping mode	Email (unformatted)	D, M	(C,D) (C,M) (D,M) (M,C) (M, D)	1. (C,D) (C,M) 2. (D,M) 3. (M,C) (M,D)	payment, forwarder, shipping mode
14. Goods on board	1. Supplier (D) 2. Forwarder (M)	Invoice, PL, tracking/AWB	Email (unformatted)	C, M	(D,C) (D,M),	(D,C) (D,M)	PN, Qty, Value, tracking
15. Goods arrival doc rele	1. Carrier (Q) 2. Proc Officer (C.)	Invoice, PL, tracking/AWB	Email (unformated)	C, N	(Q,C) (C,N) (N,Q)	1. (Q,C) 2. (C,N) 3. (N,Q)	PN, Qty, value, date
16. Pre-clearance	Customs broker (N)	cusdec, invoice, PL, AWB, DO, approvals	cusdec, physical	G, H, I	(N,G) (G,N), (N, H) (H,I) (H,N)	1. (N,G) (G,N) 2. (N,H) 3. (H,I) (I,H) 4. (H,N)	PN, Qty, value, date, HS code
17. Import clearance	Customs broker (N)	cusdec, invoice, PL, AWB, DO, approvals	verbal, physical	I, J, L, O	(N,I) (N,J) (J,N) (N,L) (L,N) (N,O) (O,N)	1. (N,I) 2. (N,J) (J,N) 3. (N,L) (L,N) 4. (N,O) (O,N)	qty, PN, value, HS code
18. Receipt of goods	Customs broker (N)	invoice, PL	verbal, physical	P	(N,P)	(N,P)	qty, PN, qaulity
19. Verification, stock in and stock out	Stores officer (P)	quality, qty conformity	verbal, email (unformatted)	A, E, C, F	(P,A), (P,F) (P,E) (P,C)	1. (P,A) 2. (P,F) (P,E) (P,C)	PN, qty, quality
20. Aircraft repaired	LLM/Engineer (A)	repair the aircraft	verbal, log book	E, B	(A,B) (A,E)	(A,B) (A,E)	repair information

4.7 Observations

Both Gantt chart and PERT diagram indicate the process has four major time constraints. They are

- Receiving quote from a supplier and order confirmation to the supplier takes minimum 12 hours each due to the geographical zone difference. To make purchasing decision and place the order it takes 34 hours and from that time 24 hours are waiting time for receiving response from the supplier.
- Payment to effect at supplier's bank account takes 21 hours, almost a day.
- Once payment effects, communication activities relevant to cargo pick up, flight booking and handing over to the carrier takes 31 hours, this is one and half a day
- Transportation of parts from USA to Sri Lanka takes minimum 49 hours, more than two days.

These activities occur at external stake holders in the upstream of the supply chain and has limited control to the operator.

The geographical location and time zone difference cause very high negative impact in communication, even with the use of advanced information and communication technology tools for communication.

Handling of logistics and transport is complex and involved with high risks of change in flight schedules, cargo offloading which results in delivery delays.

Forwarding agent and carrier are responsible for logistics arrangements and transport. When transporting urgent spare parts, very high freight charges to be paid to book space with carriers at short notice. Often forwarding agents have contracts with airlines for agreed payload for high traffic routes so that at any given time, agent can book flight to carry emergency cargo. If not, cargo must airlift on first come first serve basis. Then light cargo shipped in passenger flights bellies and heavy and oversized cargo transported in freighters which require waiting in the queue for transportation.

Under all these circumstances, for an aircraft part to search, purchase and deliver require minimum 7 days and 14 hours. Refer PERT critical path diagram figures 4.4 to 4.8.

In the PERT diagram, there are several communication activities that are not critical but required for completion of importation of aircraft spare parts. They are

- Obtaining authority approvals prior shipping the spare parts. These approvals can be obtained in one and half a days' time until the payment arranged for the purchased spare part. Refer figure 4.5.
- Cancellation of import license once goods arrived. This can be attended while inward clearance processing at BOI. Refer figure 4.6.

4.7.1 Activities that can be most likely to make errors

- Figure 4.5; Activities AB and BC – fail to identify correct part which cause aircraft un-airworthy or while communicating the part number to procurement, digit or letter could mistakenly written and sent to procurement.
- Figure 4.5; Activity CD – procurement can make mistakes in typing the part number sending RFQ to supplier
- Figure 4.5; Activity DC - Supplier's supplier can send different part number than what is requested due to an error in communication in between suppliers and brokers. Further supplier invoice may not have complete information to process payment. Incomplete information can create delay in supply of spare part and as a result, can consider as a communication error.
- Figure 4.7; Activity MQ – when forwarding agent communicate to the airline, there can happen mistakes either at agent or at airline by giving a wrong delivery address or declare the cargo under wrong harmonized code. Mistakes in airway bill can cause long delays in transportation.

