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Aircraft on ground (AOG) analysis: forecasting and inventory management of AOG spare parts

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Abstract: *Aircraft on Ground or AOG is a wide spread term in aviation industry. The term is used when a particular aircraft that is being used by a particular airline is experiencing a maintenance problem and thus needs to undergo a maintenance work resulting in a delay of a scheduled flight. The usual scenario is comprised of actions where there comes an urgent need for a spare part that is required to be delivered to the place where unforeseen aircraft halt takes place in order to put back the aircraft into operation so that the delay is successfully over and passengers can enjoy their trip or cargo gets delivered. The term of AOG can be used for any case where a spare is needed to fix an aircraft maintenance problem. The aim of this research is to analyze AOG cases in one of the air carrier companies of the Republic of Kazakhstan (hereinafter – the Company) through the data the Company has gathered in 6 years and to propose appropriate forecasting and demand models for future operations. Two approaches were used for forecasting: annual and monthly planning. Annual planning creates regular demand for which Moving Average, Weighted Moving Average, Exponential Smoothing, Non-linear, Median, and Averaging methods were used. For intermittent monthly demand Weighted Moving Average, Holt's, and Syntetos and Boylan's methods were used. The stochastic modeling was chosen due to the nature of the spare parts in airlines industry to have a long lead time, unlimited order of the parts to be demanded and our suggestion for an airline to provide a high level of service not giving a priority to economies of scale.*

Key Words: *Aircraft on ground, AOG, aviation, inventory, forecasting, demand, planning, management.*

1. INTRODUCTION:

1.1 Problem Statement

AOG is a term in aviation that defines a case when aircraft needs a spare part replacement and the needed spare part is out of stock. In this case the spare part has to be ordered from suppliers or other airlines and the flight is delayed for more than 3 hours.This is a critical problem as it affects the service level of the company and costs at which the spare part is ordered in such an emergency case. The air carrier homebased in Kazakhstan provided records of AOG cases for 6 years: 2011-2016. Recommendations need to be provided based on this data.

1.2. Methodology:

Data was analyzed to provide Forecasting and Inventory Management recommendations. Various methods were applied and compared in both these areas to provide optimal solutions that have to balance between high emergency ordering costs and expensive handling costs.

1.3. Motivation:

Motivation of this paper is to implement knowledge acquired on the program to solve the problem that relates to airline companies and a big number of people who use their services. Significant impact may be created in:

- Increasing service level – preventing flight delays that are very unpleasant for airline clients.
- Decreasing AOG cost – preventing expensive emergency spare part ordering and other AOG resolving costs as well as losses from stagnant aircrafts.

2. CURRENT PRACTICES ON AOG AND MATERIALS PLANNING:

2.1 Spare Parts Classification

The company itself divides types of spare parts into different categories according to their nature and complexity. The first group of the spare parts is named Consumables. These are the spare parts that are classified to be the liquid ones i.e., fuels, lubricants, cements, compounds, dyes, chemicals and some other that are used at maintenance activities related to the engine, equipment and aggregates. One thing that has to be outlined is a fact that these materials are used only once. The next group of the parts are named as Expendables. These are the parts which are not mentioned in any type of a repair procedure. These parts can be used several times provided that they are in a good condition. Good examples of them would be screws, nuts and some flat washers. The next family of the spare parts are classified as Kits. Kits are the parts which are classified as the one product family and awarded a single part number. Kit parts can be comprised of various categories and have both serial and part numbers. A good particular example would be some bolts, nuts, valve, etc.

The next family is named as Rotables – these are the items that have no specifically described repair procedure. They exist inside the system and tracked accordingly. Usually, the installations and operating times would be the best examples. One family of the spare parts which are similar in the name to the previous one are the Rotable Repairable items. These are items that can be restored in terms of financial aspect as well as refurbished and tested. In general, they have a specified procedure for repairment. Also they do possess serial numbers and are controlled via tracking platform. Apart from this, some items do not have serial numbers but can undergo repairing activities. Good examples would be mount bolts which are used in engines and acoustic panels. In general, this items are classified as rotable ones.
The next group of tools are the ones which are used as measurement equipment and named as Tool group. Items in this serialized group are periodically tested, calibrated etc.

