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Aircraft Preventive Maintenance Data Evaluation Applied in Integrated Product Development Process

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ABSTRACT: Initial Maintenance Review Board Report (MRBR) uses in service operation experience as a reference to define maintenance tasks intervals. However, in general, there is no structured data to compare systems performance and provide useful information to the analysts' decision-making. Even when engineering judgment is based on certification process, structural design, components intrinsic reliability and so on, the analysts responsible for maintenance tasks definitions tend to choose rather conservative proposals. This article presents a method to optimize preventive maintenance tasks intervals and use structured data based on interval optimization process to define maintenance intervals to those of similar systems under development. The method has been applied in an aircraft manufacturing company using current operation database after regulatory authorities' approval. As a result, it has been feasible to propose to the selected system, a maintenance task interval 100% higher than the one applicable to a similar system under operation.

KEYWORDS: Aircraft, Maintenance, Integrated Product Development Process.

INTRODUCTION

In the current economic scenario, to offer products with integrated services in a higher quality became a differential competitiveness factor among the companies. Organizations aiming higher competitiveness are doing great efforts in order to improve their processes through the adoption of innovative project management practices (Neves *et al.* 2013). In the aviation sector, preventive maintenance is placed as a regulation to assure physical integrity to citizen in flight or on ground and it is an extended part of the product, which can be defined as a combination between product itself (material) and related services (Seifert *et al.* 2011).

In the aeronautical industrial sector, to establish adequate maintenance tasks intervals represents Direct Maintenance Cost (DMC) reduction and, as a consequence, higher customer satisfaction after fleet entry into service. From 2009 to date, some guidelines to define preventive maintenance tasks intervals were developed and approved by worldwide aviation regulatory authorities: Issue Paper 44 (IP44) allows different manufacturers to define maintenance tasks intervals in accordance to the authorities' viewpoint.

This study presents a method to evaluate preventive maintenance tasks intervals previously defined in aircraft development phase, organize database available to customer support, evaluate data and propose reviewed maintenance tasks intervals similar to those of aircraft systems under development. The purpose of the method is to reach tangible results (DMC reduction) in the short term and intangible results (customer satisfaction, market recognition) in the middle term.

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This article has six sections, including this introduction, as follows:

"Related Work" presents main concepts necessary to understand the proposed method. It presents Direct Maintenance Cost (DMC) overview, which is the way it is possible to measure results (tangible results). Even considering this paper will not include this approach, as it is highly complex itself, it is important to understand how important this contribution is to aircraft DMC. Maintenance Steering Group 3 – MSG-3, Maintenance Review Board Report and IP44 Guidelines addresses the concepts from the process evaluated in this paper. Maintenance Database Statistical Evaluation presents an overview on statistic theory important to this evaluation.

"Method Description" provides information on how each step from proposed method needs to be applied. First step of this method complies preventive tasks interval optimization process; it considers system from aircraft in operation evaluation: how maintenance data needs to be collected, sample quantity necessary to accomplish analysis, if sample collected is in accordance to regulatory authorities view, and statistical application to evaluate if initial proposed interval is effective, according to maintenance type and system evaluated. Second step of this method is applied to aircraft under development, since it is related to similar system; thus, this step complies how to classify similar systems, and how to implement to interval definition currently used among manufacturers the statistical analysis performed in step 1.

"Application Method" describes the proposed method in a practical application, by selecting a system currently operated by a fleet in field and similar system to be installed in aircraft under development. First and second step were applied according to guidelines provided in "Method Description".

The fifth section presents comments and discussion from method application.

Finally, some conclusions and comments on the method are presented in the "Conclusion" section.

RELATED WORK

The proposed method can be positioned amongst those who deal with multi-criteria decision-maker (De Almeida *et al.* 2015). While it is possible to follow a specific literature approach to structure it, it has been adopted a practical view to do so, based upon the daily operational experience of the maintenance personnel.

