ERASMUS UNIVERSITEIT ROTTERDAM

Erasmus School of Economics

Master Thesis Urban, Port & Transport Economics

Evaluating the Aircraft-On-Ground process:

A mixed-methods study at an airline-inhouse MRO during the COVID-19 pandemic

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Abstract

This thesis research took place during the COVID-19 pandemic from March 2020 till March 2021. In this period the airline industry and related maintenance, repair and overhaul (MRO) industries have been negatively impacted, leading to stronger cost-reduction incentives. Using a mixed-method approach, this thesis research has been able to evaluate a Dutch inhouse airline MRO's emergency resupply process, also known as aircraft-on-ground (AOG) process. Answering the question: What affects the inhouse airline MRO performance in terms of number of AOG cases, lead-time and the probability of cancelled AOG cases during the COVID-19 pandemic?

Qualitative results indicate that a large number of situational factors, such as communication, ambiguity in information and poor facilities can negatively affect the performance of the AOG-process and create differences between production locations at the MRO company. This has been confirmed quantitatively in the number of AOG cases and probability of cancelled orders. Quantitative results also show that the type of aircraft, type of suppliers, distance and the number of flights operated by the MRO company's airline are factors that could affect lead time. Furthermore, the impact of the COVID-19 pandemic on supply chains shows a significant increase in the number of AOG cases while the number of flights and number of checks decrease. This opens opportunities for future research to analyse the effects of the pandemic on the disturbance of global supply chains and AOG processes. Recommendations are provided addressing the airline's network, fleet configuration, and the MRO company's inventory inaccuracies, supplier relationship and data collection.

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1. Introduction

1.1 Impact of COVID-19 pandemic on MRO companies

"While it is still impossible to predict how the recovery will play out, it is clear this is a crisis of a dimension that the aviation and aerospace industry has never experienced" (Hailey, 2020). This quote of Wolfgang Reinert, an employer at one of the biggest Dutch airline inhouse MRO in the world, gives a good impression of how dark the clouds are that have been hanging above the MRO industry. MRO, which stands for maintenance, repair and overhaul, represents all activities for damaged and worn equipment, systems and machinery that need repairing or requires replacement to make it operable again. According to Bhattacharya, Cheffi, Dey, Ayeni, Ball & Baines (2016), the aviation MRO industry can be defined as a product-centric service industry. MRO activities represent a crucial part of an airline's success as technical reliability and in turn passenger trust in an airline's fleet can be decisive to an airline's success (Al-kaabi, Potter & Naim, 2007). Moreover, MRO activities represent a large part of an airline's total cost structure (Freidl, 2009, as cited in Schneider, Spieth & Clauss, 2013). More specifically, according to a report from the International Air Transport Association (IATA), in 2019 airlines spent USD 378 million on average per year, or USD 1,095 per flight hour, on direct maintenance costs (Markou & Cros, 2021.). In 2020, the size of the global MRO industry was almost USD 50 billion. Notwithstanding a contraction by 60% in 2021 due to the COVID-19 pandemic, it may fully recover in some regions by 2023 (Hader & Thomson, 2020) and is expected to further grow to USD 65 billion by 2026 (Globe Newswire, 2021). In addition, depending on world region and scenarios of how the pandemic will evolve, it is expected to be fully recovered by 2023 (Hader & Thomson, 2020). This indicates how significantly de COVID-19 pandemic impacts the MRO industry. This contraction of historic proportion can be explained by two factors. Firstly, the pandemic has caused an unprecedented decrease in passenger travel, leading to mass groundings of aircrafts and in turn a decrease in MRO spending (Adrienne, Budd & Ison, 2020). Secondly, airlines have accelerated the retirement and replacement of older aircrafts that require more heavy maintenance checks and therefore MRO spending.

According to a survey by management consulting company Oliver Wyman, the pandemic has resulted in a significant shift in perceived top disruptors of the MRO industry (Costanza & Prentice, 2021.). In 2019, before the pandemic started, this list of disruptors used to be topped by growth of the original equipment manufacturer (OEM) aftermarket presence, followed by a shortage in maintenance and technical staff , and consolidation in the aftermarket industry. In 2021 though, due to COVID-19, changes in fleet strategies and plans are perceived as the biggest disruptor in the market. This is not surprising considering that most production facilities were closed during the first global lockdown with a heavy impact on global supply chains. The second disruptor was a reduction in both supply and demand, followed by challenges in labour and material cost management.

According to a different survey by Oliver Wyman, most airlines responded to the pandemic by reducing MRO spending and increasing the use of parking and cannibalization of aircrafts, while renegotiating existing vendor supplier agreements and reducing headcount (Constanza & Prentice, 2021). In addition, accelerated fleet retirements have led to supply surpluses of materials and components, in turn resulting in a depreciation of assets held by MRO companies and airlines. After having suffered from this depreciation, MRO companies may opt for holding less inventory in stock and become more reliant on supply chains that can provide emergency resupplies. These supply chains do need to be reliable in their speed as it can otherwise lead to a significant loss in revenue and reputation damage, the latter becoming increasingly important in the competitive airline markets.

1.2 MRO and AOG

Airline inhouse MRO companies are dependent on reliable supply chains for parts because any breakdown thereof can lead to a delay in repairments and make an aircraft inoperable. These situations are called aircraft-on-ground (AOG) situations. When an AOG situation occurs, the part that is required needs to be sourced by the MRO company, and then supplied and transported to the aircraft. These AOG situations have the highest priority for the MRO company due to their significant and costly consequences. Additionally, the process of solving an AOG situation often involves higher transportation costs, often exceeding the item price (Beata & Sebastian, 2018). Having an inhouse MRO company can be considered to be of strategic importance to an airline as it provides for a higher level of independence and control of this essential part of the operation. However, these airlines directly compete with other airlines that outsource these operations to external MRO providers, among which the increasingly competitive OEMs, which may offer these services at a lower cost. Also, inhouse MROs directly compete in the MRO market when they offer their services to other airlines. With the airline industry experiencing severe financial stress as result of the effects of the COVID-19 pandemic, more than ever inhouse MROs therefore have both a direct and indirect incentive to be competitive with external MRO providers in terms of both cost and (speed of) service.

To achieve this, airline inhouse MRO companies are expected to apply cost-cutting measures in the short term while at the same time, increase external sales, and stabilize operations in the mid- to long-term (Hader & Thomson, 2020). This creates a challenge since inhouse MRO companies need to save costs while improving performance because minimizing the impact of costly AOG processes has become ever more essential. To minimize costs in the AOG process the MRO company can in the first place try to limit the number of AOG cases. Secondly, the time of resolving a case is of the essence, the faster the case is resolved the lower the chance of loss of revenue. A loss of revenue is also created when cases are labelled incorrectly as AOG and therefore cancelled. Cancelled AOG cases take unnecessary time from the MRO company which could have been used to increase external sales and cut costs. However, only few studies have measured, let alone analysed, the performance of the AOG process in these three aspects. Moreover, the majority of studies have only used a quantitative approach when measuring performance of airline operations in general, even though operations like the AOG process, also involve human interactions.

1.3 Thesis motivation

In view of the latest developments in the aviation MRO industry and the lack of academic literature related to AOG process analysis, this thesis research conducts a case study at an inhouse airline MRO company. It will answer the following research question: *What affects the inhouse airline MRO performance in terms of number of AOG cases, lead-time and the probability of cancelled AOG cases during the COVID-19 pandemic?*

By doing so, this thesis research aims to contribute in four ways. Firstly, to extend academic literature as only few studies have been found that evaluate the AOG process. Secondly, to add to academic literature by using a mixed-method approach. Thirdly, to form a bridge between practice and academic research. Fourthly, to measure the performance of the AOG process during extreme conditions.

The structure of this thesis research is as follows. After this introduction the second section discusses the theoretical framework of this research, including an overview of existing literature on aviation MRO operations and their performance as well as other relevant studies. The third section describes the case. The fourth section explains the methodology of this thesis research and provides motivation for the chosen methodology and research process. The fifth section presents the results, both quantitative and qualitative. The sixth, final section discusses the implications of the results for this airline inhouse MRO company, as well as the limitations and conclusions of this thesis research.

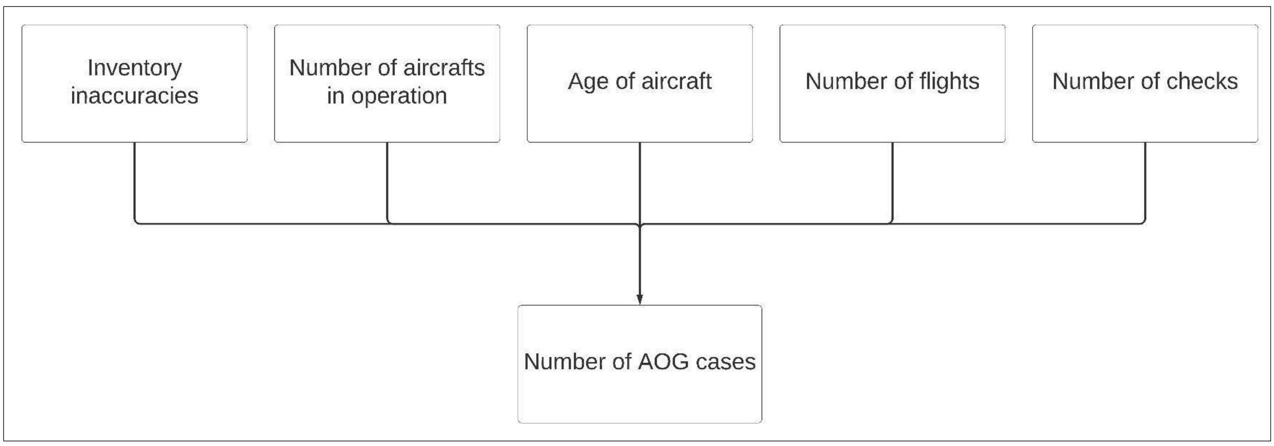
2. Theoretical Framework

2.1 Research on the performance parameters

The performance parameters of the AOG process are the number of AOG cases, total lead time and the probability of cancelled cases. Although the number of AOG cases does not describe how well the process functions, by analysing where most cases originate from, the MRO company gets more insights in which factors cause (more) AOG cases. Errors in inventory management are one of the causes of AOG cases. Making errors in inventory management is not uncommon due to inventory discrepancies like misplacement and inventory shrinkage (DeHoratius, Raman & Ton, 2001). Among others, reasons for such inventory inaccuracies are administrative errors, theft, incorrect incoming and outgoing deliveries and misplaced items (Fleisch & Tellkamp, 2005). According to Sherbrooke (2006), inventory management is challenging because of the random periods and volumes of demand while stocked parts can degrade, become obsolete or are hard to resell (Diallo, Aït-Kadi & Chelbi, 2009). Therefore, the AOG process needs to be flexible to provide optimal inventory management (Rezaei, Asian, Jolai & Chen, 2018). To prevent shortage in inventory, parts are ordered based on the probability that they are required. This probability can be affected by five reasons as shown in Figure 1 below: the number of aircrafts that the airline has in operation (Lowas & Ciarallo, 2016), the age of the aircraft type (Bugaj, Urminský, Rostáš & Pecho, 2019), the number of flights that the aircraft is being used (Mofokeng, Mativenga & Marnewick, 2020) and the number of checks which lead to the finding of issues.

Figure 1

Expected factors affecting the number of AOG cases

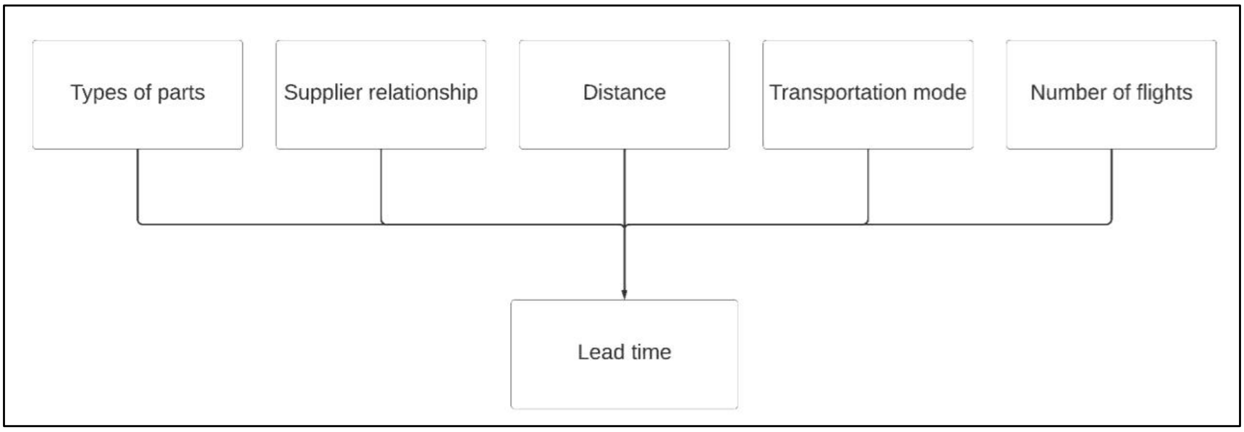


By considering these five factors, differences in the number of AOG cases associated to production locations and aircraft types are expected. Production locations with more (intensive) checks or inventory errors will be expected to have higher numbers of AOG cases. Aircraft types that are older and are used more by the airline are also expected to cause more AOG cases.

The number of different aircraft types in the world is increasing, causing a reduction in the number of available suppliers of particular parts, which has a negative effect on total lead times (Ganeshan & Guo, 1995). In addition, most parts are suitable for only one aircraft family (Kilpi, Töyli & Vepsäläinen, 2009), therefore suppliers often specialise in offering parts stock. This specialisation requires more effort of the MRO company in finding the right supplier for the requested part, impacting lead times (Baeta & Sebastian, 2018). A market overview of the supply chain management (Rodrigues & Lavorato, 2016) showed that the aviation MRO industry is characterised by having four types of stakeholders: the (sub tier) suppliers, aircraft OEMs, customers and MRO organisations. The complexity of the supply chain in this market differs between production and spare parts. The supply chain of production parts is more simple compared to the supply chain of spare parts, because in the latter more stakeholders are involved and they are supplying their competitors, which causes a conflict of interests and in turn negatively affect lead times (e.g. Cheng, Chowdhury, Prajogo & Yeung, 2012; Beata & Sebastian, 2018). Furthermore, newer aircraft types are often composed by parts that followed a complex manufacturing process and supply chain, making the supply of those parts less responsive. In addition, the relationship between the MRO company and its suppliers also affects the performance of supply chains. The level of trust, communication, cooperation and power-dependence are all dimensions determining the buyer-supplier relationship and in turn affect lead times (Hsiao, Purchase & Rahman, 2002). Other factors that could affect lead time are distance between the supplier, the chosen transportation mode and the number of flights operated by the airline of the MRO company. When available, faster transportation modes such as planes can reduce lead times significantly. Inhouse MRO companies are also expected to benefit from the airline's network as the MRO company has have more opportunities to use cargo space of the airline's planes. An increase in the number of flights of the airline should therefore give the MRO company more opportunities to transport parts faster by plane and in turn reduce lead times. These five factors affecting lead time of AOG cases and causing differences between aircraft types and suppliers are illustrated in Figure 2 below.