2.2 AOG team in organizational Structure:

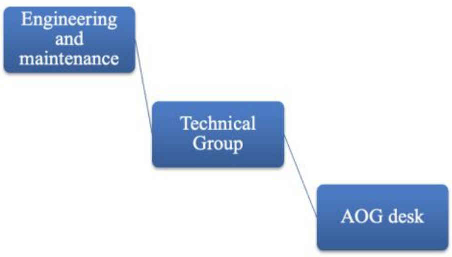


Figure 2.1. AOG within Engineering and Maintenance Department

The AOG desk is a part of Engineering and Management Department within the organizational structure of a company. AOG desk is a subdivision of technical supply group which is a part of engineering and maintenance department. AOG team does consist of 5 team members,4 of which are AOG officers and 1 is a senior AOG officer. They work 24/7 each within different shifts. AOG officer has a right to purchase parts up to 30000USD price. In case the price for a particular part goes beyond this number an AOG officer has to inform the head of Engineering department and wait for an approval. One particular thing to note that once flight crew comes across an AOG case they first contact the team named maintenance control center (hereinafter – MCC) but not AOG officer and the reason behind that scenario is an engineer from MCC should first evaluate the request from crew members and advise them some technical support and make sure if there are alternative options or some other possible options that would help the crew members to fix the problem. Once the MCC engineer is sure that the case is an AOG he passes the further action role to an AOG officer clearly stating the spare part that has to be delivered to the requested point. The communication means between the team members during the work flow are the mobile phones and corporate email. No presence of a particular software dedicated for information exchange once AOG case occurs. The company used operate on CITA software previously but opted to continue without it after a while.

3. LITERATURE REVIEW:

It follows from the aim of the present research that AOG forecasting and inventory management is the focus of the paper. That topic belongs to the broader one - general forecasting and inventory management and airlines' forecasting and inventory management. Therefore, in order to postulate the convergence of the AOG forecasting and inventory management with the broader areas, on the one hand, and to emphasize specific features of the topic, on the other hand, the overview of the published studies devoted to the problems mentioned is provided below.

3.1 Forecasting:

As it was stated by authors (1) there are many studies and research on demand forecasting in different industry sectors. Nowadays, forecasting models are automated and data represented smoothly. Precise demand forecasting is critical for air industry, due to the high cost of flight delays and spare parts. Well-developed forecasting model would be helpful for management staff to avoid enormous and unexpected expenditures.

Due to changing demand and time of occurrence correct intermittent demand forecasting has a great significance. There are various forecasting methods, including exponential smoothing; however Croston's method is widely used nowadays. Croston's method of forecasting has demonstrated strong performance comparing to exponential smoothing method. Several variations of Croston's method were proposed by Syntetos and Boylan by introducing new estimator for demand. Authors have proved that new variant is better than original one. One of the comparing project used large sample number of inventory from the Royal Air Force of UK which is highly depend on in-time available spare parts. In order to perform comparison 3,000 product from automotive industry were used.

Leven and Segerstedt proposed another variant of Croston's method; their method was targeted to deal with slow/fast moving parts. Authors argue that application of their method leads to bias avoidance.

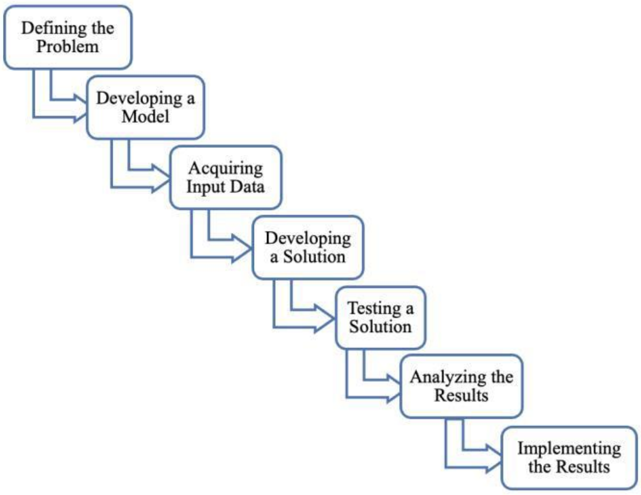


Figure 3.1 Steps of forecasting (2)

3.2 Inventory Management:

3.2.1 Inventory provisioning:

Inventory provisioning is established to be developed using mathematical tools. This assumes 2 main models: Deterministic and Stochastic. Deterministic Model represents a model where all values are known with objectively defined confidence. Stochastic also referred as Probabilistic model is a model that include values subject to some probability (2).