DIRECT MAINTENANCE COSTS (DMC)

Aircraft maintenance costs can be classified as Indirect Maintenance Costs (IMC), which comprises infrastructure costs, training, tools, human resources etc., and Direct Maintenance Costs (DMC), which includes fuel costs, engine and aircraft maintenance and tools. It is possible to consider there is only intervention from operator or aircraft manufacturer in costs related to engine and aircraft maintenance. For this reason, in order to reach higher customer satisfaction after fleet Entry Into Service (EIS), it is crucial to establish adequate maintenance tasks intervals and provide DMC reduction. Adequate maintenance interval means reduction of the unscheduled maintenance interventions quantity.

MAINTENANCE STEERING GROUP 3 (MSG-3)

American airlines companies, to increase and ensure aviation industry safety and to create regulation in commercial aviation in the United States, created the Air Transport Association (ATA) in 1936. From 1968 and on, ATA get together aeronautic industry professionals to develop services and processes analysis methodology. This methodology was renamed from the 80's Maintenance Steering Group 3 (MSG-3) and today is widely accepted by regulatory authorities and used in global aviation to Maintenance Review Board Report (MRBR) development (ATA MSG-3, 2015).

The MSG-3 is an analytical methodology based on Reliability-Centered Maintenance (RCM) (Maintenance Review Board… c2010). It contains a method to evaluate aircraft systems, structure, aircraft zones (areas) to detect obvious damages and lightning/HIRF protections. This paper is focused only in system analysis, which uses a progressive logic diagram based on functional failures and failure causes (ATA MSG-3, 2015).

System evaluation first step consists in Maintenance Significant Item (MSI) selection, the highest manageable level. After selecting MSIs, the MSG-3 analysis consists in identifying functions, functional failures, failures effects and failure causes. It is organized in two levels:

- Level 1 evaluates each functional failure in order to classify the failure effect category (Cat):
  - Cat 5 – non-hidden failure affecting operating safety;
  - Cat 6 – non-hidden failure causing operational effects;
  - Cat 7 – non-hidden failure with economic effects;
  - Cat 8 – hidden failure that impacts safety;
  - Cat 9 – hidden failure and non-safety effects.
- Level 2 evaluates each failure cause in order to create preventive tasks (ATA MSG-3, 2015). It is required by MSG-3 method to create tasks only to failure effect categories 5 and 8. Other failure effect categories require cost evaluation, including the cost to accomplish proposed task (cost to accomplish task must be lower than failure cost). For example, if an APU is lost as an effect of specific failure cause, and this effect is category 6, 7 or 9, it would be recommended a preventive maintenance task to avoid this failure and effect. Tasks to be selected are Lubrication or Servicing/Refueling (replenishment of consumables); Operational Task (verifies if system works or not); Functional Task or Visual Task (detect degradation by comparing any parameter); Restoration Task (to reduce failure rate) or Discard Task (to avoid failures or to reduce the failure rate). For category 5 or 8, it is possible to select more than one task type.

MAINTENANCE REVIEW BOARD REPORT AND IP44 GUIDELINES

Maintenance program development began in the aeronautical newsletter 7E from May 15th, 1930 (U.S. Department of Transportation… c1997), which states all aircraft, including engines and equipment, must be maintained at the highest level of operating efficiency. For this purpose certain schedule aircraft inspection and repair should be established by U.S. government (Department of Commerce) considering safety operation. After some time, it was established a board to evaluate all aircraft and create the aircraft Maintenance Planning Document.

Maintenance Planning is a document that presents schedule minimum initial requirements to new aircraft's operator and regulatory authority before EIS. Maintenance tasks created according to MRB process presents intervals with their maximum allowable intervals. This leads to a wide variety of intervals not standardized in checks or blocks of tasks. During Aircraft Development Process, it is defined an expected time to accomplish preventive tasks (many tasks together, or a block of tasks). This defined interval can be called as the maintenance opportunity, according to the program definition.

Maintenance Planning is called as Maintenance Review Board Report (MRBR), developed under MRB process using Maintenance Steering Group – Revision 3, MSG-3, methodology. Each method (system, structure, zonal and lightning/HIRF protection) is reviewed and updated by Maintenance Programs Industry Group (MPIG). Proposals from MPIG are approved by International MRB Policy Board – IMRBPB (Maintenance Review Board … c2010).