Figure 2

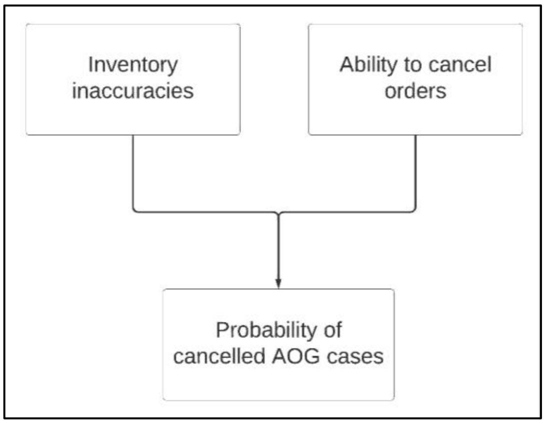
Expected factors affecting lead time



Cancelled AOG cases arise when judgment errors are made in analysing if the MRO company has inhouse capabilities to solve the case in question. Inhouse capabilities include having sufficient stock and repairment or opportunities for cannibalizing parts from other aircrafts (e.g. Riccardo, Venanzi, Costantino, Di Gravio & Tronci, 2019). According to Chen, Fang, Li & Wang (2016), these judgment errors, can be considered as a proxy for errors by inventory inaccuracy and are a factor that affect the probability of cancelled cases. The presence of inventory inaccuracies can differ between locations, as they are caused by various factors such as fatigue (Fleisch & Tellkamp, 2005) from nights shifts and time pressure (Hobbs, 2008) from large numbers of checks. Multiple dispersed facilities could also expect a difference in human resource characteristics as this dispersion increases the chance that routines and cultures between facilities change and differ over time. As a result, communication between colleagues, the skills and motivation of workers (Chase, 1978, as cited in Bhattacharya et al., 2016) and integration of operations can be negatively affected leading to higher probabilities of cancelled AOG cases. The probability of AOG cases being cancelled can also be affected by the ability of the MRO company to cancel incorrect orders of parts. Dedicated transportation modes, such as planes from the MRO company's airline, may give more abilities to cancel orders without facing costs. The same reasoning may apply with suppliers that have a better relationship with the MRO company (Hsiao et al., 2002). Figure 3 shows these two factors affecting the probability of cancelled AOG cases.

Figure 3

Expected factors affecting the probability of cancelled AOG cases



2.2 Methods of measuring performance

To evaluate and improve operations, studies have provided frameworks to describe and identify factors that could influence operations. For instance, Rankin et al. (2000) have produced a framework describing ten situational variables that could lead to human errors and in turn affect operations negatively. According to this paper, the equipment and tools, provision of information and facilities, and personal factors such as fatigue can, among others, be factors. Bhattacharya et al. (2016) also produced a framework of key operational characteristics, from Baines, Lightfoot, Peppard, Johnson, Tiwari & Shehab (2009), to describe operations and identify opportunities for improvement. Similarities between these two frameworks exist, such as the importance of information sharing and the facilities that are provided. Therefore, factors identified by Rankin et al. (2000) and Bhattacharya et al. (2016) could have an effect on the different performance within the MRO company.

2.3 Hypotheses

Concluding, based on the theoretical framework, the following hypotheses have been formulated:

1. Differences in the number of AOG cases are anticipated due to: inventory inaccuracies, the number of aircrafts that the airline has in operation, the age of the aircraft type, the number of flights and the number of checks.
2. Differences in the lead time of AOG cases: types of parts, supplier relationships, distance to the supplier, transportation mode and the number of flights.
3. Differences in the probability of cancelled AOG cases are anticipated due to: inventory inaccuracies and the ability to cancel orders.

3. Case Description

The case description has been developed based on several brainstorming sessions with important stakeholders of the AOG process in the inhouse MRO company. A brief description of the MRO company will first be given. Secondly, a description of the general parts request process is given, to map all stakeholders in the AOG-process. Thirdly, a more detailed description will be given of the most important tasks during the AOG-process.

3.1 Description of the MRO company

The inhouse MRO company that has been analysed in this thesis research is an organisation that functions primarily to serve its main customer which is a large Dutch airline. As the airline functions with a hub-and-spoke model, most activities of the MRO company are located at the main hub of the airline while having strategically located outposts across the airline's hub-and-spoke network.

Since the MRO company is part of the airline, operations of the MRO company are often bound to the performance of the airline. Therefore, when the COVID-19 pandemic started to have a negative impact on the global aviation industry in the beginning of 2020, airlines and inhouse MRO companies were required to look for cost-saving opportunities. In March, 2021, the MRO company started to notice that the number of AOG cases was rising without finding satisfactory explanations. This was an alarming phenomenon as this indicated a decline in performance during a period where the airline industry was already under heavy financial pressure. As a result, the MRO company was requested to evaluate the performance of the AOG process and improve it if possible. To do so, it was necessary to explore how the performance of the AOG process could be influenced.

3.2 Parts request at an aviation MRO

From the brainstorm sessions, a description of a general parts request process was created as shown in Appendix 1. Generally this parts request process starts when an aircraft maintenance technician identifies an issue related to the health of the aircraft (Boeing 737, 747, 777, 787 or an Airbus A330) and in turn requires maintenance and parts. The MRO considers two different types of parts, namely 'consumable' parts and 'rotable' parts. As the MRO company provides services at multiple locations, the location where the issue is identified can differ. First, the MRO company provides services at the platform of the airport, also known as 'VOP'. Often, these services are performed just before take-off. Secondly, the MRO company provides more extensive checks and maintenance in one of its hangars. These hangars have been split into two groups (hangar 11/12 and hangar 14) as they have different locations and perform different tasks. Furthermore, the MRO company also performs checks at stations abroad, also known as ‘line maintenance international’ (LMI) or at other locations in service to 3rd parties. The requests for maintenance and parts of aircrafts are communicated and issued to the duty maintenance management (DMM) who has a supervising function of these maintenance operations in general. These locations can be categorised in nine different groups. The degree of the issue is classified in multiple categories and is based on a minimum equipment list (MEL), which each aircraft needs to fulfil before it is allowed to take off due to security reasons. Not only is the degree of the issue based on the MEL, but it is also based on the expected due date that the issue can be resolved. The categorization of these issues is not fixed, as co-workers are able to review the issue and its related costs. Furthermore, when issues are not resolved before the due date, extensions of the due date can be requested when a reasonable explanation is given. If such a request is not accepted, the issue will run into its due date and in turn causing a possible AOG situation. If this occurs, the issue can be upgraded to an AOG classified issue so that the issue will be resolved with the highest priority. An issue can therefore be categorized as an AOG situation on a later stage due to a revision of the issue by a co-worker.

To place the request of maintenance and parts, the aircraft maintenance technician files an issue with the use of an enterprise resource planning (ERP) tool. This tool helps to give numerous stakeholders an overview of the workflow, material planning and point-of-maintenance. To help the maintenance technicians with finding the parts of interest, aircraft manufacturers provide manuals. These manuals include all parts and a corresponding identification code which is known as the ‘part number’ (P/N). The orders that are placed by the maintenance technicians therefore contain the part number and are subsequently reviewed by a maintenance centre (MC),located at VOP, hangar 11/12, hangar 14, LMI and other locations.

With the use of inventory management systems, the MC in turn sources if and where the part of interest is. If the stock is sufficient and the part is requested as soon as possible, the MC will send a request to the warehouse which will send the required part directly to the requested location. However, the MRO company is only able to hold a small selection of parts in stock which is under management of the supply chain department. As a result, there is a possibility that the part of interest is not in stock or that the part number cannot be recognized by the inventory management systems. If this is the case, the MC will try to source and order the part before it is required. However, if the deadline is within 72 hours, the MC will file an AOG request to the AOG-desk. This AOG request should include all required information of the part, the due date and the sourcing steps that the MC performed.

If there is sufficient stock but the issue must be postponed because the maintenance technicians, for example, do not have sufficient time to solve the issue, the issue and related part is classified as a deferred defect (DD). In turn, the requested part is placed at a temporary storage called 'Hilbak' where it can be bundled with other deferred defects. Based on the due dates of each issue, this bundle of deferred defects gives the MCs the opportunity to plan checks beforehand and the maintenance technicians to be more efficient so that they can solve multiple issues simultaneously. Compared to the MC, the network of the supply chain department is more specialised in ordering parts at lower costs with longer due dates, therefore they place orders for parts with relatively longer due dates . If a disruption in the supply chain takes place or a part is lost, the applications of the supply chain department can cause an AOG situation. As a result, the AOG-desk will be contacted to arrange the required part as soon as possible. Therefore, the planning and temporary storage for deferred defects could be used as a source for the AOG case.

When parts need to be ordered, the MRO company can source at a large number and different types of suppliers. For instance, the MRO company is able to source from strategically located warehouses across the airline's network, which can be fully dedicated to the MRO company and called 'Recall'. The MRO company can also be supplied by other repair shops which, for this inhouse MRO company, are 'other airlines' and 'AFI'. These suppliers often have an AOG-desk as well. Therefore, it is assumed that they are highly responsive to orders. In addition, AFI is also an inhouse MRO company of which its airline is partnered with the airline of this Dutch MRO company. As a result, AFI and this Dutch MRO company share inventories. The Dutch MRO company can also source from aircraft OEMs 'Boeing' and 'Airbus', system suppliers 'AVL', and non-approved vendors (Non AVL). Boeing is located in the United States of America and is not fully operable during its nights making it less responsive at those moments. Finally, the MRO company can also be supplied by locations under a special agreement with Boeing. These locations share costs and inventories and are called 'MIA', 'CSP' and 'GAIN'. However, the latter is located at the MRO company under a different agreement, namely that Boeing is required to have a specific selection of parts in stock while the MRO company only pays when those parts are being used. GAIN is therefore not regarded as an independent supplier, but as an extension of Boeing's services. The MRO company does expect that GAIN is able to supply at least 10% of AOG cases regarding consumable parts.

To transport the parts from the supplier to the requested location, the MRO company makes use of the plane, taxi, truck, shuttle and third parties transportation modes. The choice of transportation mode is often made by a forwarder. This forwarder is aware that the MRO company is part of a large airline and as such able to send parts via cargo from the airline's aircrafts and via cargo of the airline's alliances. Furthermore, the forwarder is aware that a shuttle between the organisation's main hub and AFI exists which departs twice a day. Finally, when the part arrives at the ordered destination, the part is being checked to see if it is sent correctly. If this is the case, the part is sent to either the plane directly or to the warehouse.

3.3 AOG-process

Even though the origins of an AOG situation may differ, the working process of the reporter, which is often the MC, and AOG-desk generally follows a standard procedure as shown in Appendix 2. In this procedure, the reporter plays an important role in validating if the requested part really needs to be sourced both externally and as soon as possible. Therefore, the reporter needs to validate the gravity of the issue, check if there is stock at the warehouse and check if alternative solutions such as repairment or cannibalization is possible. In doing so, the reporter must check if all administrative information is correctly provided in the AOG-request form. Finally, when an AOG-request is filed, the AOG-desk also expects that the reporter gives a summary of its previous sourcing attempts to prevent a repetition of tasks. From this moment on, the AOG-desk takes over the initiative of the issue and frequently informs the reporter or other stakeholders via the ERP tool. The AOG-desk may choose to source for multiple options when the risks are too high that a supplier does not deliver on time. When the risks in delivery of the part have been reduced sufficiently, the AOG-desk may choose to withdraw the purchase order to save costs. As a result, the AOG case receives a 'withdrawn' status in the ERP tool. Furthermore, since the AOG-desk is employed by people with a relatively higher technical know-how compared to the MC, it occasionally happens that after an AOG request has been filed, the AOG-desk finds an alternative solution that the MC did not think of before or finds the requested part due to an error in sourcing by the MC. As a result, the AOG request receives a 'cancelled' status. To close the AOG case, the AOG desk is required to set the status of the case on 'closed' after receiving confirmation from the requester that the part has arrived at the requested location.

3.4 Concluding remarks

As mentioned before, this thesis research was motivated by the MRO company's request to explore the available data about the AOG process, evaluate the performance of this process and if possible give direction to the management with opportunities for improvement. Based on the pre-study results, AOG cases can be caused due to different reasons, from different locations and be solved in different ways, as shown in Table 1 below. This list will be analysed in more detail in chapter five.

Table 1

List of origins of request, aircraft types, suppliers and transportation modes

Origin of request	Aircraft type	Supplier	Transportation mode
VOP	737	Boeing	Plane
Hangar 11/12	747	Airbus	Taxi
Hangar 14	777	CSP	Shuttle
LMI	787	AFI	Truck
DD	A330	MIA	Third parties
Other		AVL	
		Non-AVL	
		Recall	
		Other airlines	

4. Methodology

This section first provides an explanation of the research scope. Secondly, the use of the mixed-methods approach will be given. In the final part it separately describes the used quantitative and qualitative methods.

4.1 Research scope

The scope of this thesis research was determined based on the case description and the availability of data. The scope was split into two levels: (1) operational aspects and (2) data. The operational scope only included the operations and staff that work on aircraft that are operated by the airline itself. Outside the thesis scope were the operations for third party airlines because these may perform differently while there was insufficient time to cover both components of the MRO division.

To have a consistent data set, the research was based on data covering the period from 15 March 2020 till 1 March 2021, since the COVID-19 pandemic started to have an effect on the operations and supply chains on or about the 15th of March in 2020 and on the first of March 2021 the organisation started a restructuring project, which may influence the performance. The scope, source and type of data contained the following:

Table 2

Scope of data, including source and type of data

Source	Type of data	Data
ERP tool	Qualitative	Historical overview of conversations of AOG cases, including communications and response time, sourcing time and transportation time.
ERP tool	Quantitative	Historical data per case: time and date, total lead time, origin of AOG, type of part, aircraft type, transportation mode and supplier, number of (cancelled) cases
Employees	Quantitative	Flight movements, number of checks and purchase group of parts
Interviews with employees	Qualitative	Context of the AOG process

Initially, this research started with data from the ERP tool. This was extended with quantitative data from employees and qualitative data from interviews to provide control variables and more context. Consequently, a mixed-methods approach was used to estimate the performance of the AOG process. The inventory data and financial data were not available and were therefore not in scope.

4.2 Mixed methods approach

The application of the mixed-methods research design was based on the recommendations from Schoonenboom & Johnson (2017) who justify the mixed-methods approach based on five dimensions: purpose of mixing, theoretical drive, timing, point of integration and typological use.

- This thesis research used the mixed-method research design for multiple purposes. Firstly, its triangulation method increases the integrity and validity of the research findings (Bryman, 2006, as cited in Schoonenboom & Johnson, 2017). Secondly, for developmental purposes as the AOG process is complex and the availability of data is ambiguous. And thirdly, the mixed-method approach also has a complementary function in which the quantitative method focuses on evaluating the AOG process in general whereas the qualitative method is used to increase understanding of social phenomena, which are less accessible when using quantitative methods only (Silverman, 2000, as cited in Gill, Stewart, Treasure & Chadwick, 2008). Especially when surprising results from the quantitative analyses were derived, results from the qualitative method could be used to explain and provide context.