Uncertainty of the demand accounts for the existence of the inventory (3). Hence, the problem of the organizing healthy inventory management system seems to be undated. And a company seeking success should build such supply chains that meet the latest technologies and satisfy voice of the customer. The level of safety inventory is determined by the uncertainty mentioned and the level of product availability that company targets.

Two replenishment policies are used in inventory management. They are: Continuous and Periodic review. Continuous review states that the inventory level is controlled continuously and the ordering takes place once the reorder point is reached i.e., the level of inventory falls down the minimum level. Periodic review is comprised of conducting spare parts review in a particular period and thus may result in some delays as the inventory tracking activities take place from time to time i.e., long lasting review periods result in long lead time of ordering (3).

3.2.2 Airlines' inventory management:

Specialists involved in the airline industry realize that carrier's core business is transportation. It is common practice for the majority of the airlines to outsource aircraft maintenance. To be fair, this maintenance has a crucial importance. The reason for that is safety. Passengers are in danger if the aircraft experiences technical failure. According to Michael McFadden and D. Scott Worrells outsourcing of component repair and outsourcing of spare parts' inventory reduce costs and enable carriers to focus on their competence (4). With regard to inventory management authors note that inventory comes not cheap. Based on the data of 2007 it is demonstrated that carriers decreased their inventory by

14 %. Moreover, one of the executives of Jetstar Asia - low-cost airline based in Singapore - says that the company wants a contractor who can render a full range of technical services including AOG solutions.

Traditionally, inventory managers develop their inventory models using Poisson distribution for every spare part kept in one warehouse and demands for the variety of operations. In order to provide the target service level carriers should make the demanded spare part always available in the stock. Therefore, the problem of high inventory holding costs seems to be common for the airlines.

3.2.3 AOG inventory management:

It is now well established from the variety of studies that in case when AOG occurs which literally means absence of the spare part required to fix the technical issue as well as absence of the personnel at the location where the event takes place, both people and parts should be immediately taken to that place. According to the data provided by D. Draxler and M. Džunda AOG costs approximately 50000 USD per hour, while sometimes the transportation of the spare part can cost even 150000USD based on the model of the aircraft and the operating airline (5). It is estimated to be a billion-dollar industry and the parts may vary in cost. There can be a 50-dollar valve that will be preventing a one whole aircraft from operating. Money seems to be a weaker objective of consideration in opposite to time in which the aircraft has to be repaired so that it gets back to serve the customers and thus generate cash. As the practice shows most of the airlines do not have a silver bullet approach to deal with AOG case and major bottleneck that takes time to solve the issue is time spent for analysis of each unexpected case and finding out the best solution in terms of time and cost. Some other issues that have to carefully considered in dealing with AOG case are the options of dispatch warehouses, total shipping time based on calculations between aerial proximity of the locations, total shipping cost which can be a good differentiator in case a couple of several routes satisfy the time constraints, the physical characteristics of the spare parts such as the dimensional figures or the hazardous effects.

Talking about AOG inventory management it should be stated very clearly that the costs are not the main issue to be concerned about. Reliability is the focus. Recent studies on that topic are called to find key factors influencing the lumpy nature of the demand for aircrafts' spare parts. For example, it is shown that fleet size and purchasing period of the aircrafts within particular airlines generate intermittent demand (6). Moreover, in that research academics claim that it is very difficult to incorporate real historical data on demand into the calculations. Even when this information is provided, many parameters needed for demand prediction and consequently preventing no-fly failures are still unknown. The last emphasizes the complexity of AOG inventory provisioning and proves that the topic discussed represents very urgent and interesting area for research.

4. FORECASTING MODEL PROPOSED:

4.1 Data:

The company provided the data of AOG cases that have happened in 2011-2016. It consists of points shown on Table 4.1.