IMRBPB is a system of continuous development of policies, procedures and guidelines for operation in aviation, which follow the standards established in MRB process. All subjects to be submitted to IMRBPB by industry representatives or regulatory authorities must be in a document called Issue Paper (International Maintenance Review … c2016).

From 2009 and on, some guidelines to preventive tasks interval effectiveness validation were developed and approved by worldwide aviation regulatory authorities; it is provided through the Issue Paper 44 (IP44) and allows different manufacturers create tasks intervals optimization process in accordance with authorities' prospect. It requires service operation data related to each MSG-3 task evaluated. Database must be standardized according to the e-business specification set and statistic models using are mandatory to data evaluation.

Developing or optimizing a maintenance task interval through data management is a way to ensure continued applicability and effectiveness of a task and at the same time ensure the integrity of the MRB process (International Maintenance Review … c2016).

MAINTENANCE DATABASE STATISTICAL EVALUATION

After accomplish preventive maintenance task, it is possible to collect more than 200 types of data, standardized according to the e-business specification set.

Subsystems reliability can be known as per different methods: life testing, accelerated life testing, field data from different products using same components etc. However, calculating system or subsystem reliability using components test is impracticable due to economic, equipment availability and/or time issues. Therefore, component or subsystems reliability are quantified using mathematical models, able to present failure probability (or success probability) in different moments. It is possible to mention the following statistic models as examples, among others: Weibull, log-normal, normal, exponential, binomial etc. (System Reliability Engineering 2008).

Central limit theorem states that it is possible to use normal distribution for a large amount of population, no matter which distribution should be selected. To this paper, the best distribution to evaluate tasks accomplishment findings would be binomial distribution. Binomial distribution consists in identical events evaluation, one does not depend on another; event result must be classified only in "success" or "failure", and the probability of success is the same for each event (Vieira 2016). However, according to central limit theorem, it is possible to select normal distribution and provide accurate results.

After field data collection, it is necessary to evaluate the database by reading the actions required for each event classified as a failure in order to verify if there are classification errors.

METHOD DESCRIPTION
PREVENTIVE TASKS INTERVAL OPTIMIZATION PROCESS

The optimization process of scheduled maintenance tasks intervals presented in an aircraft maintenance manual, based on the analysis of operating aircraft field data, consists in the following activities:

a. Scheduled and non-scheduled maintenance data collection. The minimum necessary information to be collected in order to accomplish the method is: aircraft serial number, flight hours, flight cycles, delivery date, MRBR task number and task accomplishment result (if it was well succeeded or not). For each type of task, a specific analysis of the collected data must be performed, as follows:
   - Lubrication and servicing tasks: at the moment of the inspection, it is necessary to evaluate the lubricant condition and consumption, the component wear and tear or the corrosion harshness, based on the analyzed failure cause. It is also necessary to consider typical operational environment and specific climate conditions when analyzing deterioration characteristics; it must also be evaluated if there is more than one type of lubricant in the market – in these cases, the analysis is viable only if it is possible to distinguish events associated to different kinds of lubricant in the field.
   - Functional, operational or visual tasks: it is necessary to verify the success rate (task executed with no issues found) and to calculate the system reliability using statistics model that estimates system failure probability in a determined time interval.
   - Restoration or discard tasks: it is necessary to create specific program that includes manufacturer, suppliers, operators and aircraft repair shops in order to evaluate the system condition or the discarded component. It is also necessary to create a program to evaluate the component or system condition, analyzing the task interval threshold before the system starts to deteriorate.
b. Verification of the minimum requests attendance by the sample minimum amount; evaluation if it is necessary to collect data of a common system in different fleets. In order to calculate the minimum amount of data, it is possible to consider the calculation of the sample size for finite population (Miot 2011), since the total amount of executed tasks is known, as per Eq. 1:

$$n = \frac{N.p.q.z_{\alpha/2}^2}{(N-1).e^2 + p.q.z_{\alpha/2}^2} \tag{1}$$

where: n = minimum sample size expected for finite population; $z^2_{\infty/2}$ = critical value of the desired confidence level (equal to 1.96, equivalent to confidence level of 95%); p = expected proportion of favorable results in the population; $q = (1-p)$ = (expected) proportion of unfavorable results in the population; e = accepted error; N = finite population size. Sample size for finite population equation is applicable to all systems analysts who choose to evaluate, whether or not the system is repairable (it must be considered in level 2 analysis, where the tasks are created). The exception is those tasks accomplished less than 30 times, which means that the population must be greater than 30 to apply Eq. 1.