4.7.2 Most common errors

By experience, identified several most common mistakes take place in communication and information sharing which cause major delays as well as extra costs.

- Incomplete or wrong part number given by the engineering team either due to typing errors or wrongly identified technical fault
- Supplier ship different part number instead the purchased part number especially when parts are directly shipped from 2nd tire suppliers on behalf of the 1st tire supplier

- Goods shipped to different location without following the given delivery instructions. This occurs at logistics department at the supplier or at forwarders due to negligence and/or carelessness.
- Short delivery of order without prior information

4.7.3 Most involved stakeholders for procurement process

Reference the results obtained from table 4.2, frequency chart prepared to determine the frequency of stakeholder's involvement in 20 key activities identified in aviation spare part procurement process.

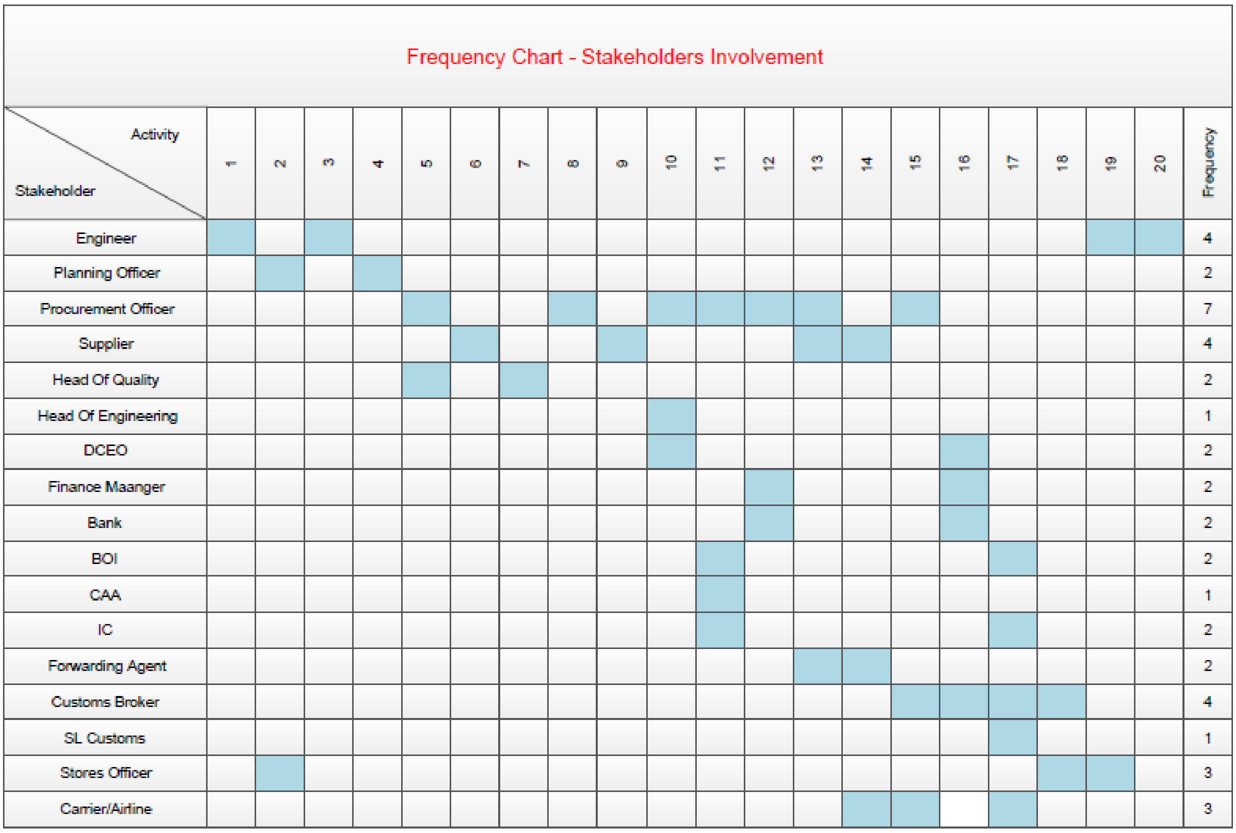


Figure 4.10 : Frequency of stakeholder involvement in communication activities

Frequency chart, figure 4.9 shows the activities that each stakeholder responsible for and the frequency of taking part in communication and information sharing the procurement supply chain. Figure 4.10 was drawn to identify the most involved stakeholders in the supply chain.