- The theoretical drive of this mixed-methods approach makes use of a more equal-status research design as advocated by Greene (2015) and Johnson, Burke, Anthony, Onwuegbuzie, Lisa & Turner (2007). This means that both the qualitative and quantitative research components interact while the outcomes are collaboratively incorporated to answer the research question. This interaction is used to identify problems during the research process and in turn helps to adjust the methodology of both analyses so that the results give more insights about the AOG process and a better estimation of its performance.
- The timing aspect is determined by the fact that the design of one of the analyses depends on the outcomes of the other. For this thesis research, both a dynamic and simultaneous order of analyses was applied, as defined by Schoonenboom & Johnson (2017).
- The point where the qualitative and quantitative components are integrated takes place both in the analytical phase for the construction of the best suitable methodologies and in the results section to achieve a more complete research.
- The design typology of this mixed-method approach can therefore be described as a multilevel mixed design.

4.3 Quantitative analyses

The quantitative analyses are primarily used to evaluate the performance of the AOG process. In doing so, this thesis research first evaluated a number of conventional methods that were applied in other studies with a similar objective. Since the AOG process is complex and the MRO business lacks data on performance, these conventional methods were evaluated on their applicability. The evaluated conventional methods include multi-criteria-decision-making methods (MCDM) such as the data envelopment analysis (DEA), the decision making trial and evaluation laboratory (DEMATEL), the analytic network process (ANP) and analytical hierarchy process (AHP) models. Other performance evaluation methods such as the supply chain operations reference model (SCOR) and the balanced scorecard (BSC) have also been considered. However, none of the conventional methods were applicable on the research data, either because of the complexity of the method, the requirement of financial data, or the method evaluated a change in operations that was not in scope of this thesis research.

Therefore, this thesis research used a proprietary model to estimate the performance of the AOG process, consisting of multiple analyses and variables. The data was extracted from the ERP tool and combined with the quantitative data from the employees to construct the main dataset. In some cases the raw data had to be transformed into usable variables. This model contained three parameters (outcome variables), which individually determine the performance as described in the theoretical framework:

1. The number of all AOG cases;
2. Total lead time, and;
3. The probability of cancelled AOG cases.

AOG cases are issues reported with an AOG priority. Total lead time represents the time starting from the moment the AOG case is reported at the AOG desk until the moment that the required part has been received and reported to the AOG desk. The lead time can be split in time of response, time of sourcing and time of transportation. The time of response is the time between the moment that the AOG case is reported at the AOG desk and the first message from the AOG desk confirming the issue. The time between the first message and the moment of placing the order of the requested part at the supplier is the sourcing time. The transportation time is the time between placing the order at the supplier and the last message that the required part has been received and reported to the AOG desk. An AOG case is cancelled when the requested part was ultimately not required, for example because the MRO company already had the part in stock or alternative remedies for the AOG case.

To estimate the effect of all variables mentioned in the theoretical framework that are expected to affect the performance of the AOG process, a number of variables from the MRO company were constructed. This is shown in Table 3.

- Types of parts: rotable, consumable and GAIN parts. The types of parts were derived from the product codes from the raw data in the ERP tool.
- The variable shift was constructed as follows. Based on the time of reporting, all AOG cases starting between 07:00 AM and 15:00 PM were categorised as cases that were reported during the day shift, while between 15:00 PM and 23:00 PM during the afternoon shift, and between 23:00 PM and 07:00 AM during the night shift.

- Aircraft types: 737, 747, 777, 787 and A330. These types were derived from the system codes from the raw data in the ERP tool. Based on these system codes, cases have also been excluded as they served other airlines.
- Origins of requests: VOP, hangar 11/12, hangar 14, LMI and DD. These represent all production locations of the MRO company. Even though DD is not a location were checks are performed, it is a location that can start an AOG case, due to for instance errors made in inventory administration.
- Suppliers: Boeing, Airbus, CSP, AFI, MIA, AVL, non-AVL, recall and other airlines. This supplier variable was derived from the order numbers from the raw data in the ERP tool.
- Transportation modes: plane, taxi, shuttle, truck and third parties. These modes were derived from airway bill number and flight number from the raw data in the ERP tool.
- Communication in the ERP tool: number of conversations from the reporter of the issue and the AOG desk, the presence of relevant remarks (steps taken before reporting the AOG case) from the reporter in the conversation, the use of a priority level for the issue, and the presence of a due date for the issue given by the reporter in the conversation.

The following control variables were included in this thesis research: the number of flights, the number of checks and the distance to the supplier in kilometres. The number of flights are flights of the main airline only. The number of checks at each location were analysed separately. The distance to the supplier was measured as the distance between the MRO company and the nearest airport of the supplier.

Table 3

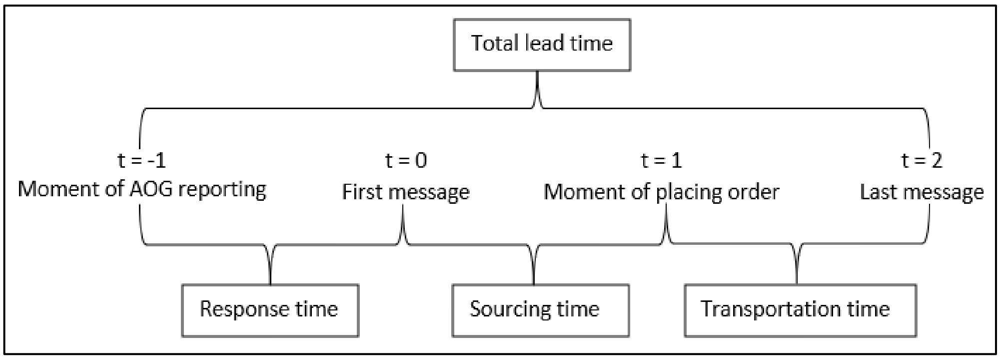
List of variables from dataset and theoretical framework

Variable dataset	Variable theoretical framework
Types of parts	Type of parts, Supplier relationship
Shift	Inventory inaccuracies
Aircraft types	Type of parts, age of aircraft, number of aircrafts in operation,
Origin of request	Inventory inaccuracies
Suppliers	Supplier relationship, ability to cancel orders
Transportation modes	Transportation mode, ability to cancel orders
Communication	Inventory inaccuracies
Number of flights	Number of flights
Number of checks	Number of checks, inventory inaccuracies
Distance	Distance

The multiple analyses used in the quantitative approach of this thesis research were: a content analysis, a descriptive analyses, and a regression analysis using SPSS. The content analysis was based on historical conversations from the ERP tool and was performed to create more insights into the operations of the AOG process. The qualitative historical conversation data was transformed into quantitative data by counting the number of conversations for each AOG case and measuring the presence of relevant remarks, the use of priority level, and the presence of a due date. In addition, based on these conversations the moment of reporting (t = -1), the first message from the AOG desk (t = 0), the moment of placing the order at the supplier (t = 1) and the last (closing) message (t = 2) were identified and used to measure the response, sourcing and transportation time, as illustrated in Figure 4. The content analysis included 100 AOG cases, which were randomly chosen to avoid a selection bias.

Figure 4

Procedure of measuring total lead time, response time, sourcing time and transportation time



The descriptive analysis used both quantitative datasets. With this data, the variables ‘types of parts’, ‘shifts’, ‘aircraft types’, ‘origins of requests’, ‘suppliers’, and ‘transportation modes’ were individually compared based on the three performance parameters to provide more insights into the effect of the variable on these parameters. Matrices were constructed for the variables ‘shifts’, ‘aircraft types’, ‘origins of requests’, ‘suppliers’ and ‘transportation modes’ to improve interpretability when comparing their performances. Of these matrices, the x-axis indicates the percentage of cancelled AOG cases while the y-axis indicates the median average lead time. The length of these axes were sometimes adjusted to make it easier to identify differences in performance between the categories. The size of the bubble represents the relative number of AOG cases. The percentage of the total number of cases is indicated next to the bubble. Two gridlines were added to each matrix to indicate the average total lead time and the average percentage of cancelled cases. In addition, the control variables (‘number of flights’ and ‘number of checks’) were analysed over time to identify correlations between the variables and the performance parameter 'number of AOG cases'. These control variables were also taken into account with the use of regression analyses.

Linear and binomial regression analyses were used to take the control variables into account, producing a better interpretation of how the variables influence the three performance parameters. To prevent potential sources of bias and retain accuracy, a number of tests were performed beforehand to identify violations of assumptions that are required when using more powerful parametric tests instead of non-parametric tests.

To enable an estimation of the number of AOG cases per day, an additional dataset was created from the quantitative data of the ERP tool. The data was transformed from a case-by-case report (1667 cases) to the number of AOG cases per date (351 dates), therefore decreasing the number of values. but still allowing the evaluation of AOG cases over time. To estimate the relationship with the parameter 'number of AOG cases', the theoretical framework identified five factors: inventory inaccuracies, the number of aircrafts that the airline has in operation, the age of the aircraft type, the number of flights and the number of checks. Data did not provide sufficient information to link the variables 'aircraft types', 'level of communication' and 'shift' with the variable 'number of checks' at each location. Therefore, only the variables 'number of flights' and 'number of checks' at each production location were used while assuming that an even number of aircrafts of each type was being checked at all production locations.

For the parameter 'lead time', the theoretical framework identified five factors: type of parts, supplier relationship, distance, transportation mode and number of flights. These factors would be estimated by the variables 'suppliers', 'aircraft type', 'distance', 'transportation mode' and 'number of flights'. However, the variables 'transportation mode', 'suppliers' and 'aircraft types' included a large number of categories, making the regression analysis too complex. To solve this issue, the variable 'transportation mode' was excluded from the analysis. In addition, two regression analyses were constructed instead of one, to evaluate the relationship of the variables 'suppliers' and 'aircraft types' separately. Both regression analyses included the control variables 'number of flights' and 'distances to the supplier'.

For the third parameter, 'probability of cancelled AOG cases' the theoretical framework identified two factors: inventory inaccuracies and the ability to cancel orders. The effect of inventory inaccuracies was estimated with the variables 'origins of request', 'shifts' and 'number of checks'. To evaluate the second factor, the ability to cancel orders, the variables 'suppliers' and 'transportation modes' were available. However, due to the large number of categories, evaluating both variables would make the regression analysis too complex. To solve this issue, both variables were excluded from the analysis.

4.4 Qualitative analyses

To conduct a legitimate qualitative scientific research, particular aspects such as the method, the number and choice of participants and the proposed questions are based on influential guides (Englander, 2012, Granot, Brashear & Motta, 2012) and studies (e.g. Siponen, Haapasalo & Harkonen, 2019). Based on these guides and studies, multiple semi-structured interviews with a number of employees were conducted to evaluate the AOG process. The semi-structured method was chosen because unstructured interviews may be prone to more confusion, while structured interviews with only pre-determined questions would not create sufficient depth of information. Employees who work at the MCs, the AOG-desk and DMM department were interviewed. MC employees operate at the beginning and ending phase of the AOG process. AOG-desk employees take the lead once the AOG request has been filed. Although the DMM is not directly involved in most AOG cases, this department does have a supervising and, at times, a directing role, and therefore was also included in the study. Seven participants were selected, of which three were from the AOG-desk, three from the MCs and one from the DMM department. The participants from the MCs work at different locations (VOP, Hangar 11/12 and Hangar 14) to measure differences in work processes and conditions between the locations. One participant from the DMM department was selected to create insights from a supervising and directive point of view. The participants included in the study were chosen based on having, according to the management team, a sufficient level of expertise and knowledge of the AOG process.

All pre-determined questions were formulated as open-ended questions with the use of recommendations from Gill et al. (2008) and Granot et al. (2012). Nine of the ten situational variables from Rankin et al. (2000) were used to construct nine pre-determined questions each targeting different aspects of the AOG process, as shown in Table 4. In addition to these predetermined questions, the participants were also asked to give examples when describing phenomena to create more context.

Table 4

Situational characteristics and corresponding interview questions

Situational variables	Questions
Information	How would you describe the available and used information that is relevant to the AOG process?
Equipment & tools, parts	What do you think of the tools and equipment you use during this process?
Job & task	How do you experience your position and tasks with regard to this process?
Technical knowledge & skills	What is your perception of the available and required knowledge and skills for this process?
Factors affecting individual performance	How do you perceive other factors that may affect your individual performance during this process?
Environment & facilities	What is your perception of the environment and facilities at your position/department?
Organisational & environmental issues	How do you experience the working atmosphere/working conditions/work processes with regard to this AOG process?
Leadership & supervision	What is your perception of the leadership and supervision during the AOG-process?
Communication	How do you experience communication during the AOG-process?

Based on Rankin et al. (2000)

All semi-structured interviews took approximately forty five minutes and were conducted, depending on the availability of the participant, either on the work floor or at a designated and calm location. The interviews were recorded and noted in an anonymous way. These notes did not include a complete transcription of the participants' answers, only the answers considered as relevant were taken into account for this thesis research.

4.5 Concluding remarks

In conclusion, this thesis research used a mixed-methods approach. Quantitatively, the AOG process was evaluated based on three performance parameters with the use of content, descriptive and regression analyses. These performance parameters are the number of AOG cases, lead time and number of cancelled cases. Qualitatively, the AOG process was evaluated with the use of seven semi-structured interviews including nine pre-determined questions that targeted situational characteristics that could affect the performance of the AOG process. These qualitative results were used to develop understanding of social phenomena, complement quantitative results and as a result, triangulate the performance evaluation.

5. Results

The quantitative results are described in this section and is supported by qualitative results from Appendix 4 when considered as a complement in interpretation of the quantitative results. First, the results from the content analyses of AOG reports will be given. This will be followed by the results of the descriptive analyses and thirdly, by the results of the regression analyses.

5.1 Content analyses of AOG reports

Initially, the content analysis started with 100 reported AOG cases. Depending on the type of variable (communication in the ERP tool vs. time), different numbers of cases are reported in the analysis. For the communication variables, nine AOG cases are excluded from the analysis, because these AOG cases were commissioned by another MRO company or airline. As a result, 91 cases are included in the content analysis. Due to missing data in the time variables, the dataset includes 61 values to analyse the time of response, sourcing and transportation.

As shown in Table 5, 64% of the communication cases included a due date, 65% received a priority indication from either the reporter or the AOG-desk, and 48% included relevant remarks from the reporter. According to these results, the operations do not adhere to the expectations of the management team because every AOG case should have remarks and due dates, while this is not the case for the use of a priority indication. This conclusion is supported by the qualitative results as, according to the AOG-desk, reporters often do not perform the required sourcing tasks before sending a request to the AOG-desk. This can be explained by the fact that MCs lack information to perform the requested sourcing tasks and therefore do not have remarks inserted in the request. Another explanation is the perceived lack of information and agreements about work instructions.

Significant variations in the number of conversations were reported. Therefore, the median value of 14 conversations is more representative than the average number of conversations per AOG case. According to the qualitative results, these conversations are generally good and the quality of communications between departments has improved significantly over time.