c. Verification of IP44 requests attendance by the collected data. The analyst may evaluate in a general way if the collected data are coherent and complete. A previous analysis must be performed in order to guarantee that there is no mandatory request related to task intervals imposed by aeronautical authorities in specific regions; the analyst may also guarantee that the data were collected in every world's region, if the interval between tasks execution was modified in the analyzed period etc. If the sample is not sufficient in any world region, it is necessary to evaluate if the system operation is modified according to specific characteristics; for example, does high temperature affect the system? If no interference is observed, the analysis may continue.

d. Validation of the findings classification performed by the operator. To guarantee that there is no incorrect classifications.

e. Statistical study application in order to evaluate the collected data reliability. In this phase, it is necessary to calculate the reliability of the system in a detailed way. In order to do so, a statistic model is used to provide the system failure rate in function of time, *i.e.*, to estimate the system failure probability in a determined time interval. Analyzing a probability distribution function, not all data may be treated in the same way. Considering only the essential fields, in order to establish if each task accomplish success or not, it is necessary to classify each maintenance intervention as Failure (F) or Suspension (S). It is considered a failure if the maintenance event is unsuccessful; it is called suspension every maintenance task successfully accomplished (it is not called "success" because it is not possible to know if system was about to failure or not).

f. MSG-3 Analysis Reevaluation using as reference the performed statistical study.

g. Evaluation of new (task) interval proposition possibility. After reviewing the MSG-3 analysis and all the failure causes and the system functional failures, it is possible to conclude if the proposition of changing the task interval is viable. If there is any objection to this task interval change (sometimes, for example, it will be necessary to propose a different type of task in order to guarantee the increase of the reliability of the system), the exercise of optimizing the task interval must be finished.

h. Preparation of the follow-up item document (a basic document that describes the MSG-3 analysis modifications) with the proposition of changing task intervals, when possible. Similarity analysis must be accomplished to every system to be selected. The following parameters needs to be compared in the selected system:

- System operation type: evaluates if the altitude of the aircraft operation or any other parameter (maximum takeoff weight, maximum passengers quantity allowable in aircraft, engine power, avionics technology etc.) impacts in the system operation.

- Maturity of the system in operation: evaluates if selected system is mature; if it is possible to expect same behavior of the system in operation compared to the system under development. Evaluates if there is any relevant difference in the system when in operation and/or under development.

- Availability/field data minimum amount: the field data availability is associated to the system maintenance interval during the aircraft operation. This is because if the task is part of a maintenance package (maintenance opportunity interval selected during development process), it might guarantees higher chances of collecting maintenance data.

- Ease of data acquisition: verifies if the aircraft manufacturer needs to monitor the components life cycle. Evaluates if it is possible to perform a specific analysis described in item "a" of this subsection.

PROCEDURE TO DEFINE NEW MAINTENANCE TASKS TO SIMILAR SYSTEMS

To define the analyzed task interval to be adopted in a similar system under development, it is necessary to perform an evaluation of the project characteristics related to:

- Function: evaluate if the new system under development presents changes in its function (new functions when compared to the system in operation).
- Specification and performance: evaluate if there is relevant changes in the number of components in the subsystem under development.
- Part Number (PN): evaluate if PNs were modified.
- Components' material: verifies if there is material differences, coating, thermal treatment or manufacturing processes among components.
- Mechanical components' geometry: verifies if there is relevant modification in the mechanical components' geometry.
- Product assembly: evaluate if the system assembly presents relevant modifications.
- Other aspects if considered relevant by the analyst.