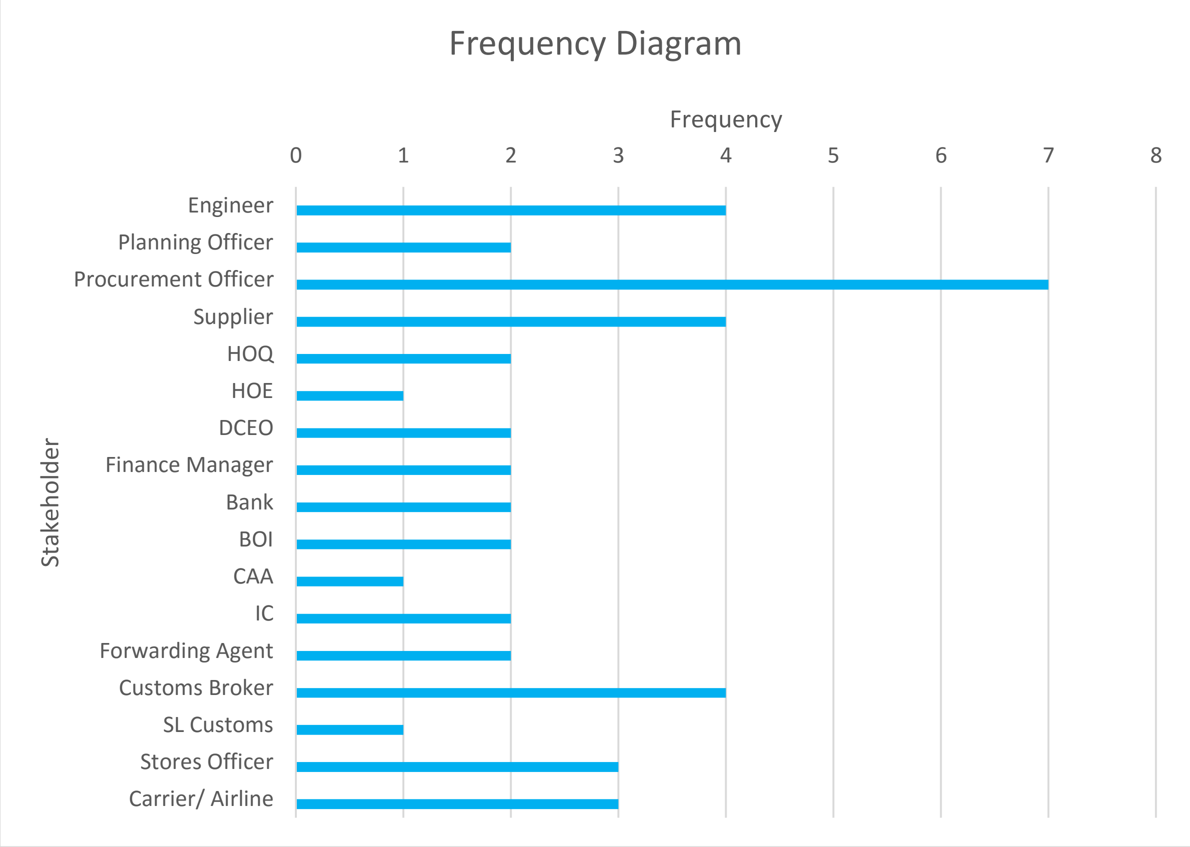


Figure 4.11 : Frequency diagram – Stakeholder involvement

As per the above figure 4.11, the most involved stakeholders in the spare parts procurement process are identified as;

- Procurement officer
- Engineer
- Supplier
- Customs broker
- Airline or the carrier
- Stores officer

This shows the gravity of responsibility in the shoulder of procurement officer, then engineer, supplier and customs broker in completing procurement task satisfactorily.

4.7.4 Priority order of communication identified

Communication activities and the key information required to communicate in order to minimize delivery delays can be explained in table 4.2 and critical path diagrams illustrated in figures 4.4 to 4.8. Activities are listed in sequential manner and priority order of communication starts with engineer finding the technical fault in the aircraft, recognize the part number to be replaced, request supply the same for aircraft repair. Then planning officer pass the information to procurement officer and commence search the part, purchase and deliver to the line station for aircraft repair.

5 Discussion of Results

5.1 Interpretation of results

Research data analysis shows that information and communication play key roles in supply chain management. Any short coming in information shared or communication can lead to delays in the supply of aircraft parts. There is an impact of information and communication on delivery lead time. Examples are discussed as follows;

a) The proxy for the case study is an old model aircraft in the fleet. Lack of economies of scale caused difficulty in maintaining service contracts directly with OEM, MRO or airline having similar type of aircraft in the fleet. As a result, Fits Aviation procurement value chain often extended to 2nd tire suppliers during parts search. Therefore, timely communication of right information is very important to keep the delays at a minimum when making purchasing decisions. When sending quotation requests for parts supply, communicated information repeated and reproduced within the supplier as well as among the suppliers in the upstream of supply chain to find the aircraft part. If any error in communicated information occurs during this information transformation, it can result in supply of a wrong part. If the wrong part received, correct part to be re-order and wrong part need to return. These create additional costs to the operator and long delays in repairing the aircraft.

b) Communication flow matrix illustrated the responsibilities of each stakeholder in communication of information across the supply chain for successful completion of a procurement process. Engineer (A), Planning Officer (B), Procurement Officer (C), Supplier (D) and Forwarding Agent (M) are the key responsible people in the procurement process.
In this case "D" denotes communication between 1st tire supplier and Fits Aviation Procurement Officer. The communication between 1st tire supplier and 2nd tire supplier transaction cannot demarcate as the duration and communication flow not disclosed to the customer. This is one of the gray areas in the information and communication flow among external stakeholders in the aviation supply chain.