Aircraft number	#####
Aircraft Series	ERJ190-100LR
Aircraft Date of Manuf.	21-Apr-12
Require Date	23.06.2014
Quantity required	1.00
Part number	180500-200-0
Part description	CABLE UNLOCKING LONGITUDINAL
Supplier code	FE0114
Req delivery location	ALA
Delivery date	27.08.2014
Issued by	Person's Name:

Table 4.1 - Sample of AOG documentation

There were 3433 AOG cases in total.

4.2 Observations

Some observations regarding the data:

- Distribution of AOG cases by months can be seen on Figure 4.1. From this data we can conclude that there is no clear seasonality.

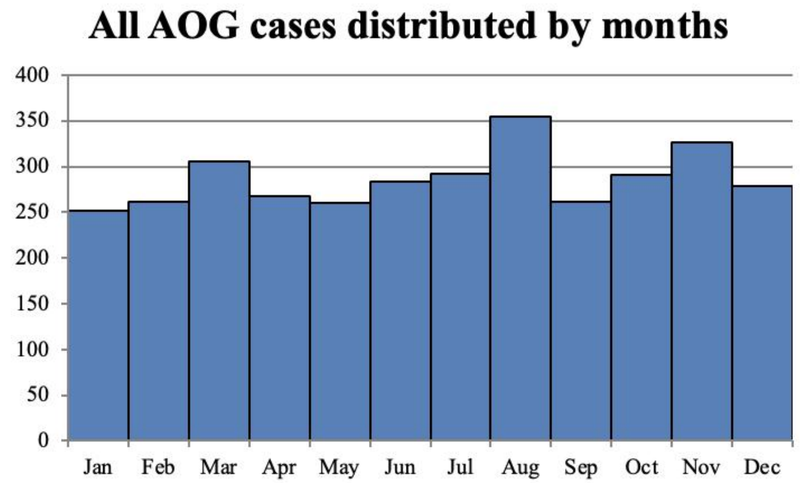


Figure 4.1 - AOG by month histogram

- It seems to be a correlation between age of the aircraft and number of AOG cases it experiences. Correlation factor equals to 86%. Therefore, one of the possible ways to decrease number of AOG cases in the Company would be refreshing their fleet.

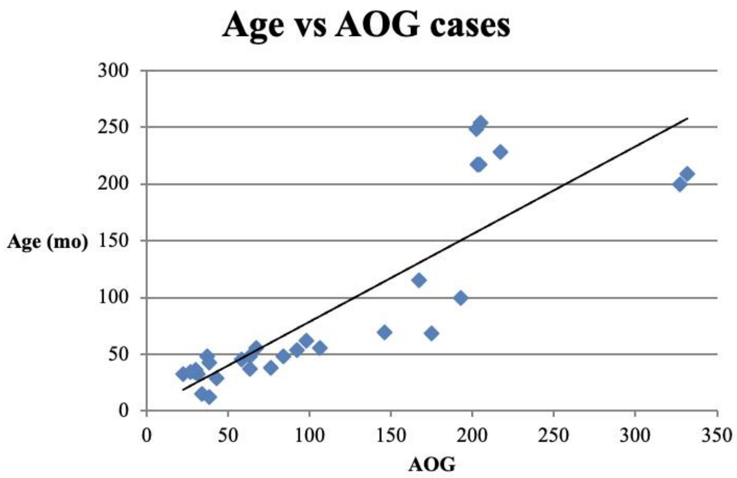


Figure 4.2 - AC Age vs AOG

- There are 2719 unique spare part that were needed for AOG between 2011 and 2016. In order to simplify the problem it was decided to analyze which spare parts are ordered more frequently. Note that it is not quantity of spare parts ordered but number of orders. Factors like price and lead time play secondary role in AOG according to the Company managers as every AOG case is critical and prevents aircraft from flying.
  It turns out that around 66% of spareparts were ordered only once. Max ordering frequency is 10. Distribution can be seen on Table 4.2. We chose 5 SPs that were ordered most frequently (7-10 times) in order to test out hypothesis.