The procedure to define the new maintenance task interval is based on the system or component data and can be represented by Fig. 1.
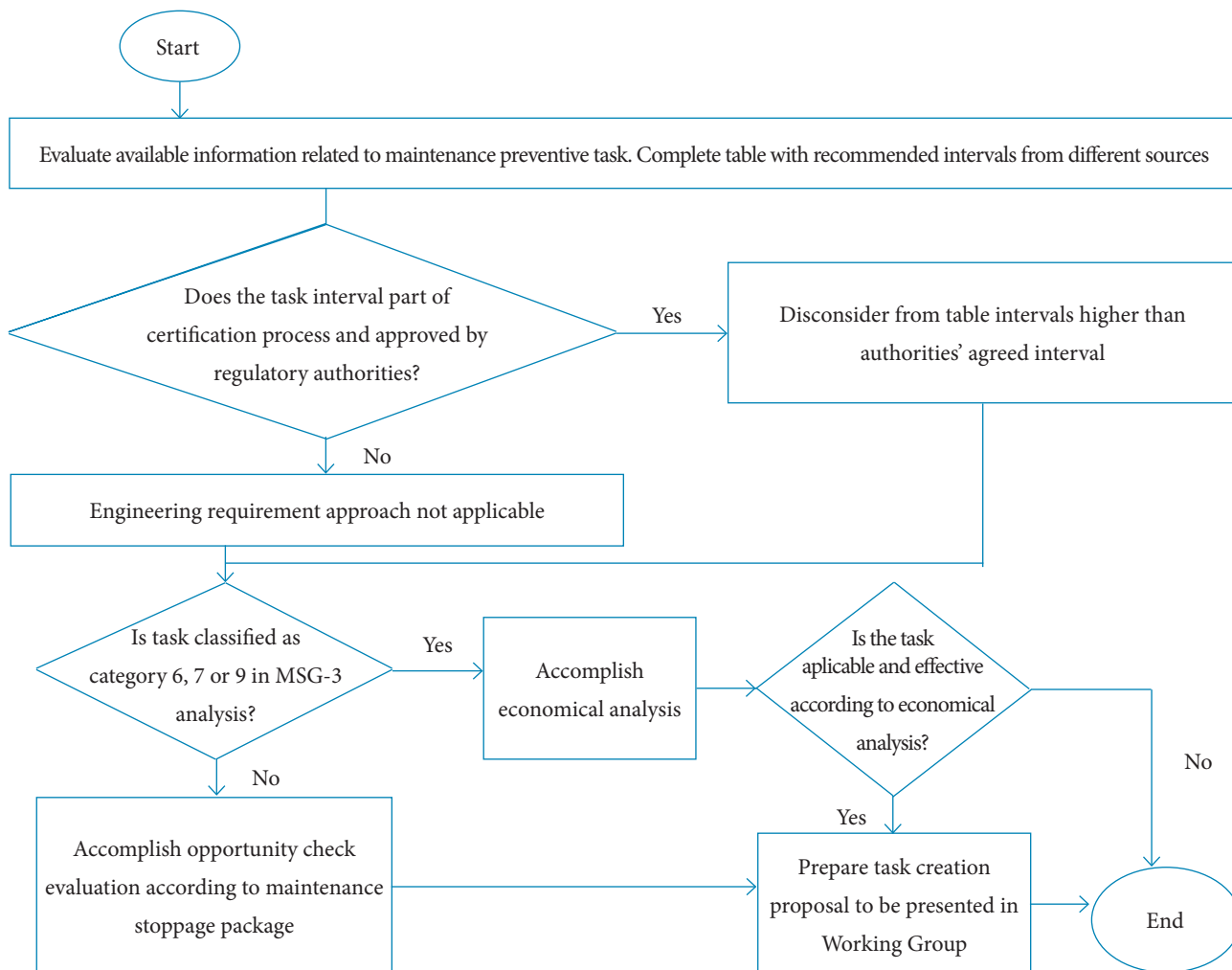

Figure 1. Procedure to define the new maintenance task interval.