Table 5

Results of content analysis

Variable	N	Mean	SD	Median
Conversations per case	91	16.18	12.50	14
Remarks per case	91	0.48	0.50	0.00
Priority indicated	91	0.65	0.48	1.00
Due date given	91	0.64	0.48	1.00
Time of sourcing (hrs)	61	7.97	19.03	0.78
Time of transportation (hrs)	61	56.73	91.43	21.87
Total lead time (hrs)	61	72.05	115.68	27.98

Due to large variations in lead times, again the median values were used as a better representation of sourcing, transportation and total lead times. The median transportation time is almost 22 hours, which represents a significant part of the nearly 28 hours of the total lead time. Furthermore, only 47 minutes are required to source the parts, indicating that the inventory management and sourcing tools perform to a level that they represent only a small portion of the total lead time. These qualitative results suggest that the management and sourcing tools function well, although beginners perceive these tools to be challenging and they do not receive sufficient introductory support. The time of response is five hours and 20 minutes, which is relatively long compared to the sourcing time.

Other relevant findings regarding the AOG process were found in the qualitative results. These findings generally showed negative characteristics of the AOG process, such as a lack of up-to-date, formal and documented information, and process instructions. On the positive side, the participants generally perceived the horizontal structure of responsibilities to be functioning well.

5.2 Descriptive analyses

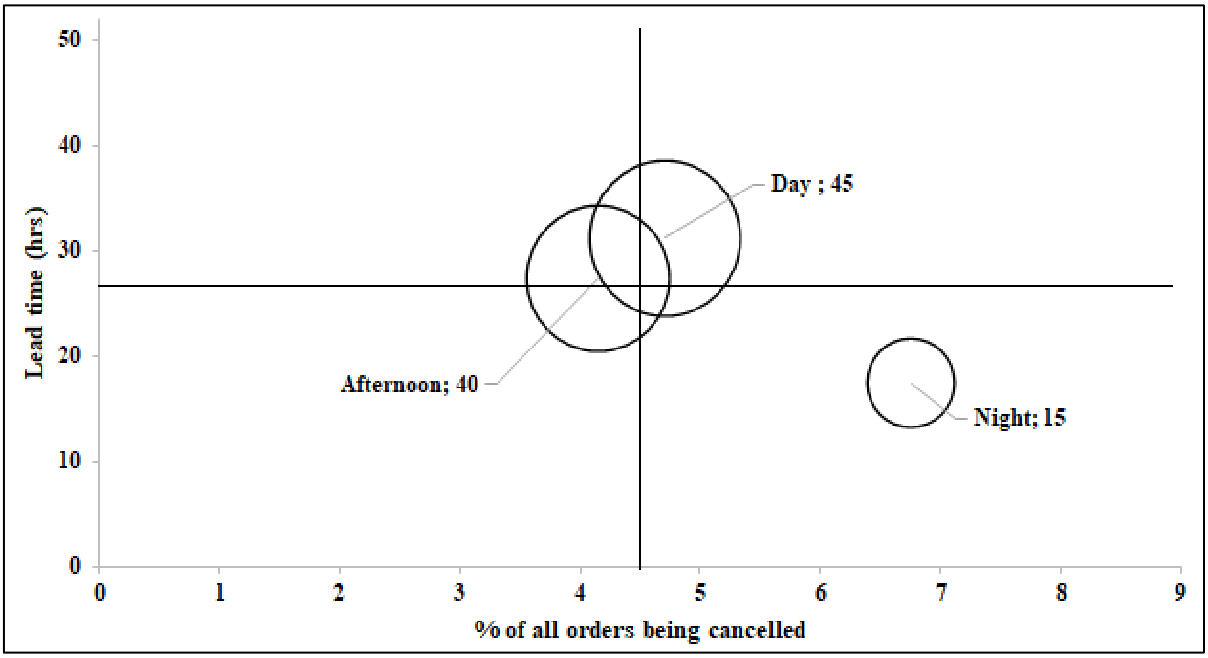
The descriptive results started with 1667 reported AOG cases. 89% of these AOG cases were closed, 5% withdrawn, and the remaining 6% cancelled. For 1608 cases the total lead time could be calculated. For these cases the median average of total lead time was 26 hours. Sixteen percent of cases were solved in an alternative fashion: through cannibalization of parts (11%)

and by borrowing parts (5%). Furthermore, the ratio of rotable and consumable parts in cases were equal (50-50%).

As mentioned before, matrices were developed to show the results of the variables on the three performance parameters simultaneously. These results are shown with more detail in Tables A-F in Appendix 3.

Figure 5

Performance between types of shift

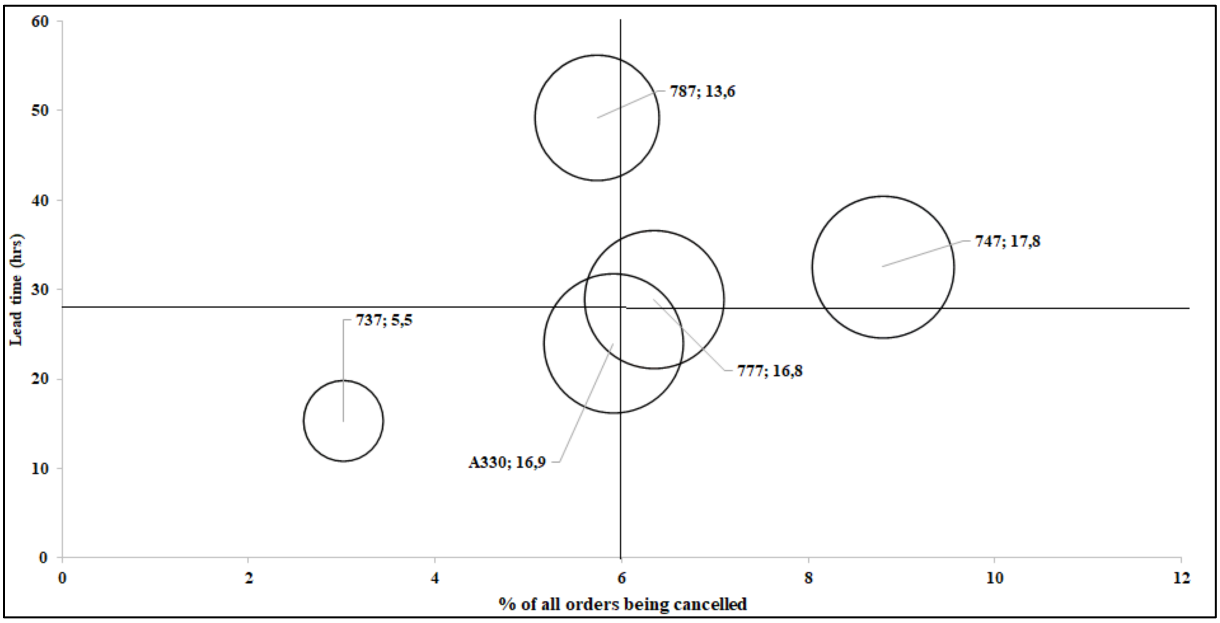


The results from Figure 5 show that day and afternoon shifts score similar on all three performance parameters. The majority of AOG cases are reported during the day (45%) and afternoon shifts (40%). Only 15% of AOG cases are reported during night shifts. However, night shifts are associated with a larger percentage of cases being cancelled (7%). This high percentage of cancelled cases is confirmed by the qualitative results. According to employees from both the MC and AOG desk, fatigue during night shifts is a factor that negatively affects individual performance. This could be errors by inventory inaccuracies. Of all three shifts, the night shift is associated with the lowest lead times (17 hours). An explanation for this may be that many AOG cases are solved by parts of the supplier Boeing (see Figure 8), which is more responsive during night shifts compared to day shifts, as they are located in the Western Hemisphere.

Most AOG cases are associated with the 777 aircraft type (32%), followed by the 737 (21%) - see Table 10. However, Figure 6 shows that when taking the number of aircrafts per type into account, the 737 is associated with the least AOG cases (6%), while in contrast the majority of cases involve the 747 aircraft type (18%). Possible reasons for these results are that the 747 is an older aircraft type with less reliable equipment, the MRO company has a lower level of inventory for this aircraft type, and the MRO company has less aircrafts to cannibalize parts from.

Figure 6

Performance between aircraft types



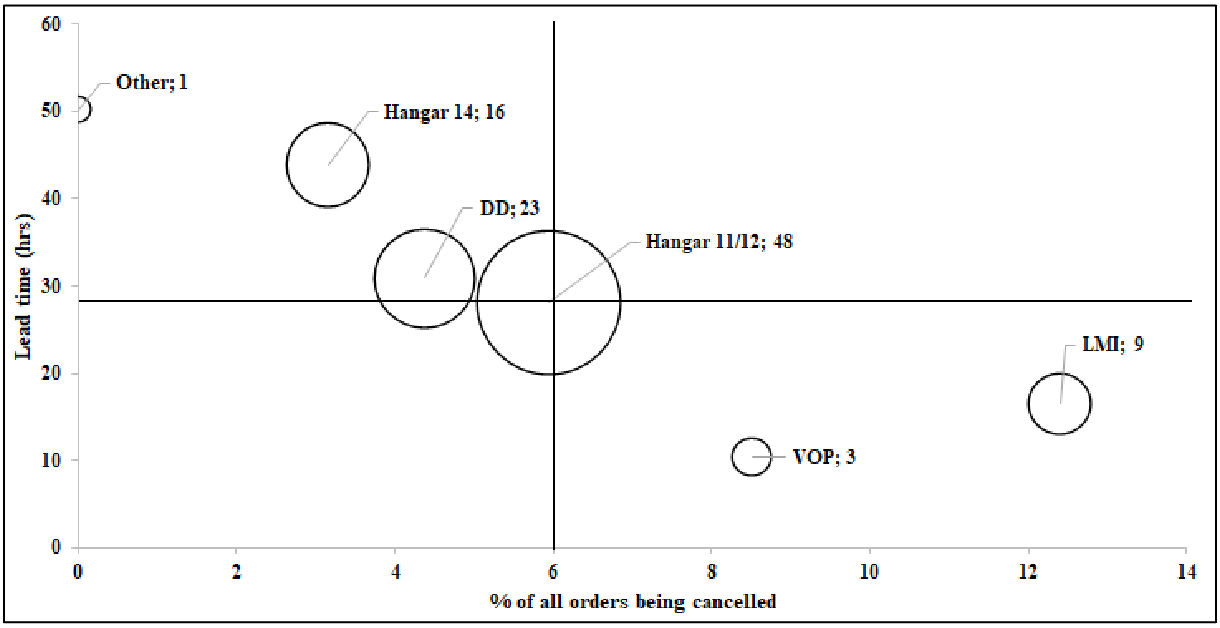
Note: the size and percentage of AOG cases is based on the number of aircrafts that the airline of the MRO company has in operation.

The 737 outperforms the other aircraft types in terms of order cancellations and lead times, while the 747 scores worst in terms of cancellations (9%) and the 787 in terms of lead time (49 hours). The difference in lead time may relate to the complexity of the supply chain. For the 747, the large percentage of cancelled cases may be due to inventory inaccuracies. Figure 7 illustrates that the LMI location is the location with the highest percentage of cancelled orders. At this location most AOG cases are associated with the 747, according to table 14 in Appendix 13. Therefore, the large percentage of cancellations may be explained by inventory inaccuracies at the LMI location(s). However, no causal relationship can be confirmed which means that AOG cases from LMI are caused by the 747 aircraft type.

As shown in Figure 7, we can identify significant differences in performance between the origins of request. In contrast to the aircraft types, it is more difficult to identify a location that is scoring best or worst on all three parameters. VOP (3%) and other locations (1%) have the lowest number of AOG cases, while hangar 11/12 (48%) has the highest. Reasons for the large number of AOG cases in hangar 11/12 are the large number of checks and more extensive checks performed, since increasing the number of checks increases the chance of finding an issue. This indicates that the AOG desk is largely serving operations from hangar 11/12.

Figure 7

Performance between origins of AOG requests



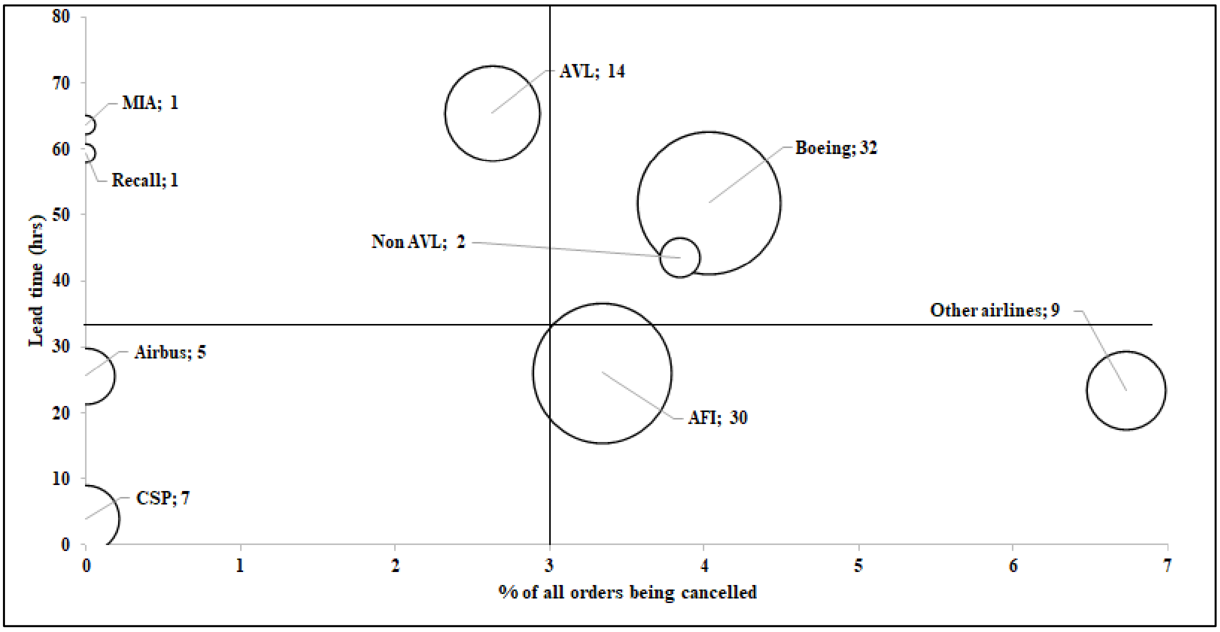
The location DD is associated with relatively high number of cases (23%) even though no checks are being performed at this location. Therefore, the presence of high levels of inventory inaccuracies or failed sourcing attempts by either the supply chain department or MC is plausible. These inaccuracies are more present at LMI, as mentioned before, and VOP as they are associated with relatively high cancelled orders. The qualitative results show that ambiguity about sourcing tasks and unfavourable working environments and facilities may be more present at LMI and VOP, therefore explaining the higher inventory inaccuracies and cancelled cases.

In terms of lead time, AOG cases from other locations (50 hours) and hangar 14 (44 hours) are associated with the highest lead times. One explanation from the qualitative results is that parts can be misplaced (uncertainty of location) when they arrive at the destination, causing employees to lose time in finding these parts for the AOG case, resulting in higher lead times. In addition, the reporters from these locations may not directly announce that the parts have arrived to close the case, due to poor communication and/or lack of understanding of the process as indicated in the qualitative results.