Number of repetitions	Number of SP with many repetitions	Sum	Percent
1	2258	2258	65.77
2	313	626	18.23
3	88	264	7.69
4	37	148	4.31
5	14	70	2.04
6	4	24	0.70

7	1	7	0.20
8	1	8	0.23
9	2	18	0.52
10	1	10	0.29
	2719	3433	
	Total unique SPs	Total AOG cases	

Table 4.2 - AOG Spare part ordering frequency

4.3 Results:

Two approaches were used in forecasting. First is to treat data on a monthly basis and thus have an intermittent demand. Second is to aggregate data into years and have regular demand.

4.3.1 Intermittent demand forecasting

5 most demanded spare parts were forecasted using WMA, Holt's and Syntetos and Boylan methods. SBM performed better than other two for every single spare part. However, all it forecasted was 0s for every period. Therefore, MAD was identical to average demand for this spare parts. This can be explained by a huge fraction of 0 demand periods – 76-88%. Analysis of the results is given in Table 4.6. It has to be noted that MADs of all 3 methods are close to average demand, which means that there will be large variation.

Spare part	Average demand	Holt's MAD	Holt's Rank	WMA MAD	WMA Rank	SBM MAD	SBM Rank
SP1	1.531	2.835	3	2.723	2	1.531	**1**
SP2	0.208	0.33	2	0.333	3	0.208	**1**
SP3	0.196	0.273	2	0.273	2	0.196	**1**
SP4	0.408	0.772	3	0.766	2	0.408	**1**
SP5	0.276	0.379	2	0.407	3	0.276	**1**

Table 4.6 - Intermittent demand forecasting results

4.3.2 Regular demand forecasting:

Data can also be treated in combinations as demand is rare. Therefore we aggregated it into years and used Moving Average, Weighted Moving Average, Exponential Smoothing, and Non-linear methods for this regular demand. 4 methods were compared for 5 spare parts. WMA and ES performed similarly well – one suited some spare parts and another one suited other ones. After that go Non-linear approach and MA respectively.

Spare part	Non-linear MAD	Non-linear Rank	MA MAD	MA Rank	WMA MAD	WMA Rank	ES MAD	ES Rank
SP1	13.24	3	18.5	4	12.67	2	12.48	**1**
SP2	4	4	3.25	3	3	2	1.75	**1**
SP3	0	**1**	3.5	4	2	3	1.5	2
SP4	2.25	3	2.5	4	1.67	**1**	1.87	2
SP5	1	3	0.5	2	0.33	**1**	1	3

Table 4.11 - Regular annual demand forecasting results

5. INVENTORY POLICY PROPOSED FOR AOG SPARE PARTS:

5.1 Application of the Order up-to model to the Company data:

Following the justification made in the previous Forecasting chapter for the intermittent demand the Company first can place an initial order for AOG spare parts and then review them periodically using the order-up-to model that is provided below.

The data on Figure 5.1 was used for the development of the order up-to model.

SP	Price, USD	Lead time, DAYS	Lead time, MONTH = Lead time, DAYS/30	Single period demand: Mean	Single period demand:Mean Rounded
1	642,71	6,58	0,22	1,56	2
2	15 218,88	4,71	0,16	1,00	1
3	6 283,19	7,63	0,25	1,00	1
4	370,71	4,04	0,13	2,90	3
5	389,27	5,64	0,19	1,07	1

Figure 5.1 - Initial data for Order up-to modelling
(data provided by the Company is shown in black, calculated data – in red)

Lead time is the number of days between the date when the part was in need (the date of AOG) and the delivery date. According to the interview with the Company managers the delivery date is referred as AOG case solution date, because the problem was solved urgently. Single period demand is given by the Company. To make it clear how this data was obtained in the company an example of SP #1 is provided on the Figure 5.2.

YEARS, when SP caused AOG	Demand per year	Demand per month = Demand per year/12
2012	2	0.1667
2013	26	2.166666667
2014	32	2.666666667
2015	15	1.25
Average		1.5625

Figure 5.2. Demand for SP #1 in 2012-2015

Review period is defined as 1 month.

According to the data provided by the Company, holding cost per month amounts to 21.9 % of the item's price. Backorder cost is taken as 35 % as it is accepted in similar studies (7).