Communication between forwarding agent (M) and carrier (Q) also cannot be measured as it happens externally and agent doesn't disclose the details of flow of information and communication. Therefore, room for improvements in communication activity duration is limited.

c) PERT diagrams indicate that communication activity on node and flow direction from the arrow. The information shared are listed under section 4.6, sources of communication and information shared. Within the PERT network there are several communication activities which are more susceptible for making information and communication errors causing delays in delivery of spare parts.

   I. Activity AB, figure 4.4: If engineer made a mistake in identifying the unserviceable part number, the erroneous part number will be requested for purchase and supply. Until the part is fixed and tested this mistake will not highlighted. Then procurement has to undertake the same exercise for different part number on AOG basis. This cause high costs to the operator.

   II. Activities BC, CD and DC, figure 4.4: When complete information about the part required purchase is not communicated in 1st communication, information to obtain in several steps of communication which leads to delay the purchasing decision. Since aviation spare parts need conform to the quality and safety airworthiness requirements, it is essential to know the available certificates, back to birth history and tested date and accuracy of the part number in making purchasing decision.

   III. Activity DM, figure 4.6: If the logistics department at supplier, made mistake in communicating delivery address forwarder can ship parts to wrong address. Same time, if the logistics department mistakenly handover the wrong package to the forwarder, consignee will receive wrong parts at destination. There will be long delays and high costs to the operator in both incidents.

   IV. Activity IH, figure 4.5: Bank will fail to transfer funds to the supplier, if the supplier's bank details are not clearly and accurately declared in commercial documents.

V. Activities MQ and QM, figure 4.6: these two communication activities are critical for logistics arrangement. Very essential to communicate clear instructions and right information; cargo type, weight and dimension, urgency, delivery address etc. to the carrier and get confirmation on space availability, transit points and flight schedules.

VI. Activity QC, figure 4.6: with advanced ICT tools, shipments in transit can be monitored and both the shipper and consignee can have real time tracking of the package. This is very useful in AOG deliveries to monitor the movement of the parts and adopt alternative solutions if there are any deviations from the scheduled delivery plan.

Findings from literature review in chapter 2, recognizes information and communication as two key influential factors that can create high impact on delivery lead time in supply chain management. For example;

- "Supply chain management practices and information system practices are inextricably intertwined and need integrative approach to improve the efficiency of the supply chain" (Ekrem Tatoglu et al., 2016)
- Fiala in his research, identified information asymmetry as a source of inefficiency in the supply chain. He has said that supply chain partnership leads increase in information flow, reduce uncertainty and reduce costs. (Fiala, 2005)
- Fiala (Fiala, 2005) describes successful stories of information sharing for the improvement of efficiency of vendor managed inventory of supply chain management at world famous international organizations, Campbell and Barilla S.P.A, Procter & Gamble and Wal Mart.
- Lee and Whang have identified inventory levels, order status, delivery schedule and sales data as frequently shared different types of information in supply chain management. (H. Lee & Whang, 2000)
- Treuner in his survey on aviation and aerospace supply chains reveals the findings that 91% of the disruption of aviation industry supply chain occurs in the upstream of the chain and beyond the control of the operator. He claims communication, product quality, supplier inefficiency and freight forwarders as the major contributors for the disruptions. ("Aviation and aerospace supply chains move eastwards," n.d.)

RFID, GPS, ERP, cloud computing, computerized shipping and tracking are few examples of ICT tools that are used in supply chain management, creating better visibility within the supply chain which will, enable to have more control over the business and stay ahead of the competition. These technologies electronically link the members of supply chain and provide end to end electronic communication and automatic data capture and transmission. These provide cheap, faster and convenient real time communication and information among stakeholders in the supply chain. (Krmac, 2005)

In Chapter 4.4, PERT diagrams shows that current aircraft spare parts procurement procedure is a complex sequential chain of communication and information flow that follows execution of one activity after the other. Except obtaining authority approval, all other activities need start after finishing previous activity. As a result, the time taken for purchase and supply aircraft spare part is as long as seven and half days. This network was identifying as an inefficient procurement system which needs improve to reduce delivery lead time of aircraft spare parts.

It is recommended to further study the internal communication flow within the operator, across the departments, to introduce parallel processes for critical activities such as obtaining quality approval and payment process approvals.