As shown in Figure 8, third party repair shop suppliers AFI and other airlines represent 39% of all AOG cases combined, making these important actors in the supply chain of the MRO company. They are closely followed by the aircraft OEMs Airbus and Boeing, which supply 37% combined, whereas system suppliers (AVL) supply only 14%. Of all consumable parts, 12% were accounted as GAIN items and required sourcing from other suppliers instead of the GAIN department. Remarkably, Boeing supplied the majority of these cases (70%), which may indicate poor service and inventory management from the GAIN department.

Figure 8

Performance between suppliers



Differences between suppliers in the percentage of cancelled orders are low. Only other airlines (7%) are associated with significantly more cancelled cases which may suggest that the MRO company has relatively more abilities to cancel orders from this supplier compared to others. A reason for this is that the MRO company has a good relationship with the other airlines, as they are the same type of organisation. AVL suppliers, MIA, Recall and Boeing are associated with relatively long lead times. This can be explained by longer transportation times as the suppliers further located from the MRO company. Other reasons may be that these suppliers do not have stock directly available or that these suppliers underperform due to complexities in providing the required certifications.

Most parts are transported by plane (69%) or taxi (23%), while the other transportation modes combined make up 8% of all AOG cases (Figure 9). Similar to the analysis between shifts, the scale and therefore the variety in the percentage of cancelled cases is smaller compared to the other descriptive analyses. The highest percentage of cancelled cases are associated with plane transport (3.3%) because the MRO company may have more abilities to cancel orders when being transported by their own planes in contrast to transportation by truck, third parties or taxis. In terms of lead time, the choice of transportation mode is most probably largely a function of the distance. It is therefore not a surprise that planes are used for orders from distant suppliers, leading to relatively higher lead times (44 hours), whereas taxis are associated with relatively the lowest lead times (23 hours).

Figure 9

Performance between spare transportation modes

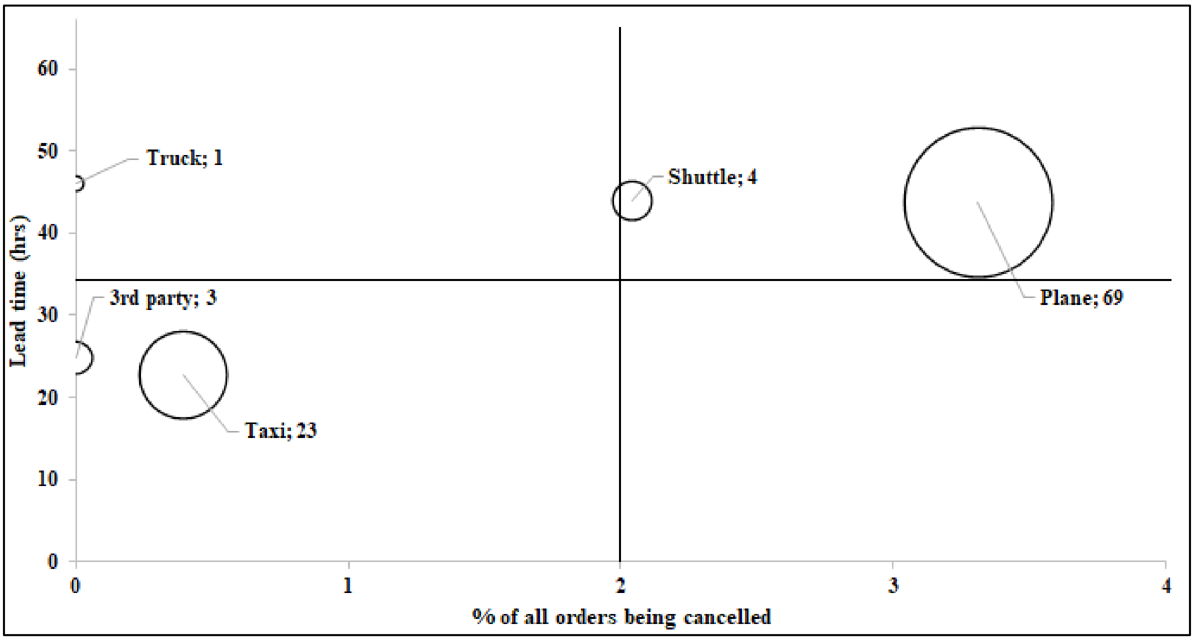
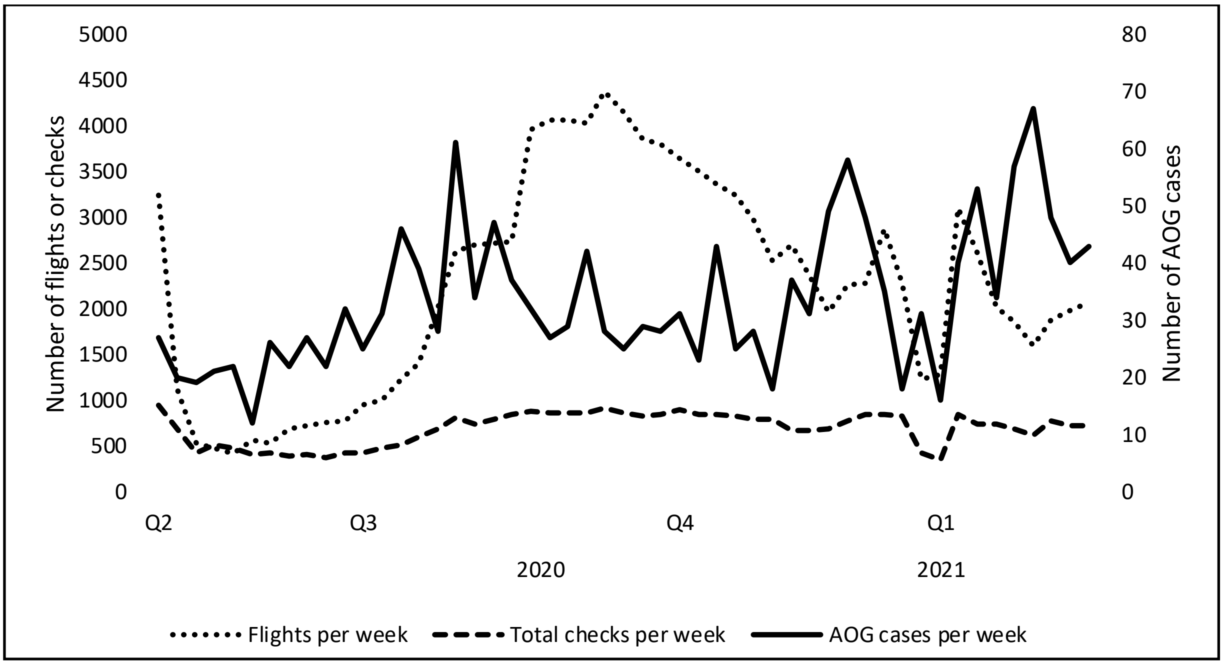


Figure 10 shows the evolution of the number of checks and number of flights per week between the 15th of March, 2020 and the first of March 2021. On average 34 AOG cases, 2256 flights and 689 checks were recorded per week. Since March 2020, both the number of flights and checks initially decreased significantly due to the COVID-19 pandemic. While the number of checks remained relatively stable during this period, the number of flights and number of AOG cases were more volatile in numbers. In the beginning of 2020, the number of flights and number of AOG cases both simultaneously decreased and increased since May 2020, indicating a correlation. However, the number of flights started to increase again by the middle of the third quarter of 2020 while the number of AOG cases decreased. A possible explanation could be that the re-opening of the global economy during the COVID-19 pandemic led to a growth in number of flights, supporting supply chains. This opening makes it easier to keep a sufficient stock of inventory, leading to less AOG cases. By the end of 2021 the number of flights decreased again, which caused disruptions in supply chains and made inventory management more challenging. This in turn led to more AOG cases.

Figure 10

Number of AOG cases, flights and checks per week over time



It is therefore not a surprise that the Pearson test for correlation does not show a correlation between the number of flights and the number of AOG cases per week, r (51) = 0.303, *p* = .15. Instead, the Pearson test for correlation does show a weak and positive correlation between the number of AOG cases and number of checks, r (51) = 0.277, *p* = .05, and a strong and positive correlation between the number of flights and number of checks, r (51) = 0.899, *p* = .00. When measuring the number of flight checks and AOG cases per day, the Pearson tests for correlation show similar results. No correlation is found between the number of flights and AOG cases (r (352) = 0.038, *p* = .47), a weak and positive correlation between the number of checks and number of AOG cases (r (352) = 0.128, *p* = .02), and a strong and positive correlation between the number of flights and number of checks, (r (352) = 0.833, *p* =

.00). As such, AOG cases are caused by the number of checks and arguably the number of flights.

5.3 Regression analyses

To further analyse the relationship between number of checks, flights and the number of AOG cases, a regression model is constructed. The number of AOG cases, flights and checks were measured per day *i* including 342 values. The number of checks were separated between the locations as shown in model (1) below. However, data was only available for the locations VOP, hangar 11/12 and hangar 14. Therefore, an analysis of other locations was not possible.

1) $Number\ of\ AOG\ cases_i = a + \beta_1 flights_i + \beta_2 Checks\ VOP_i + \beta_3 Checks\ hangar\ 11/12_i + \beta_4 checks\ Hangar\ 14_i + \varepsilon_i$

Initially, the number of AOG cases violated the assumption of normal distribution as the observations of the normal probability quantile-quantile (Q-Q) plot in Figure A, Appendix 5, do not lie on a straight line and the Shapiro-Wilk test for normality is rejected, W (352) = 0.88, p = .00. To solve this issue, a log-transformation was applied on the dependent variable. According to the Shapiro-Wilk test for normality, this transformation was not successfully, W (352) = 0.94, p = .00. However, the Q-Q plot shown in Figure B, Appendix 5, does show a more normal distribution of observations. This model has a low adjusted R-square score (0.03) indicating that it does not explain many variations in the number of AOG cases with the chosen explanatory variables. The results of this model are shown in Table A in Appendix 6.

An alternative regression analysis was performed using a similar model, but instead measuring the number of AOG cases, checks, and flights on a weekly basis. This model included 50 values and has a higher adjusted R-square score (0.12) and violated the assumption of normal distribution according to the Q-Q plot shown in Figure C Appendix 5 and the Shapiro-Wilk test, W (50) = 0.95, p = .03. Therefore, a log-transformation was applied on this dependent variable giving a normal distribution of observations (see Figure D, Appendix 5), W (50) = .99, p = .95. Yet, the number of checks at the VOP location show a high VIF score (11.7), indicating collinearity issues for the number of checks at the VOP location in the model. This was solved by excluding the flights from the model.

Table 6

Alternative regression analysis on the number of AOG cases per week

Variables (per week)	Unstandardized Coefficients	*t*	*p*	95% CI [LL, UL]	VIF
Constant	2.74	11.90	.00	[2.27, 3.20]	
Checks at VOP	0.00	0.80	.43	[0.00, 0.00]	1.62
Checks at hangar 11/12	0.01	1.75	.09	[-0.00, 0.02]	1.66
Checks at hangar 14	0.02	0.63	.53	[-0.03, 0.06]	1.03

As shown in Table 6, the results indicate that the number of checks at hangar 11/12 is the only statistically significant explanatory variable for the total number of AOG cases ($p < .1$). The results show that when the number of checks at hangar 11/12 increase by one (representing 2% of the average number of checks per week), the total number of AOG cases per week is expected to increase by 1%. The qualitative results indicate that this may be due to beginners who find the work challenging at this location. Furthermore, the qualitative results suggest that hangar 11/12 has poor facilities and work environment due to noise disturbance. Presumably, more checks at hangar 11/12 lead to more exposure to noise disturbance which results in more AOG cases that may not have been necessary.

For the evaluation of total lead time the second and third regression models (2 & 3) were constructed to estimate the total lead time in hours per AOG case *i*. The second model analyses the relation between total lead time and aircraft types, and the third model analyses the relation between total lead time and suppliers. Only closed cases are considered in the second and third models as cancelled or withdrawn cases are expected to have shorter lead times, therefore including them would affect the results of the regression analyses. Both the Q-Q plot shown in Figure E Appendix 5 and the Shapiro-Wilk test of normality show that the data does not follow a normal distribution, W (1581) = 0.53, p = .00. Data transformations with the natural log or square root did not solve this issue making non-parametric regression tests required (see Figure F Appendix 5), W (1581) = 0.97, p = .00. The use of a non-parametric regression tests makes collinearity issues less of a concern and are therefore not shown with VIF values. In addition, the average total lead time is measured in medians instead of means as the latter is more affected by outliers. To prevent a dummy trap, the second model uses the A330 aircraft type as a reference category. This model therefore includes dummy variables representing all aircraft types (D_3 till D_6), with the exception of the A330, while controlling for the number of flights and the distance to the supplier. This model has a Pseudo R-squared value of 0.20.

2) $Total\ lead\ time_i = a + \beta_1 Flights_i + \beta_2 Distance_{2i} + \beta_3 D_{3i} + \beta_4 D_{4i} + \beta_5 D_{5i} + \beta_6 D_{6i}$

As shown in Table 7, the 787 aircraft type is statistical significant ($p < .05$). This means that compared to the A330, only the 787 aircraft type has a statistically influence on total lead time. Therefore, the results indicate that AOG cases concerning parts for the 787 are estimated to take almost 32 hours longer than any other aircraft types when controlling for the distance to the supplier and number of flights per day. This suggests complexities in the supply of 787 parts compared to parts for other aircraft types, due to for instance a greater deficit of global supply of 787 parts. Furthermore, the results show that when analysing the influence of aircraft types on total lead times, the distance and number of flights are irrelevant as they do not have a statistical effect on the relation.

Table 7

Results of total lead time between aircraft types regression analysis

Variables	Coefficient	Std. error	*t*	*df*	*p*	95% CI [LL, UL]
Intercept	30.90	13.72	2.25	110	.03	[3.71, 58.10]
Distance (in km)	0.00	0.00	0.17	110	.77	[-0.00, 0.00]
Number of flights (per day)	-0.00	0.01	-0.06	110	.95	[-0.03, 0.03]
737	-16.72	12.48	-1.34	110	.18	[-41.46, 8.02]
747	5.63	9.67	0.58	110	.56	[-13.53, 8.02]
777	-3.19	9.13	-0.35	110	.73	[-21.27, 14.90]
787	31.59	10.29	3.07	110	.00	[11.20, 51.98]

Note: results are compared to lead time of cases requiring parts for the A330 aircraft type

For the analysis between suppliers, MIA was excluded as the corresponding locations and distances for this supplier to the MRO company were unknown. Other airlines were used as the reference group for the prevention of a dummy trap. As a result, dummies D_3 till D_9 represent all suppliers with the exception of MIA and other airlines. This model has a higher Pseudo R-squared value of 0.21.

3) $Total\ lead\ time_i = a + \beta_1 Distance_i + \beta_2 Number\ of\ flights_{2i} + \beta_3 D_{3i} + \beta_4 D_{4i} + \beta_5 D_{5i} + 6D_{6i} + \beta_7 D_{7i} + \beta_8 D_{8i} + \beta_9 D_{9i}$

As shown in Table 8, the results indicate that both the distance and number of flights are variables to take into account when evaluating the influence of suppliers on total lead time performance (p < .05). More specifically, based on an average distance of 7708 kilometres, distance to be covered generally takes 15 hours of total lead time, ceteris paribus, while an average number of 336 flights per day generally reduces 30 hours in total lead time, ceteris paribus. After taking the distance and number of flights into account, AOG cases supplied by other airlines and Airbus are solved fastest. In contrast, AOG cases supplied by Boeing generally take more time after considering the distance from the supplier to the MRO company and the number of flights operated by the airline per day.