Each step presented in Fig. 1 is detailed below:

- Evaluate the available information related to maintenance preventive task. Complete the table with recommended intervals from different sources – it is the industry practice, as per ATA recommendation, to consider and include in analysis different recommended interval before task proposal creation. According to ATA MSG-3 volume I, it is necessary to consider all relevant data available in order to define initial interval to any aircraft system.

- Does the task interval part of certification process and approved by regulatory authorities? – Certification Maintenance Requirements (CMRs) is a scheduled preventive task defined during design certification of systems airplane. It is a limitation of type certificate and cannot be changed unless a Certification Maintenance Coordination Committee (CMCC) and its pertinent process is followed.

- Do not consider in the table intervals higher than authorities' agreed interval – if the evaluated task is a CMR, the interval defined to CMR is the highest acceptable value.

- Engineering requirement approach not applicable – it is necessary to confirm that maintenance task interval is not part of a Fault Tree Analysis developed by system engineering during aircraft development process.

- Is the task classified as category 6, 7 or 9 in MSG-3 analysis? – Evaluate if the task covers failure effect related to operation safety (cat 6 – operational impact, cat 7 – economic impact, cat 9 – hidden failure, non-safety and cost impact).
  - » Yes – accomplish economic analysis – if the task does not cover a failure which affects operational safety, a maintenance task is required only if the cost analysis proves that the cost of failure is less expensive than task accomplishment in the field.
  - » No – accomplish opportunity check evaluation according to multiple intervals maintenance – according to the ATA MSG-3, it is mandatory to create a preventive maintenance task to all the functions in the system, which failures affect the operational safety. For this reason, it is important at this point to define the best interval according to the maintenance opportunity check.

- Is the task applicable and effective according to economic analysis? – Details on how to perform economic analysis will be provided on next pages.
  - » Yes – prepare the task creation proposal to be presented in the working group – after the interval and task defined, it is necessary to prepare an official document to present proposal to the regulatory authorities.

Each data used is generated through different information sources, that must be evaluated in accordance with the confidence pattern associated to them. This classification is used in order to guarantee that real data, associated with identical components and based on operation data collection, will be more representative than assumptions adopted due to lack of field reference or lack of similar components comparison. The information which present lower confidence pattern is shown in group 1, for low confidence/reliance; data with intermediate confidence/reliance classification are shown in group 2, intermediate confidence/reliance; information with high confidence/reliance is shown in group 3, high confidence/reliance. The values must be collected and classified according to the information availability, *i.e.*, it will not be mandatory to use all the values described in the table. The result of this first phase of the procedure for defining new (task) intervals is the collection of recommendations for intervals from different sources.

The information associated to group 3 is related to the task interval optimization procedure and available data during the execution of this process, except for those associated to recommendations by the Systems Development Engineering. The information of group 1 and 2 are commonly used in industry. If there is a task interval used to certify the system with regulatory authorities, all the superior values must be excluded from the table. After completing the available data, it will be necessary to verify the task category. The task selection for categories 5 and 8 is mandatory according to MSG-3 rules. In this way, it will be necessary to verify multiple task intervals values (maintenance opportunity), defined by the program for scheduled maintenance downtime during the aircraft operation. Finally, attention must be paid when selecting an interval in order to the maintenance task to be inserted in the package that best fits the program intervals, considering the group 3 task intervals with higher priority when compared to groups 1 and 2.

Category 6, 7 and 9 tasks exist only to reduce the fleet operators' maintenance costs, which means that executing the scheduled maintenance task may cost less than the unscheduled failure. In this way, an economic analysis must be performed with the following observations:

- Evaluation of which aircraft accesses may be removed in order to make the task accomplishment viable.
- Possibility that task execution take place at the operator's hangar or a MRO – Maintenance, Repair and Overhaul service center.
- Cost of the part, if it needs to be removed.
- Execution of an analysis of the maintenance procedure in order to determine the estimate amount of necessary hours to accomplish the task. It is important to consider if it is necessary to remove the fuel tank, the aircraft interior assembly, the APU and engine, etc.
- Verification of the existence of a system backup for the function.
- Verification of the maintenance opportunity, according to task interval multiple packages of the new program.