Inventory model with the target in-stock probability equal 90 % for the part that caused AOG more frequently than others - SP #1 - illustrates that the Company should keep 4 pcs of SP #1 in the stock to provide 90% service level (Figure 5.3).

Inputs are in red, outputs in black

Lead time, month	0,219333333
Mean, Single period demand:	2
μ (mean demand over *l*+1 periods)	1,86558
Order up-to level to achieve a target in-stock probability	
Target in-stock	90,00%
S	4,00
Order up-to level to minimize holding and backorder costs	
h, holding cost per unit per period, USD	140,7528385
b, back order cost per unit, USD	224,9474588
Critical ratio: *b* / (*h* + *b*)	0,6151
S	2,00
price for one pcs, USD	642.7070251

Performance Measures	
Order up-to level, *S*	4
Expected back order, *L(S)* :	0,06
Expected (end of period) inventory :	2,19
Expected pipeline inventory:	0,34
In-stock probability:	95,87%
Stock out probability:	4,13%

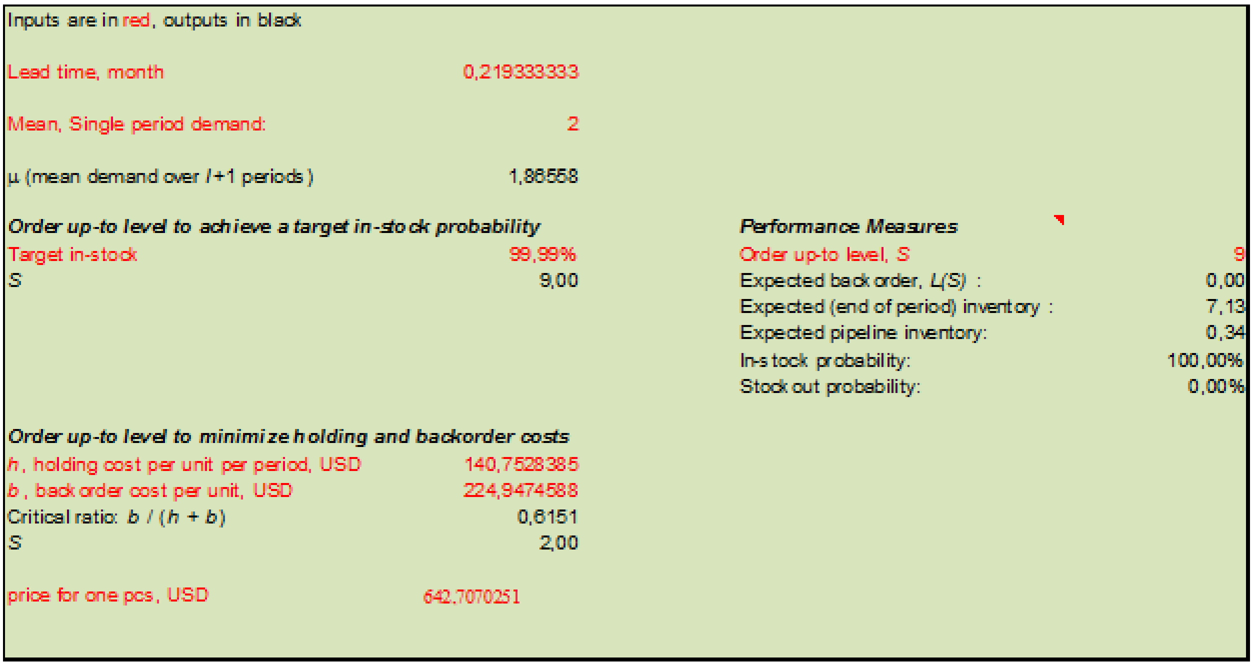
Figure 5.3 - Order up-to model with the target in-stock probability 90 % for the SP #1 (Source: (7) Excel template for the order-up to inventory model, using the Poisson distribution)

The results obtained from the calculations for the SP #1 are summarized in the Table 5.1:

Table 5.1 Order up-to inventory models for different service levels for the SP1

Service level	Order up-to level
90 %	4
95 %	4
99 %	6
99,99 %	9

As it is proved, improvement of inventory provisioning performance (increase of service level) adds the cost of inventory. Interestingly, the outcomes differ more than 2 times for the service levels of 90% and 99.99 %. The extreme case - inventory model with the target in-stock probability equal 99.99 % for the SP #1 is shown on the Figure 5.4.