5.2 Critical evaluation of the study

This research was done to study the impact of information and communication on spare parts delivery lead time at AOG situations in aviation industry. The main concern was to identify the communication errors, key information that lead to delay in delivery lead time during procurement of aircraft spare parts. Refer to the case study, data analysis and observations, there is an impact of information and communication on delivery lead time. This impact can be positive or negative depend on the extent of information shared and effectiveness of communication channeled across.

Research findings further shows that long waiting hours such as one and a half day caused in the procurement process due to globalization of spare parts distribution. Operator and supplier are geographically located at different time zones and this gap creates 10 to 12 hrs waiting time for feedback from one party to the other.

Similarly, due to the unpredictable nature of logistics and transport facilities, time taken for transportation of spare parts will be extended than 82 hours and 30 minutes predicted in figure 4.5. These activities are beyond the control of operator and supplier as transporters have higher bargaining and controlling power in logistics services.

The model organization uses formatted and unformatted emails as main source of communication to transfer information to internal and external responsible people. Key feature of these email communications is the structured format adopted for easy understanding and minimize loss of information or wrong information transformation. This is avoid misreading the message due to language barriers when communicating with international suppliers where the native language is different from English. This is a benefit to the effective communication. Key information communicated across the supply chain are included part number, quantity, quality and certification, warranty, delivery lead time, price, transport mode and the forwarder/Airline.

Key people responsible for spare parts procurement are identified as Procurement Officer, Engineer, Supplier, Customs broker and Airline. If any of these representatives make a mistake in communication or information transferring, it will create huge negative impact on the delivery lead time due to extra time to be spent on doubts clarification and repeat action for correcting the error.

Gantt chart revealed the bottlenecks in the system that contribute to the delay in delivery lead time. Even though the information transfer instantaneously, feedback communication activity takes place delayed due to the external factors discussed above and ability to control are very limited.

- Quotation received
- Order confirmation
- Payment process
- Transport time

In this research, the procurement supply chain was studied under 20 key activities which further elaborated with sub activities mainly to estimate the time taken for each communication activity. During the time intervals estimate, lag and lead times related to activities were considered as embedded in the predecessor and successor respectively. This is due to the limited time availability for completion of the project.

But if we can communicate with the respective stakeholder and obtain permission to do a time study for each activity to identify the lag time and lead time, it will help to reorganize the PERT diagram and establish the new critical path which can be taken as a guide to leveling or crashing activities to reduce the activity completion time.

These bottleneck activities which have long duration time, can be evaluated for value generating causes and non-value generating causes. Thereby eliminate the non-value activities. When the contributing factors for waiting time was identified, it is easier to schedule the activity with a lag or lead for predecessor and successor.

The expected outcome of this study was to propose methods to reduce the operational costs by minimizing communication errors, reduce the spare parts delivery delays during AOG situations.

In order to achieve this, as mentioned in previous chapters, it is necessary to eliminate non-value activities in the information and communication flow. Propose re-structure the procurement process in such a manner time taken for internal communication is minimized and happened parallel instead serial. Further structure the communications as much as possible to minimize errors that can occur during communicating information.

For communication activities takes place within the organization, activity time duration can be reduced by introducing several changes to the current procurement system.

Proposed changes to internal procurement procedure are;

I. With the ICT tool, cloud facilities (Office 365) share the spare parts inventory list among engineer, procurement and stores and update by stores officer the inventory list daily basis to validate the information shared. By this method, activities BP and PB can eliminate from PERT diagram in figure 4.4. This saves 1 hour and 10 minutes approximately.

II. Once received order confirmation, an email can be shared with all three management representatives; Head of Engineering, Deputy Chief Executive Officer and Finance Manager for payment approval. Enable them to approve the Invoice and Purchase Order for payment in one communication platform sequentially following the organization's communication protocol. This will save time for procurement officer by eliminating resending the same email three times to each individual. Order approval hierarchy remains same but people replying to one same email. If not, the approval required Purchase Order and Invoice/Order Confirmation can shared in one drive given options to comment. One approved, finance can communicate the payment request to the bank using shared invoice and purchase order. This method not only saves time but also reduce the paper usage in the organization and results in reduction of overhead costs. If this approach becomes successful, steps CG and CH activities from figure 4.5 can eliminate with a saving of 1 hours and 30 minutes approximately. In order to ensure everyone response timely, IT system can generate reminder pop ups until the process completes.

III. To reduce the delay in payment arrangement, procurement need to have contracts with frequently dealing vendors for credit facilities for emergency purchases. Then activities HI, IH and HC from figure 4.5 will become non-critical communication flow. Time saved will be 29 hours and 10 minutes for the payment process.

IV. Once order confirmed and until goods are prepared for shipping, supplier can update the forwarding agent with package details; commodity, weight and dimensions. So that forwarding agent can check with airline for temporary flight booking to minimize the waiting time. Supplier can share the invoice and packing list with forwarding agent to make the communication with the airline easier. Then the duration for activities in figure 4.6 from CM to MQ can be reduced and thereby reduce the delivery lead time.