The recommended intervals can be presented in hours (Flight Hours, FH), in cycles (Flight Cycles, FC) or Months (MO).

APPLICATION AND RESULTS OF THE PROPOSED METHOD

To apply the proposed method, the fire protection system of an aircraft model was selected. Fire protection system is mandatory in all commercial aircraft. The following parameters of the referred system were compared:

- System operation type: the altitude of the aircraft operation affects in the system operation, due to the extinguisher agent pressurization inside the bottle. However, the selected aircraft (under development) operates in an equivalent altitude (from aircraft in operation); there is no alteration in the type of operation for the compared systems.
- Maturity of the system in operation: the fire protection system is mature; the system behavior in operation and under development is regular. There is no relevant difference in the system when in operation and under development. The development of the system was performed based on characteristics of the system in operation.
- Availability/field data minimum amount: for the purpose of this paper, the task of the selected system is part of a maintenance package, with the interval established at 6,000 hours. The most operated aircraft in the fleet (fleet leader) has more than 40,000 flight hours and there are more than one thousand of this aircraft in operation. For these reasons, it is possible to considerate that there is a great chance of having availability of the minimum amount of field data in order to perform the analyzed task interval optimization.
- Ease of data acquisition: because it is a common system in all commercial aircraft and because it is a protection system, it is mandatory for the aircraft manufacturer to monitor (the life cycle of all) the components.

The task selected for the application of the method presented in this paper is a functional type, because data analysis is more objective and does not demand complex analysts' evaluation. It was also prioritized an essential system for a commercial aircraft, which was under evaluation in a working group of the responsible technical department when this paper was being developed and with field data available for analysis and implementation of the method.

Task MRBR: 26-21-00-001

Title: Fire Extinguisher System Functional Test.

After replacing the values to define minimum sample to be collected, considering. $p = 90\%$; $q = 10\%$; $e = 4\%$ (for category 8 task); $N = 1276$ (total number of executions expected for this task considering fleet – in operation – operational data until the analysis date); $z = 1.96$.

The value of the minimum sample collect, acording to Eq. 1, equal to 185.

Considering operational data, the value of the sample necessity was also divided by regions. The value of the population is distributed in geographic regions and the sample value is distributed in the same way, according to IP44 guideline. On Figs. 2-6, it is possible to verify the total population, which means total times the evaluated task was accomplished in analyzed fleet, minimum sample necessary according to Eq. 1, sample data collected and distributed according to worldwide regions and failures and suspensions classification.
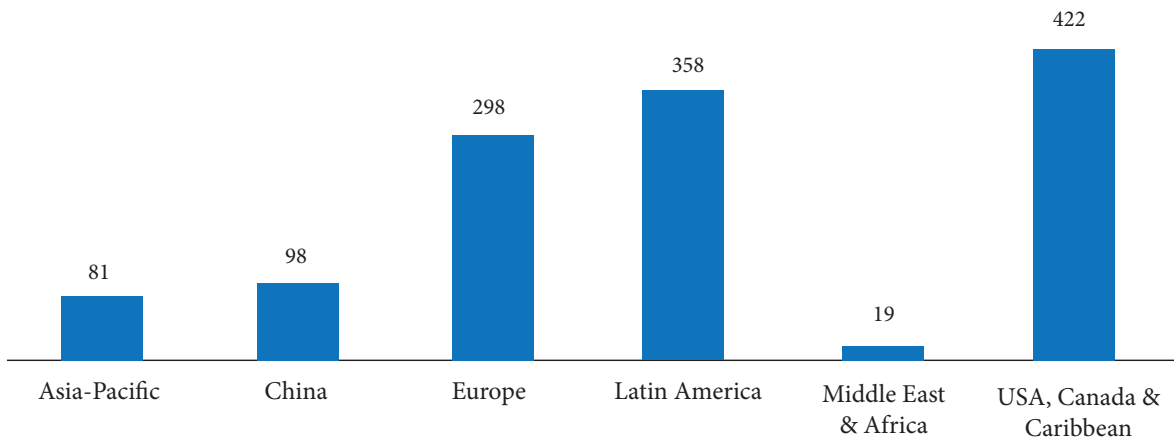
Figure 2. Value of the expected population distribution in geographic regions for the selected task, considering fleet operational data (Total population – total expected events – 1,266).
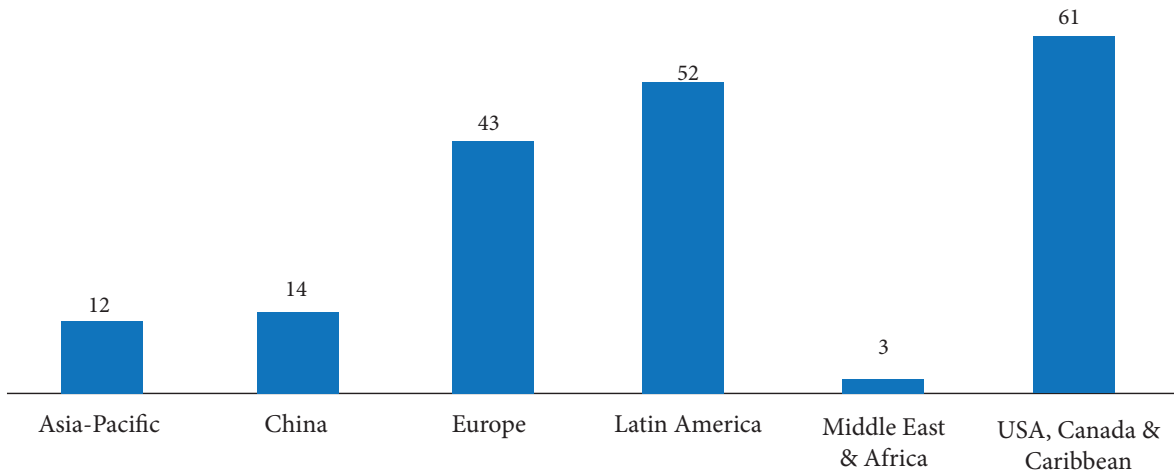