Inputs are in red, outputs in black

Lead time, month	0,219333333		
Mean, Single period demand:	2		
µ (mean demand over *l*+1 periods)	1,86558		
Order up-to level to achieve a target in-stock probability		***Performance Measures***	
Target in-stock	99,99%	Order up-to level, *S*	9
S	9,00	Expected back order, *L(S)* :	0,00
		Expected (end of period) inventory :	7,13
		Expected pipeline inventory:	0,34
		In-stock probability:	100,00%
		Stock out probability:	0,00%
Order up-to level to minimize holding and backorder costs			
h, holding cost per unit per period, USD	140,7528385		
b, back order cost per unit, USD	224,9474588		
Critical ratio: *b* / (*h* + *b*)	0,6151		
S	2,00		
price for one pcs, USD	642,7070251		

Figure 5.4. - Order up-to model with the target in-stock probability 99.99 % for the SP #1 (Source: (7) Excel template for the order-up to inventory model, using the Poisson distribution)

According to the calculations, order up-to level of SP #1 for the service level of 90% (4 pcs) corresponds to the actual data of the Company. Following historical data this SP caused AOG in 2012, 2013, 2014, 2015. Demands per year equal 1, 3, 3, 2 respectively. Moreover, the real in-stock probability found by Poisson distribution for the Order up-to level of 4 pcs equal 95.87% - even more than targeted before - 90%.

5.2 Discussion of the results

The results in this chapter highlight the importance of service level that the air carrier plans to achieve.
Taking into account the real data regarding high holding cost of the inventory and the necessity to maintain special conditions to keep such important stock as aircraft spare parts, the proposed inventory model can be judged as expensive solution. This order up-to model was chosen on purpose, because AOG parts are critical ones and it is worthy to secure high level of service. It is up to the Company managers what service level is considered to be their aim. During the work under present project it has become apparent also that many factors are involved in AOG solutions. One of them is a supplier of the spare parts. Distance, availability, contract terms, etc. affect the lead time. Therefore, the last one is not certain for every AOG case. Therefore, there is a need to classify AOG parts based on the lead time, the availability of the parts from the supplier, the cost of the parts etc. In such complicated conditions holding cost seems to be minor importance factor in AOG inventory management. Because of the nature of the problem the failure of even the cheapest spare part can stop the dispatch of the aircraft and, consequently, bring the loss for the company.

6. CONCLUSION:

6.1. Forecasting:

Several sources mentioned in literature review claim that Syntetos-Boylan approximation fits perfectly into intermittent demand cases. Indeed, it showed better performance on a monthly basis compared to other methods. However, what it suggests is not to keep any extra stock. Even though this theory displays smallest error compared to other methods, it lacks practical implementation in Company's case. AOG is a critical issue leading to huge direct financial and indirect losses. Therefore it is suggested for the Company to go with an expensive solution: to plan and keep stock in advance on an annual basis.This is the general guideline/strategy suggested. Another deliverable to the Company would be tested methods on Excel spreadsheets that they can utilize for future forecasting calculations.

6.2 Inventory:

The order up to model is suitable for items with uncertain demand and many reorder requests. Order up-to level contributes towards delivering the right amount of inventory and thus showing good performance rate. High level of order up-to number results in a higher number of items in stock. The most important factors that identify the level of inventory to be found in stock are the lead time of the items within a period of renewal/replenishment, the in-stock probability target number and uncertain nature of demand.

Looking deeper in the results obtained allows to give following recommendations for the Company:

- A high level of service and consequently minimizing (predicting) AOG cases can be achieved through a higher level of in-stock probability. It depends on the Company decision what level of in-stock probability to choose for their inventory provisioning.
- It would be beneficial to classify all AOG spare parts depending on the practice of their availability, lead time, supplier, etc. In such case the Company can allow to keep more stock of some less available (difficult to emergently find) or "rare" items. For that set of AOG spare parts, the Company initially can place an order of enough parts to be covered and then fine tune the ordered quantity with other models incorporating more factors for consideration.

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