This research was carried out with experiences and data collected from a small scale international air cargo operator. So that the findings will be more suitable for similar type of airline operator to be adopt for their delivery lead time improvements.

Further, this operator had a single aircraft in that type in his fleet and the analysis may differ if the fleet had several aircraft from the same time. It will help especially in identification of part number with the fault faster with more confident than previous case. Also, the operator can invest on more spare parts to be stocked in the airline inventory due to the frequent stock turn.

On the other hand, if the same operator under same conditions, found in geographical location such as North America, Europe or Africa the delivery lead time of spare parts would be much less. When more operators having similar aircraft in their fleet, vendors can be found established their business in those regions. As a result, access to spare parts are easier and faster. Airlines even can borrow spare parts from other operators at an AOG situation to reduce delivery lead time.

6 Conclusion and Recommendations

6.1 Conclusion

The research findings show that information and communication flow can highly influence the delivery lead time of aviation spare parts procurement process. If any communication error occurs in the upstream of the supply chain, it causes delays in purchasing decision making and thereby delay the supply of spare part to the line station.

The costs involved with delivery lead time delay in supplying aircraft spare parts during an AOG situation can demonstrate as follows;

In order to demonstrate the AOG cost, below figures are arbitrarily taken for calculation. These do not take from the operator. Assume;

No of flying hours per month = 150

Average no of flying hours per day = 5

Operating cost of the aircraft per hour = USD 3000

Additional per hour cost to the operator at AOG situation = USD 650

Delivery lead time of spare parts, Figure 4.8 = 183 hours (assume 8 days)

If the spare part delivered as per the estimated time, AOG cost = 8 x 24 x 650 = USD 124,800

Any delay in spare parts delivery to line station during an AOG situation will cause increase in this AOG cost to the operator.

Therefore, spare parts delivery lead time in aviation industry is very critical and factors contributing to such delays need to eliminate. Therefore, communication errors need to eliminate in aviation supply chain.

6.2 Recommendations

In order to eliminate spare parts delivery delays and lost to the airline operator propose improvement to the communication methodology.

- Adopt formatted structure in email communication, always present technical data and requirements in a tabulated form to minimize communication errors in both generating and receiving the information.
- Share the information among stakeholders using common platform such as cloud communication so that repetitions are minimized
- During email communications, always mention only the key points in bullet form

The research can be extended to medium air cargo operator having several aircraft from same type in the fleet for the comparison of findings. Then generalize the results for freighter operators in the region to consider as a model for improving delivery lead time for their individual procurement supply chins.

7 Bibliography

Airbus. (2015). Airbus Procurement Organisation, (June). Retrieved from http://www.airbus.com/company/americas/us/alabama/information-for-suppliers/procurement-strategy/

Airbus and Boeing put pressure on supply chain. (n.d.). Retrieved January 9, 2018, from https://www.ft.com/content/e0d51872-516c-11e6-9664-e0bdc13c3bef

Aircraft MRO & Engine Maintenance Repair & Overhaul Engineering Services | Delta TechOps. (n.d.). Retrieved January 9, 2018, from http://www.deltatechops.com/

Aircraft Spare Parts Pooling: Art Or Science? (n.d.). Retrieved January 9, 2018, from http://www.mro-network.com/maintenance-repair-overhaul/aircraft-spare-parts-pooling-art-or-science

AOG Loan-Borrow Recovery | Sterling Courier. (n.d.). Retrieved January 16, 2018, from http://sterling.quick.aero/logistics/aog-aircraft-parts-rapid-return-recovery

Aviation and aerospace supply chains move eastwards. (n.d.).

Baker, J. (2014). American Airlines, (July), 1–2.

Benefits, S., Transport, A., & Findings, K. (2017). Fact Sheet Aviation Benefits Beyond Borders, (December).

Boeing Case Study | Operations Management | Supply Chain. (n.d.). Retrieved January 14, 2018, from https://www.scribd.com/document/323294873/Boeing-Case-Study

Boeing Set to Use 3D Printed Titanium Parts for 787 - 3D Printing. (n.d.). Retrieved January 13, 2018, from https://3dprinting.com/metal/boeing-3d-printed-titanium-parts-787/

Cachon, G., & Fisher, M. (2000). Supply chain inventory management and the value of shared information. *Management Science*. Retrieved from http://pubsonline.informs.org/doi/abs/10.1287/mnsc.46.8.1032.12029

Cord Blood Company - Quick Specialized Healthcare Logistics. (n.d.). Retrieved

January 17, 2018, from http://healthcare.quick.aero/about-us/case-studies/cord-blood-company/

Delivery of Time- and Temperature Sensitive Donor Tissue During a Major Snowstorm - Quick Specialized Healthcare Logistics. (n.d.). Retrieved January 17, 2018, from http://healthcare.quick.aero/about-us/case-studies/delivery-of-donor-tissue/

Denning, S. (2013). What went wrong at Boeing. *Strategy & Leadership*, *41*(3), 36–41. https://doi.org/10.1108/10878571311323208

Europe, E., Canada, A., Zealand, N., Airlines, A., Airlines, B., Airlines, C., … Airlines, T. (2010). Deutsche Lufthansa AG. *Corporate Communications*, (June).