Table 8

Results of total lead time between suppliers regression analysis

Variables	Coefficient	Std. error	*t*	*df*	*p*	95% CI [LL, UL]
Intercept	18.69	3.78	4.93	51	.00	[11.08, 26.29]
Distance (in km)	0.002	0.00	7.70	51	.00	[0.00, 0.00]
Number of flights (per day)	-0.089	0.00	-10.08	51	.00	[-0.11, -0.07]
AFI	28.28	3.67	7.71	51	.00	[20.92, 35.65]
Boeing	48.50	3.61	13.44	51	.00	[41.25, 55.75]
Airbus	-12.92	8.83	-1.46	51	.15	[-30.65, 4.80]
CSP	32.92	4.98	6.61	51	.00	[22.92, 42.91]
Recall	32.69	6.55	4.99	51	.00	[19.55, 45.83]
AVL	34.99	3.84	9.12	51	.00	[27.29, 42.69]
Non-AVL	30.66	4.46	6.88	51	.00	[21.71, 39.61]

Note: results are compared to lead time of cases supplied by other airlines

To analyse the probabilities of AOG cases being cancelled, a fourth and final regression model (4) was constructed. In this model, the variables shifts, origin of request, number of checks and number of flights were taken into account. The day shift and VOP location are used as the reference groups to prevent dummy traps. As such, dummies D_2 and D_3 represent the afternoon and night shift whereas D_4 till D_8 represent the other origins of request. No outliers are identified for the number of checks. The model shows significant results, $\chi^2 = (8,\ N = 1360) = 15.77, p = .05$, and it shows a good fit of the variables according to the Hosmer and Lemeshow test value, $\chi^2 = 9.19, df = 8, p = 0.33$. However, the model does not predict the probability of cancellation much as only 1% and 4% of variations are explained in this model according to the Cox & Snell R-square and Nagelkerke R-square respectively.

4) $Probabilty\ of\ cancelled\ AOG\ process\ =$

$$\frac{1}{1+e^{-(a+\beta_1 Checks_i+\beta_2 D_{2i}+\beta_3 D_{3i}+\beta_4 D_{4i}+\beta_5 D_{5i}+\beta_6 D_{6i}+\beta_7 D_{7i}+\beta_8 D_{8i})}}$$

The results from this model are shown in Table 9 below. Only hangar 14 has a statistically significant effect on the probability of cancelled AOG cases. This indicates that while controlling for the total number of checks and types of shift, AOG cases from other locations have similar probabilities of being cancelled as those from VOP. With the exception of hangar 14, as AOG cases originating from VOP are four times ($\frac{1}{0.25}$) more likely to be cancelled compared to AOG cases from hangar 14. Therefore the results show that when taking the number of checks and shifts into account, hangar 14 performs best in terms of the number of cases being cancelled. In addition, the type of shifts do not have an effect on the probability of cases being cancelled.

Table 9

Results of cancelled orders regression analysis

Variables	B	SD	Wald	*df*	*p*	Exp(B)	95% CI [LL, UL]
Checks (per day)	-0.0	0.01	1.06	1	.30	1.0	[0.98, 1.0]
Hangar 11/12	-0.61	0.57	1.21	1	.27	0.54	[0.18, 1.61]
Hangar 14	-1.37	0.69	3.92	1	.05	0.25	[0.07, 0.99]
DD	-0.87	0.60	2.09	1	.15	0.42	[0.13, 1.36]
LMI	0.06	0.62	0.01	1	.92	1.07	[0.32, 3.56]
Other	-18.88	8948.53	0.00	1	1	0.00	[0.00, 0.00]
Afternoon	-0.47	0.30	2.46	1	.12	0.63	[0.35, 1.12]
Night	0.02	0.37	0.00	1	.96	1.02	[0.50, 2.08]
Constant	-1.64	0.76	4.69	1	.03	0.19	

Note: results are compared to probabilities of cancelled cases originating from VOP reported during day shifts

In addition, an alternative regression analysis was performed including the types of shift and only the locations VOP, hangar 11/12 and hangar 14 to control for the number of checks at those locations specifically. The results from this analysis can be found in Appendix 6, Table B. This analysis has a better fit of variables according to the Hosmer and Lemeshow test value, $\chi^2 = 8.55, df = 8, p = 0.38$, but explains less of the variances (between 1% and 3%) and was not able to find any significant regressions, $\chi^2 = (5, N = 508) = 5.55, p = .35$). Thus, in contrast to model 4, this alternative analysis does not find a significant relationship between the probability of cancelled AOG cases and the variables shifts, number of checks and locations VOP, hangar 11/12 and hangar 14.

5.4 Concluding remarks

The content analyses shows that although communications are perceived to be good and improved according to the participants, they do not adhere to the operational expectations of the management team. Furthermore, inventory management and sourcing tools function well as sourcing takes little time. Having said this, response times are high.

The descriptive results indicate that most AOG cases are filed during day and afternoon shifts and originate from hangar 11/12, with a positive correlation between number of AOG cases and number of checks. Furthermore, the results show that transporting parts by plane is the most common transportation mode for the AOG process and other repair shops are the most essential type of supplier for the MRO company. One of the least operable and oldest aircraft type, the 747, is associated with the highest number of (cancelled) AOG cases, suggesting that inventory levels, low possibilities to cannibalize from other aircrafts and aging are also causes of AOG cases. Poor results in the probability of cancelled cases indicate that more unnecessary AOG cases are caused by inventory inaccuracies and fatigue during night shifts at LMI and ‘other locations’. On the contrary, regression results indicate that hangar 14 performs best with statistically lower cancelled cases, even when taking the shifts and number of checks into account. The aircraft type 787 is associated with higher lead times and when taking distances into account, significant differences between suppliers and poor scores for the 787, indicate that different types of parts are associated with different supply complexities. Regression results show that parts supplied by other airlines and Airbus have the lowest lead times while parts supplied by Boeing have the longest lead times. In addition, descriptive results show that suppliers have different associations in terms of the probability of cancelled AOG cases. This indicates that supplier relationship and ability to cancel orders are relevant factor that influence the AOG process.

6. Discussion

The mixed-methods approach of this thesis study has acquired valuable quantitative and qualitative information for the evaluation of the MRO business's AOG-process. Not only has it created insights about the process, it was also able to answer the research question: *What affects the inhouse airline MRO performance in terms of number of AOG cases, lead-time and the probability of cancelled AOG cases during the COVID-19 pandemic?*

Based on the first hypothesis, inventory inaccuracies, the number of checks, the number of aircrafts that the airline has in operation, the age of the aircraft type and the number of flights were expected as factors influencing the number of AOG cases. However, only inventory inaccuracies, number of checks and number of flights were analysed with the use of regression analyses. Low adjusted R-squared values indicated that these three variables do not predict much variability in the number of AOG cases. An increase of the number of variables in the regression model would presumably have increased the R-squared values but made the model too complex due to the large number of categories. The results did show that differences in the number of AOG cases are caused by different responses between production locations after an increase in the number of checks, confirming that inventory inaccuracies and number of checks are factors. Surprisingly, the results differed between the initial analysis with daily values and the alternative analysis with weekly values. For instance, correlation issues were found when analysing the number of flights with weekly values while no issues were found when analysing with daily values. Furthermore, more variables showed significant results with the initial analysis even though less variation in the number of AOG cases was explained. This could be explained by the larger number of values (352) in the initial analysis making the model more accurate compared to the smaller number of values (50) in the alternative analysis. As such, the significant results for the variable 'number of flights' should not be overlooked. In contrast to what was expected, this variable showed a negative relationship with the number of AOG cases. Based on this research, no explanation can be made for this negative relationship.

As formulated in the second hypothesis, type of parts, supplier relationship, distance to the supplier, transportation modes and number of flights that day were expected to affect lead times of AOG cases. Regression results confirmed that, with the exception of transportation modes, all factors have an effect on lead time and were able to predict relatively high percentages of variabilities. However, different results between both regression models as the analysis including 'aircraft types' did not find a significant effects for the variables 'distance' and ‘number of flights’ on lead time whereas the analysis including ‘suppliers’ did find significant effect for these variables. Even though non-parametric tests were performed, multicollinearity issues could explain this difference. Post-research showed the variables ‘distance’ and ‘number of flights’ are significantly correlated, r (1548) = -0.17, p = .05. In addition, these two variables individually showed numerous correlations with the variable ‘aircraft type’ and almost no correlation with the variable ‘suppliers’. Thus, the p-values in both regression results may be misleading, in particular the results including the different aircraft types. Even though the variables ‘distance’ and ‘number of flights’ showed to be insignificant in this model, these variables may still be of importance and affecting lead times of AOG cases.

Based on the third hypothesis, inventory inaccuracies and the ability of the MRO company to cancel orders were expected as factors influencing the probability of AOG cases being cancelled. Regression analyses only evaluated the influence of inventory inaccuracies based on differences between production locations and shifts. Results showed that only two production locations significantly differed from each other affecting the probability of cancelled AOG cases even though qualitative and descriptive results suggest that night shifts are related with fatigue and lead to higher probabilities of cancelled orders. Furthermore, differences in results were found between the initial and alternative regression analyses. In contrast to the results from the initial regression analysis, the production location hangar 14 did not found enough statistical evidence of a difference in probabilities compared to VOP. This could be explained by the lower number of observed values in the alternative regression model, making the initial regression analysis preferred for identifying factors that influence the probability of cancelled AOG cases.

Other findings were made in this thesis research. Descriptive results showed that aircraft types that are old and less in operation are subject to a relatively high number of AOG cases and cancelled AOG cases as a result of wear and tear, lower inventory levels and fewer possibilities to cannibalise parts for that aircraft type. Furthermore, descriptive results showed that other repair shops and aircraft OEMs were identified as the most important type of suppliers in the MRO company’s supply chain because they supply most AOG cases. In addition, supplies from other airlines are preferred as descriptive results suggest that those supplies are easier to cancel, presumably due to more favourable contractual agreements. Furthermore, regression results show that other repair shops and aircraft OEM Airbus are associated with the lowest lead times. Finally, descriptive results suggest that the plane is the most preferred transportation mode for the MRO company as the plane is associated with the highest number of AOG cases and number of cancelled AOG cases. One reason could be that the MRO company is able to use available cargo space of its airline's operations which presumably offers more possibilities to order and cancel incorrect orders without additional costs. In addition, regression results showed that higher number of flights by the airline leads to shorter lead times, which confirms the importance of the airline's operations for the AOG process. In terms of communications, conflicting results were found. The qualitative results indicate that the quality of communications is good and improved. However, the quantitative results show that expectations in terms of the provision of information in the ERP tool are not sufficiently adhered to.

6.1 Recommendations

The results lead to the following recommendations. Because transportation time takes most time within the total lead time, the first recommendation is to pay more attention to the relationship with suppliers and transporters as advocated by Rodrigues & Lavorato (2016). Improved relationships with suppliers offer more abilities to cancel orders. Furthermore, it can lead to more opportunities in finding faster supplies (Cheng et al., 2012) and conversely to more opportunities for external revenues. Secondly, it is recommended to evaluate current agreements with suppliers because results indicate poor service for supplies from Boeing, and GAIN parts in particular. The dependency of planes as a transportation mode in the AOG process emphasizes the importance of the airline's network. Therefore, the third recommendation is to take the locations of important suppliers into account when configuring the airline's network. The configuration of the airline's fleet is also an important factor to the AOG process. The fourth recommendation is to take AOG performance into account when planning the airline's fleet configuration. Results have shown that older aircraft types cause more AOG cases, while newer aircraft types lead to longer lead times. More aircrafts of the same type leads to more opportunities to cannibalize and prevent AOG cases.

There are also opportunities to improve the AOG process internally. Firstly, the MRO company is recommended to provide more and clear work instructions about expected tasks to make operations more uniform between locations. Secondly, the MRO company should also provide more information in general about how the AOG process operates to help novice employees. Thirdly, the effect of unfavourable work environments, such as noise disturbance at hangar 11/12 and fatigue during night shifts should be more taken into account. Proactively approaching employees helps to understand the wellbeing of employees and in turn to notice preferences in shifts and other factors for underperformance. In contrast, it helps to understand why particular locations operate better, such as hangar 14, which has a four times lower probability in creating cancelled cases. Fourthly, the MRO company is recommended to invest more in the acquisition of data. The MRO company should issue (more) instructions about the data that employees are required to administrate. Furthermore, the construction of ERP tools that can automatically generate performance dashboards is recommended because relevant information is currently acquired from various sources, require numerous transformations before making analyses possible, or lack data such as costs and inventory levels. Similar problems in data analysis have been recorded years before (e.g. Dekker & Scarf, 1998) making this a known problem. However, such ERP tools do facilitate organisational learning as advocated by Amaratunga & Baldry (2002) and gives the opportunity to use more conventional quantitative methods to evaluate the performance of the AOG process in the future.

6.2 Limitations

Even though conventional quantitative methods were not used, the alternative method presented in this thesis research can be accounted for as generalisable. However, a number of limitations exists. Firstly, the low adjusted R-squared scores and Pseudo R-squared scores show that most regression models do not explain much of the variations in the dependent variables. This indicates that more factors influence the performance of the AOG process then current regression models have included. This could be explained by the exclusion of the variable ‘transportation modes’ and the separation of the variables ‘suppliers’ and ‘aircraft types’ in the regression analyses. Future research should try to include these variables in the analyses if data is available and try to find alternative variables that could affect the AOG process.

Secondly, this thesis research was required to use two non-parametric tests, which can be considered as a limitation because non-parametric tests are less powerful than parametric tests due to the need of compensating for unmet statistical assumptions. As a result, in reality more variables may have a statistical effect on total lead time than what the currently used regression models indicate. However, those that are found to be significant in current models can still be considered as relevant factors affecting total lead time. To prevent similar limitations, future research should use larger datasets by investigating larger time periods or multiple MRO companies because these allow to drop the normality assumptions as stated by the central limit theorem (CLT).

Thirdly, the effect of different types of checks on the number of AOG cases at locations was not considered in depth during this thesis research as this information was acquired at a late stage. This is a limitation as performing more extensive checks should lead to more findings of issues and in turn AOG cases. Future studies should therefore take the types of checks more into account.

Fourthly, the variable distance may not accurately measure the exact distance between the supplier and the MRO company as the location of the supplier is based on the location of the nearest airport. Therefore, the distance between the airport and supplier is not taken into account. As a result, the lead times associated to planes may not be accurate as parts may have been transported by slower transportation modes to cover the distance between the supplier and the airport. Having said that, the loss in accuracy may be insignificant because most suppliers such as other airlines have their MRO operations close to the airport.