Everything You Need To Know About PERT in Project Management. (n.d.). Retrieved January 21, 2018, from https://tallyfy.com/pert/

Fiala, P. (2005). Information sharing in supply chains, *33*(5), 419–423. https://doi.org/10.1016/j.omega.2004.07.006

Fritzsche, R., & Lasch, R. (2012). An integrated logistics model of spare parts maintenance planning within the aviation industry. *Proceedings of World Academy of Science,*. Retrieved from http://www.waset.org/publications/8970

Gu, J., Zhang, G., & Li, K. (2015). Efficient aircraft spare parts inventory management under demand uncertainty. *Journal of Air Transport Management*. Retrieved from http://www.sciencedirect.com/science/article/pii/S0969699714001288

How to Handle AOGs: An Airline’s Perspective — Skylink. (n.d.). Retrieved January 8, 2018, from http://www.skylinkintl.com/blog/how-to-handle-aogs-an-airlines-perspective?rq=aog cost

IATA. (2015). *Guidance Material and Best Practices for Inventory Management*. Retrieved from https://www.iata.org/whatwedo/workgroups/Documents/MCTF/inventory-mgmt-2nd-edition.pdf

IATA - About Us. (n.d.). Retrieved January 13, 2018, from http://www.iata.org/about/pages/index.aspx

Inderfurth, K., Sadrieh, A., & Voigt, G. (2013). The Impact of Information Sharing on Supply Chain Performance under Asymmetric Information. *Production and Operations Management*, *22*(2), 410–425. https://doi.org/10.1111/j.1937-5956.2012.01372.x

International Civil Aviation Organization. (n.d.). About ICAO. Retrieved January 13, 2018, from https://www.icao.int/about-icao/Pages/default.aspx

Kamaleswaran, by A., & Ramachandram, L. (2015). IMPROVING DELIVERY LEAD TIME IN MEDICAL DEVICE SUPPLIES TO PUBLIC HOSPITALS IN MALAYSIA. Retrieved from http://eprints.usm.my/30647/1/KAMALESWARAN_AL_RAMACHANDRAM.pdf

Kost, G. J. (1986). Application of Program Evaluation and Review Technic (PERT) to Laboratory Research and Development Planning. *Am J Clin Pathol*, *86*, 186–192. Retrieved from https://watermark.silverchair.com/ajcpath86-0186.pdf?token=AQECAHi208BE49Ooan9kkhW_Ercy7Dm3ZL_9Cf3qfKAc485ysgAAAa0wggGpBgkqhkiG9w0BBwagggGaMIIBlgIBADCCAY8GCSqGSIb3DQEHATAeBglghkgBZQMEAS4wEQQMaGNej3rUjGoFKAXFAgEQgIIBYKD60i-MA1S0vNPB_dV3tvnwFhAVpsBiONGBnqStJZbrqcXz4WdfEAE9N1vbQViYcEuwoXLiKZnlFh1Ad1XsBcfZY0rrHfjnnTbVPCiTyByfkp5Zvn8Ltr-Z2MJXdnzaU48LHThcEniENyp3XI8AAjLXYAYA6LuUw__Nf65Y_Xz6u1bOhy-2mm1hwUi8wWfM234pCK3QHRzvLFHedYCndiXGN4dADEWwpqD5pK060HO92sWBoTNML1U3E402pzSU7f2t5XfeWodQE3AtHA2_MzjSrFYbpuRZ6fE_umdewlyrvwZnT32rIRPBId_UmqLQ1IcsikSgfWVFCdcpODpUEgnR9qumN2vqDkUM47hGFa617pwauV2oH59cDJkXrOOEcpTxPbIi8aLccHEJ_xiEZBSOUJaKBhx4jx75OYglW_7k5U73wW7zvfwQyHM8T2YSbsKfDI-o9sm_nstMae51tlI

Krajewski, L. J., Ritzman, L. P., & Malhotra, M. K. (2013). *Operations Management:Processes and Supply Chains: Global Edition*. *Operations Management*. https://doi.org/10.15358/9783800644858

Krmac, E. V. (2005). TECHNOLOGIES AND TOOLS FOR SUPPLY CHAIN, 303–309.