The final limitation concerns the reliability of the data from the ERP tool that was used to calculate the response, sourcing and transportation time. These calculations may not be accurate because employees may not administrate all steps directly even though this is expected from them. For instance, the AOG-desk may forget to communicate that it has started with sourcing directly after the AOG case has been reported. This could explain the large response times and question whether the moment of order is also not accurate. In addition, the results from the evaluation of the suppliers and transportation modes may have been affected by the impact of the COVID-19 pandemic on supply chains. Therefore, these results may be less generalisable as current and future global supply chains may be in different conditions. Analysing the impact of the COVID-19 pandemic on global supply chains and in turn the AOG process is therefore recommended in future research

Therefore, future studies that analyse the performance of the AOG process should use larger datasets and use more variables, such as inventory levels and costs, to explain variations in the number of AOG cases, total lead times and number of cancelled cases. Furthermore, the impact of COVID-19 should be taken into account in future studies as it had a distorting effect on global supply chains and led to health and job insecurity in turn affecting individual performance of employees.

6.3 Conclusion

In conclusion, this thesis research has aimed to fulfil the inhouse airline MRO's objective while contributing to literature about the evaluation of AOG processes. Even though this thesis research was not able to use conventional quantitative performance evaluations due to a lack of resources, this approach did find valuable insights. By analysing the distribution of AOG cases, the corresponding lead times and the probability that a case is cancelled, this thesis research has been able to create more insights about from where most AOG cases originate and how they are solved. In addition, both internal and external differences in performance were found. These findings give directions for potential improvement in operations other than in employee cost and performance. Consequently, this mixed-methods research approach shows to be a valuable alternative for bridging the gap between academic research and practice, which proved to be even more challenging during periods of crises like the COVID-19 pandemic.

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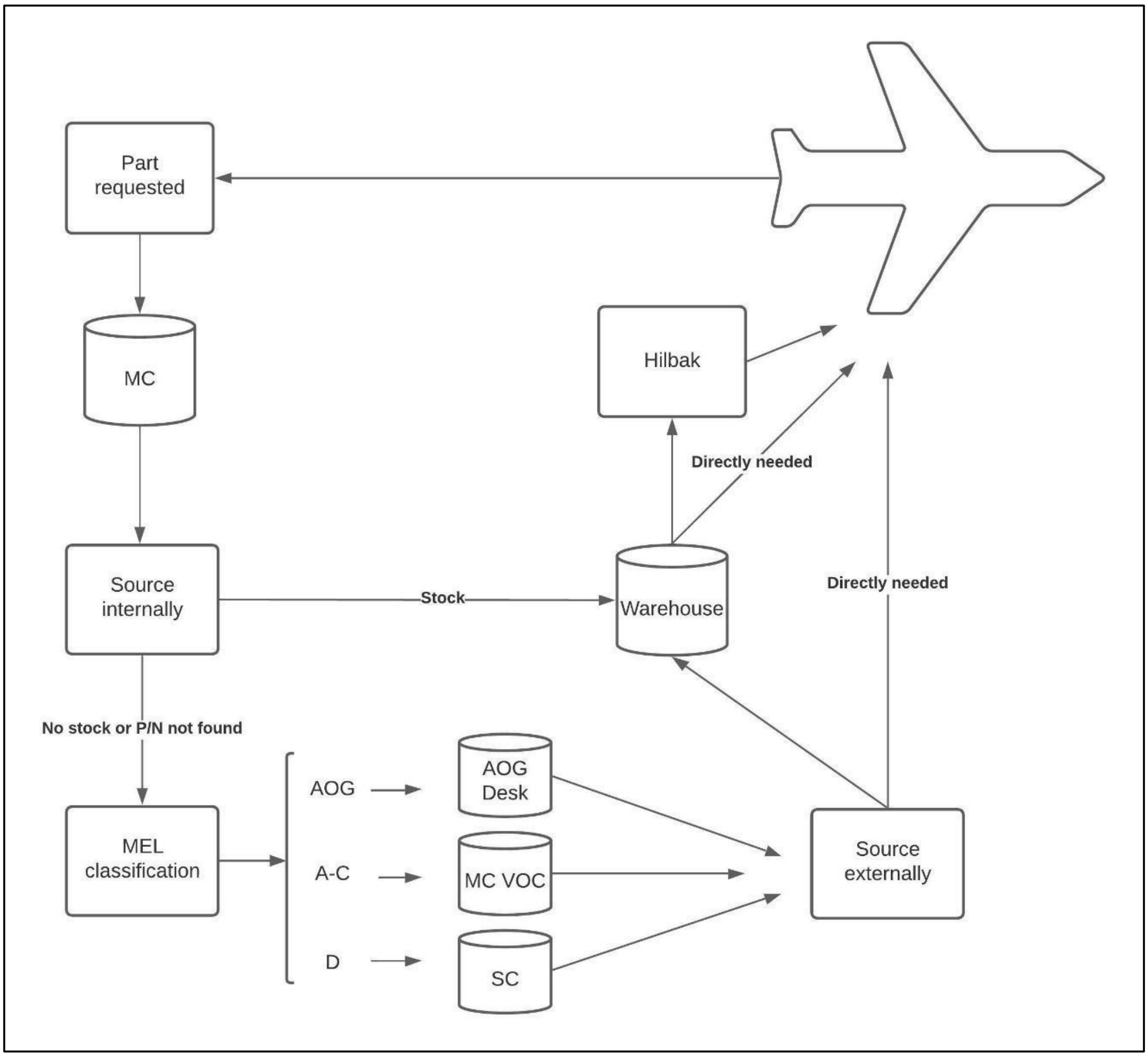
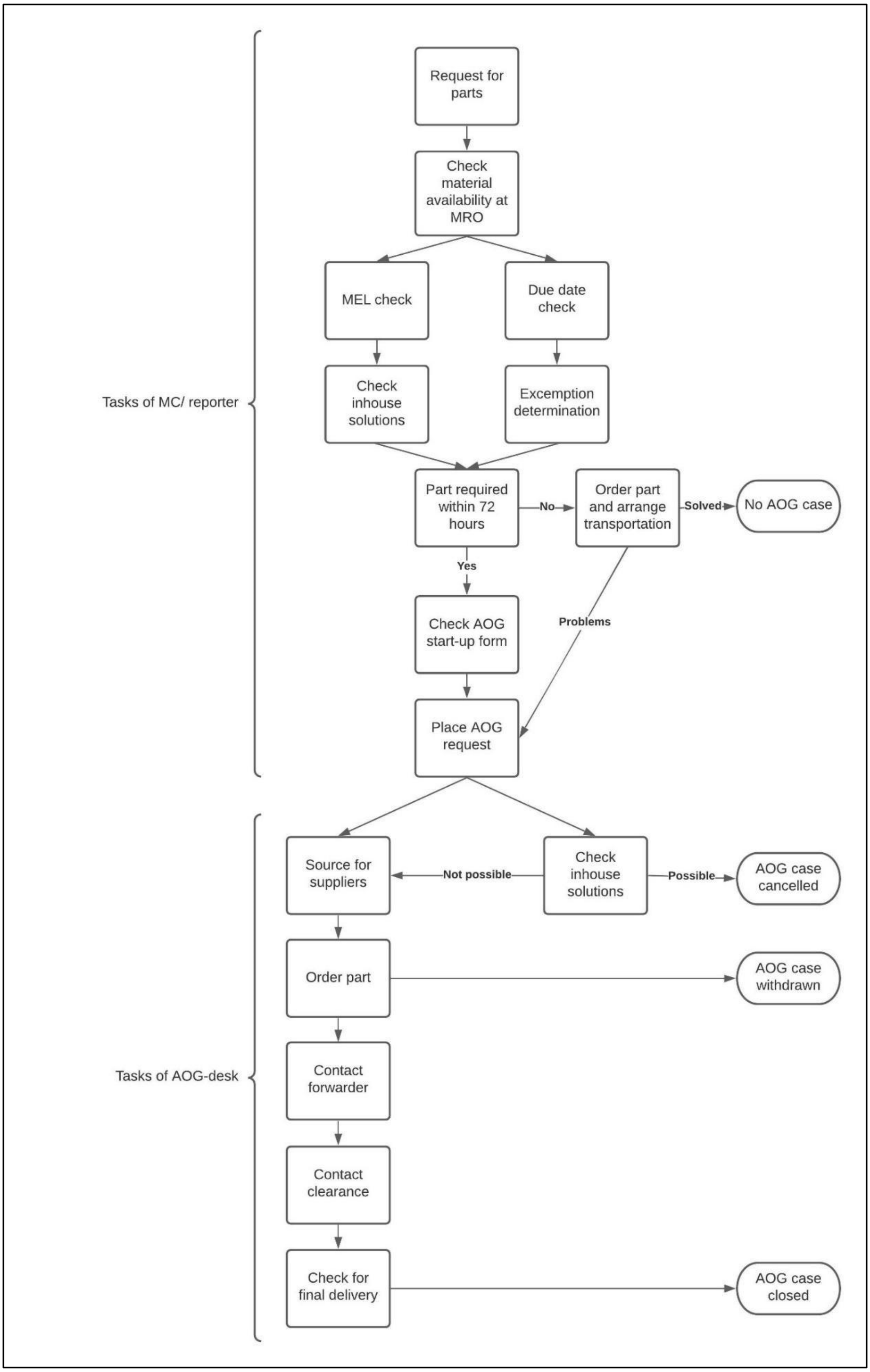
Appendix 1 – General parts request process



Appendix 2 – Standard AOG process



Appendix 3 – Descriptive analyses

Table A

Descriptive results of shifts

Variables	Day	Afternoon	Night
Number of cases closed	660	606	215
Number of cases withdrawn	28	17	6
Number of cases cancelled	34	27	16
Total number of AOG cases	722	650	237
Median lead time (hrs)	31	27	17

Table B

Descriptive results of aircraft types

Variables	737	747	777	787	A330
Number of cases closed	305	244	446	216	202
Number of cases withdrawn	17	15	26	14	5
Number of cases cancelled	10	25	32	14	13
Total number of AOG cases	332	284	504	244	220
Number of AOG cases per aircraft type	5,5	17,8	16,8	13,6	16,9
Median lead time (hrs)	15	33	29	49	24

Table C

Descriptive results of origins of request

Variables	VOP	Hangar 11/12	Hangar 14	DD	LMI	Other
Number of cases closed	43	576	206	304	106	20
Number of cases withdrawn	0	56	9	2	0	0
Number of cases cancelled	4	40	7	14	15	0
Number of AOG cases	47	672	222	320	121	20
Median lead time (hrs)	10	28	44	31	17	50

Table D

Descriptive results of suppliers

Variables	AFI	Boeing	Airbus	CSP	MIA	Recall	AVL	Non AVL	Other airlines
Number of cases closed	313	325	53	73	6	6	147	25	97
Number of cases withdrawn	5	8	0	1	0	0	1	0	0
Number of cases cancelled	11	14	0	0	0	0	4	1	7
Total number of AOG cases	329	347	53	74	6	6	152	26	104
Median lead time (hrs)	26	55	26	4	64	59	65	44	24

Table E

Descriptive results of AOG transportation modes

Variables	Plane	Taxi	Shuttle	Truck	Third parties
Number of cases closed	718	249	48	7	35
Number of cases withdrawn	12	4	0	0	0
Number of cases cancelled	25	1	1	0	0
Total number of AOG cases	755	254	49	7	35
Median lead time (hrs)	44	23	44	46	25

Table F

Distribution of AOG cases associated to types of aircrafts and location of requests (in %)

Aircraft type	VOP	Hangar 11/12	Hangar 14	DD	LMI	Other
737	21	21	22	23	10	0
747	17	21	0	12	33	80
777	32	31	40	36	23	0
787	15	14	12	17	25	7
A330	15	14	25	12	9	13

Appendix 4 – Summary of interview results

Category	In general	MC	AOG-desk
Information	− Outdated WPI	− Start-up forms − Due dates	+ Own constructed instruction lists − Lack of available/alternative information sources
Equipment, tools & parts	+ Work well + Useful − Challenging for beginners	− Not custom-designed − Restricted and unclear information	− Rotable ERP tool not user-friendly
Job & tasks	+ Distribution and amount of work − Challenging for beginners	+/- Freedom	− MC not performing required sourcing tasks − Administration after AOG process
Technical knowledge & skills		+ Sufficient level of knowledge and skills − Some have difficulties in understanding technical issues − Some have difficulties in understanding flow of operations	− Significant difference in level of knowledge and skill between colleagues − Loss of knowledge
Factors affecting individual performance	− Fatigue and stress (especially during night shifts)	− Management not proactively checking for factors when planning work schedules	+ Collaboratively solve issues that may affect individual performance
Environment & facilities	+ Good location	+ Hangar 14: great environment and facilities	+ Great environment and facilities − Poor IT support

		− Hangar 11: noise disturbance, bad thermal insulation − VOP: disturbance by colleagues	− Messy desks and broken chairs
Organization & environmental issues	+ Working atmosphere − Ambiguity and job insecurity due to reorganizations − Uncertainty about location of parts	+ Escalation process with forwarders − Lack of motivation and help from colleagues − Less work councils	− Chaotic situations and corresponding communications − Convincing elderly colleagues to use new methods or tools − Dependency on forwarders
Leadership & supervision	+ Horizontal structure of commands	+ Management on top of operations + Good balance with working atmosphere − Feeling of loss in control	+ Authority and control − Lack of supervision from management team − Support for beginners − Management focuses on solving symptoms instead of the causes of issues
Communication	+ Good in general − Improvement is required when switching shifts	+ Noticeable improvements in communication due to the ERP tool and younger colleagues − Mixed perceptions about frequency of use and accessibility of phone calls	− Quality of communication varies between colleagues − Use of jargon − Lack of feedback sessions after AOG-process − Communication with forwarders − Lack of administrating conversations by phone on digital environment

Note. *+ = positive results, +/- = mixed results, - = negative results. Findings from the interview with the DMM have been added to the general results because no distinct results were identified.*