Kuckelhaus, M., & Yee, P. M. (2016). 3D Printing and the Future of Supply Chains. *DHL Customer Solutions & Innovation*, *November*(November), 1–31. Retrieved from http://www.dhl.com/content/dam/downloads/g0/about_us/logistics_insights/dhl_trendreport_3dprinting.pdf

Lee, H. L. H., & Whang, S. (2000). Information sharing in a supply chain. *International Journal of Manufacturing Technology*. https://doi.org/10.1016/j.omega.2014.08.001

Lee, H., So, K., & Tang, C. (2000). The value of information sharing in a two-level supply chain. *Management Science*, *Lee, H., S*. Retrieved from http://pubsonline.informs.org/doi/abs/10.1287/mnsc.46.5.626.12047

Lee, H., & Whang, S. (2000). Information sharing in a supply chain. *International Journal of Manufacturing*. Retrieved from http://www.inderscienceonline.com/doi/abs/10.1504/IJMTM.2000.001329

Lufthansa Technik - Lufthansa Technik AG. (n.d.). Retrieved January 9, 2018, from https://www.lufthansa-technik.com/

Management, T. L. (2011). Controlling of logistics projects, (4), 107–123.

Mathew, J., John, J., Kumar, S., & Management, O. (n.d.). New Trends in Healthcare Supply chain. Retrieved from https://www.pomsmeetings.org/confproceedings/043/fullpapers/fullpaper_files/043-0259.pdf

Mayer, A. (2014). Supply Chain Metrics That Matter: A Focus on Aerospace & Defense. Retrieved from https://www.kinaxis.com/Global/resources/papers/metrics-that-matter-aerospace-and-defense-supply-chain-insights-research.pdf

Mocenco, D. (2014). Supply Chain Features of the Aerospace Industry Particular Case Airbus and Boeing. *Scientific Bulletin – Economic Sciences*, *14*(2), 17–25.

MRO & Support : DHL wins two new MRO logistics contracts. (n.d.). Retrieved January 13, 2018, from https://www.journal-aviation.com/en/news/38052-dhl-wins-two-new-mro-logistics-contracts

National aviation authority - Wikipedia. (n.d.). Retrieved January 13, 2018, from https://en.wikipedia.org/wiki/National_aviation_authority

Organs & Tissue - Quick Specialized Healthcare Logistics. (n.d.). Retrieved January 16, 2018, from http://healthcare.quick.aero/organs-and-tissue/

Pros and Cons of Program Evaluation Review Technique (PERT). (n.d.). Retrieved January 15, 2018, from https://blog.ganttpro.com/en/what-are-pert-charts-and-all-about-program-evaluation-and-review-technique/

Rago, L. J. (1968). The Purchasing Function and PERT Network Analysis. *Journal of Purchasing*, *4*(1), 69–81. https://doi.org/10.1111/j.1745-493X.1968.tb00587.x

Saúde, J. M. M. L. da. (2015). Aircraft Maintenance, 25.

Series of management. (n.d.). Retrieved from https://managementmania.com/en/pert-method

Sigala, M. (2005). Collaborative Supply Chain Management in the Airline Sector: the Role of Global Distribution Systems (Gds). *Advances in Hospitality and Leisure*, *1*(December), 103–121. https://doi.org/10.1016/S1745-3542(04)01007-0

Statistical Modeling in Supply Chain Continued: When should we incorporate uncertainty into project schedule estimates? (n.d.). Retrieved January 14, 2018, from https://blog.kinaxis.com/2013/06/statistical-modeling-in-supply-chain-continued-when-should-we-incorporate-uncertainty-into-project-schedule-estimates/

Supply Chain Management: Boeing’s outsourcing flaws. (n.d.). Retrieved January 10, 2018, from http://cmuscm.blogspot.com/2013/09/boeings-outsourcing-flaws.html

Systems, R. (2014). Aircraft Parts Planning, (August).

Tang, C., Zimmerman, J., & Nelson, J. (2009). Managing new product development and supply chain risks: The Boeing 787 case. *Supply Chain Forum: An*, *10*(2), 74–

86. Taylor & Francis. https://doi.org/10.1080/16258312.2009.11517219

Tatoglu, E., Bayraktar, E., Golgeci, I., Koh, S. C. L., Demirbag, M., & Zaim, S. (2016). How do supply chain management and information systems practices influence operational performance? Evidence from emerging country SMEs. *International Journal of Logistics Research and Applications*, *19*(3), 181–199. https://doi.org/10.1080/13675567.2015.1065802

Treville, S. De, Shapiro, R., & Hameri, A. (2004). From supply chain to demand chain: the role of lead time reduction in improving demand chain performance. *Journal of Operations Management*. Retrieved from http://www.sciencedirect.com/science/article/pii/S0272696303000792

Unknown, Tedone, M. J., Sternatz, J., Tiacci, L., Sternatz, J., Stories, T., … Flapper, S. D. (2013). Spares forecasting. *Annals of Operations Research*, *33*(6), 1689–1699. https://doi.org/10.1002/jcaf

UPS is testing drones for delivering medical supplies - Business Insider. (n.d.). Retrieved January 26, 2018, from http://www.businessinsider.com/ups-is-testing-drones-for-delivering-medical-supplies-2016-9