Appendix 5 – Tests for assumptions

Figure A

Normal probability (Q-Q) plot of AOG cases per day

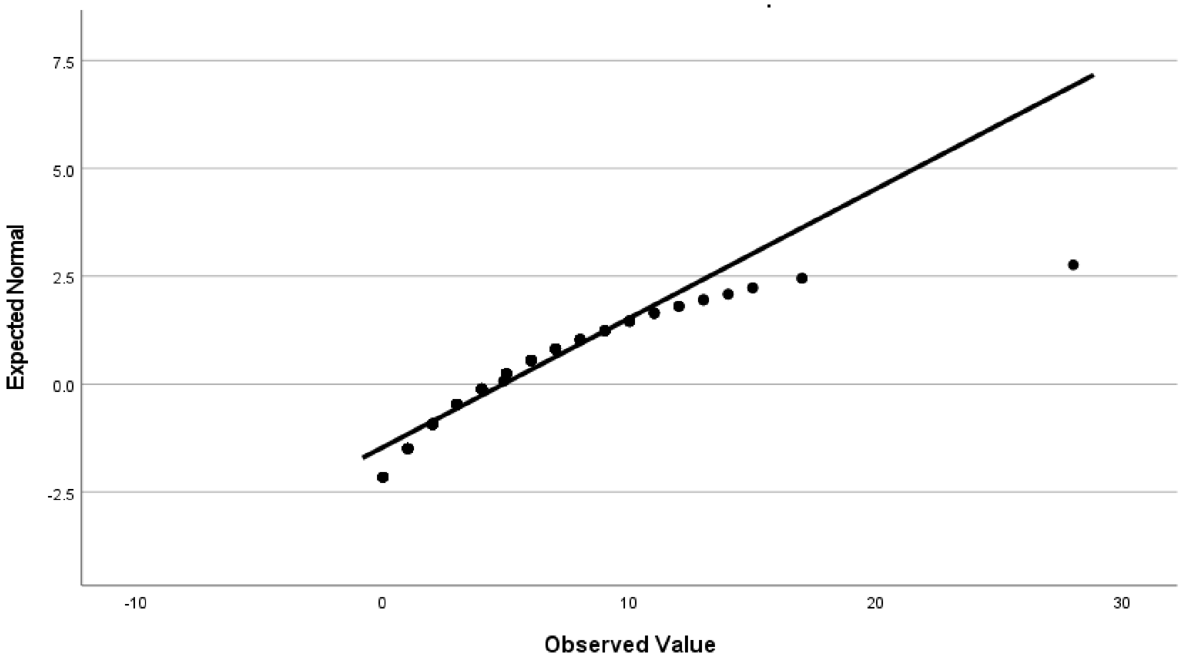


Figure B

Normal probability (Q-Q) plot of (log-)transformed AOG cases per day

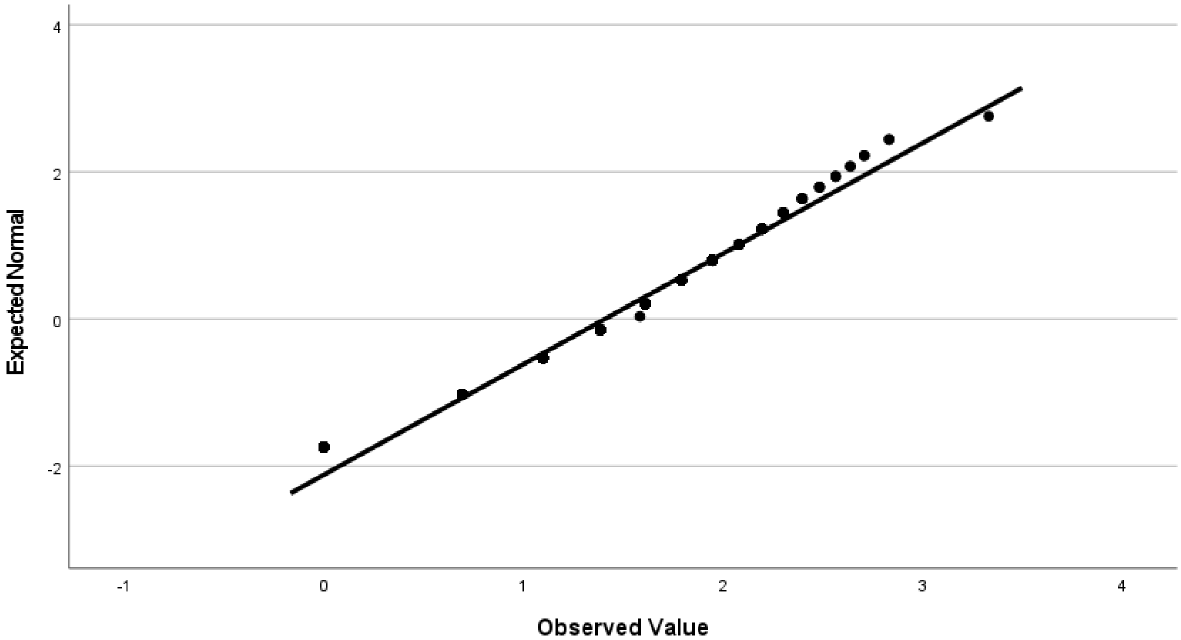


Figure C

Normal probability (Q-Q) plot of AOG cases per week

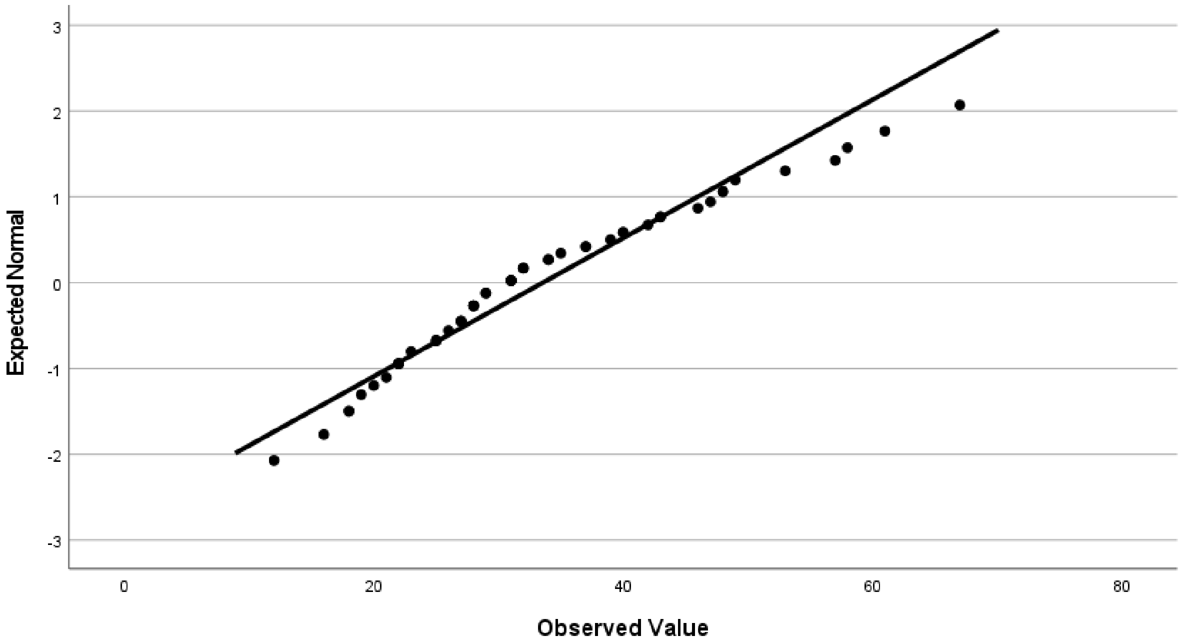


Figure D

Normal probability (Q-Q) plot of (log-)transformed AOG cases per week

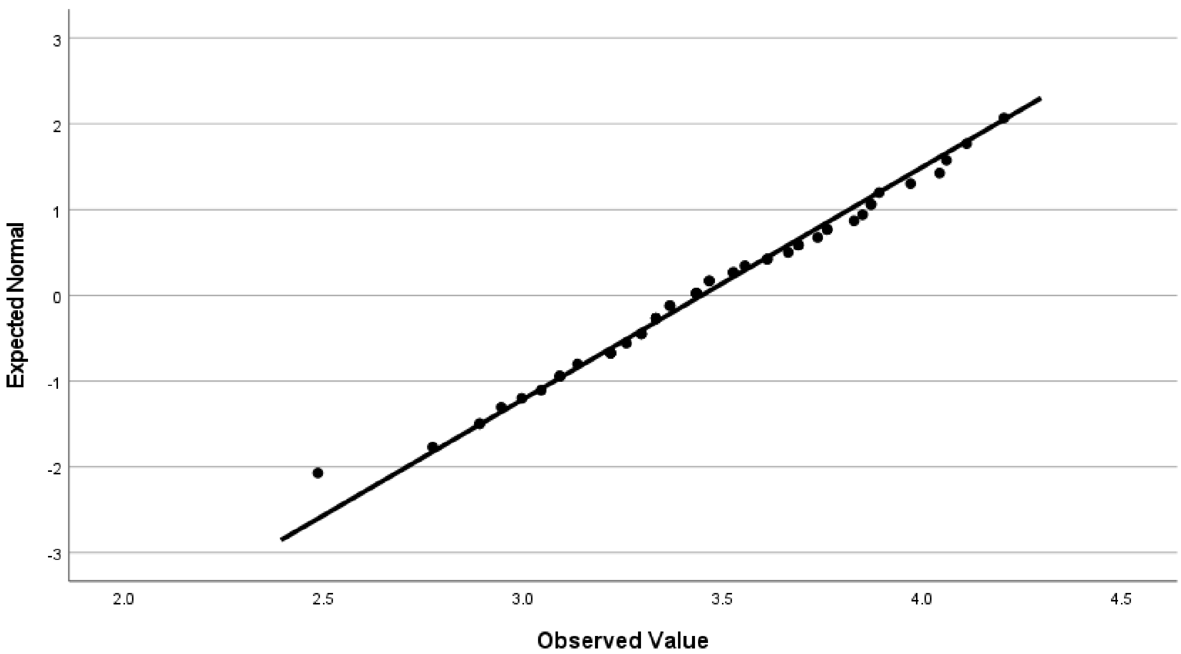


Figure E

Normal probability (Q-Q) plot of total lead time values

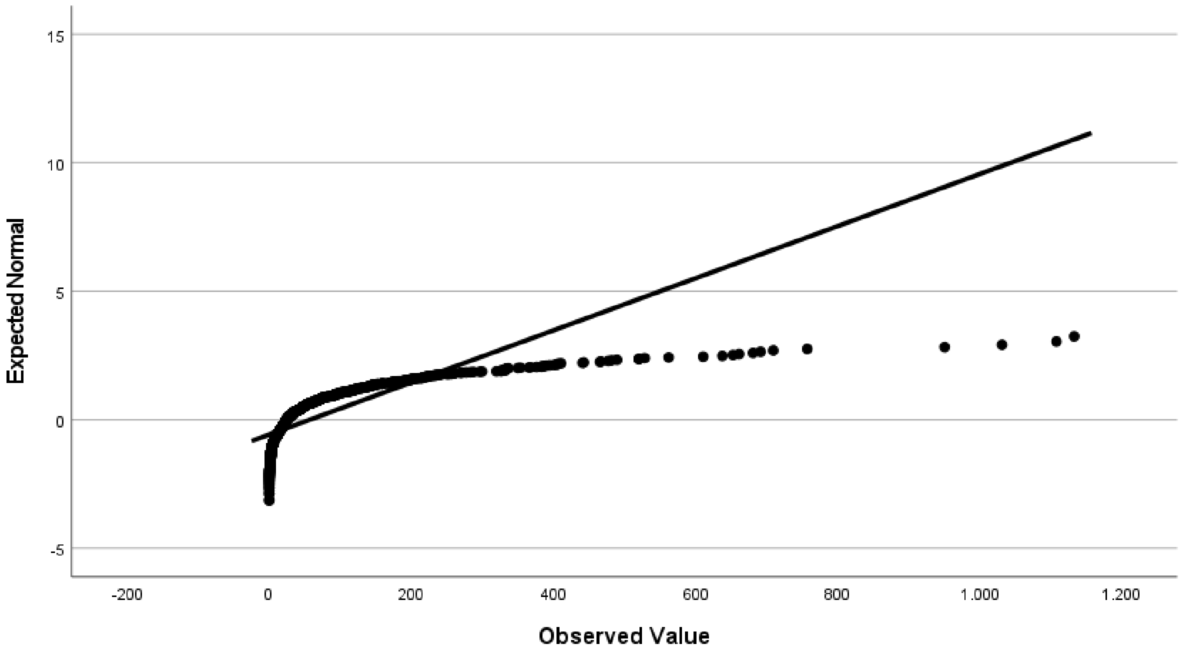
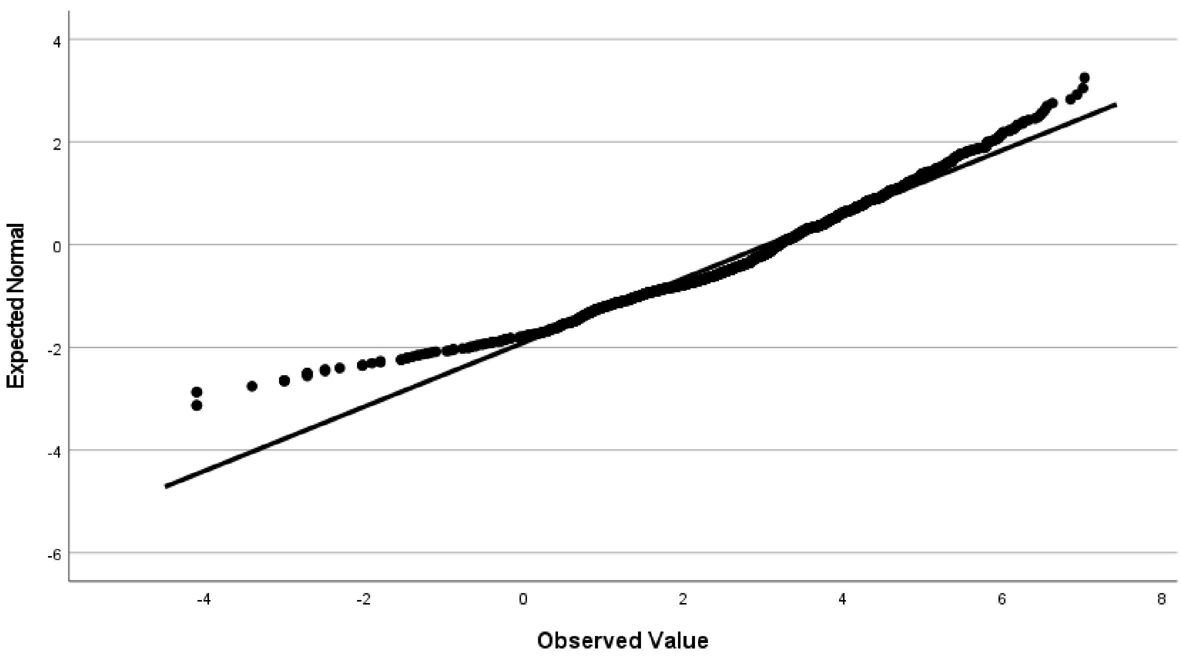


Figure F

Normal probability (Q-Q) plot of (log-)transformed total lead time values



Appendix 6 – Regression results

Table A

Results of number of AOG cases per day regression analysis

Variables (per day)	Unstandardized Coefficients	*t*	*p*	95% CI [LL, UL]	VIF
Constant	0.86	3.27	0.00	[0.53, 1.18]	
Flights	-0.00	-0.94	.07	[-0.00, 0.00]	3.52
Checks at VOP	0.01	0.67	.02	[0.00, 0.01]	3.64
Checks at hangar 11/12	0.03	2.78	.03	[0.00, 0.05]	1.07
Checks at hangar 14	0.03	-0.06	.63	[-0.08, 0.13]	1.01

Table B

Results of alternative regression analysis on the probability of cancelled AOG cases

Variables	B	SD	Wald	*df*	*p*	Exp(B)	95% CI [LL, UL]
Checks (per day)	-0.01	0.01	1.94	1	.16	1.01	[0.02, 55.46]
Hangar 11/12	-0.13	0.77	0.03	1	.87	0.88	[0.20, 4.00]
Hangar 14	-1.32	1.02	1.67	1	.20	0.27	[0.04, 1.99]
Afternoon shift	-0.04	0.47	0.01	1	.94	0.97	[0.38, 2.44]
Night shift	0.26	0.59	0.20	1	.66	1.30	[0.41, 4.08]
Constant	-1.82	1.00	3.32	1	.07	0.16	

Note: results are compared to probabilities of cancelled cases originating from VOP reported during day shifts