Figure 3. Value of the minimum sample necessary, distributed in geographic regions, for the selected task considering finite sample calculation (Minimum sample amount – Field data minimum amount – 184).
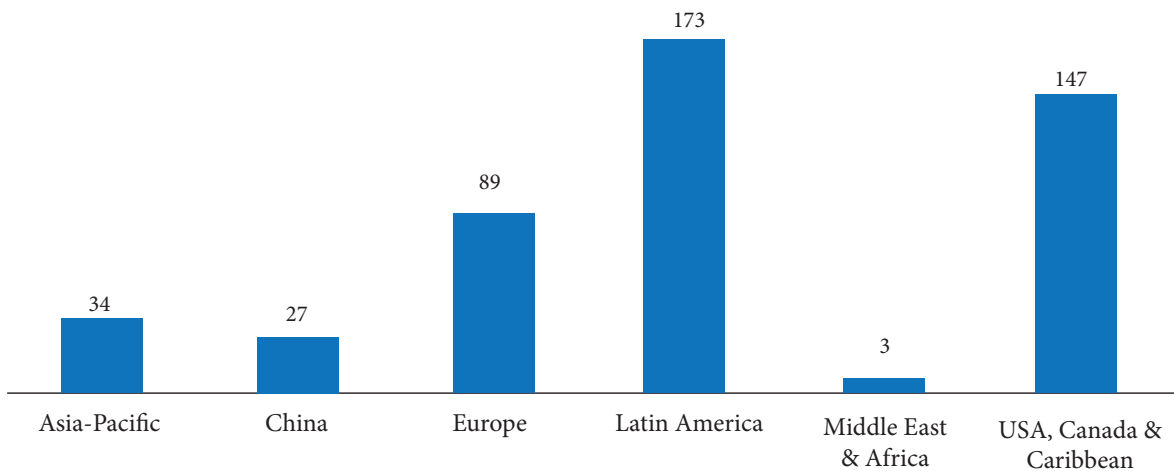

Figure 4. Total sample collected amount, distributed by region, based on databank of events associated to the selected task execution (Total - 473).
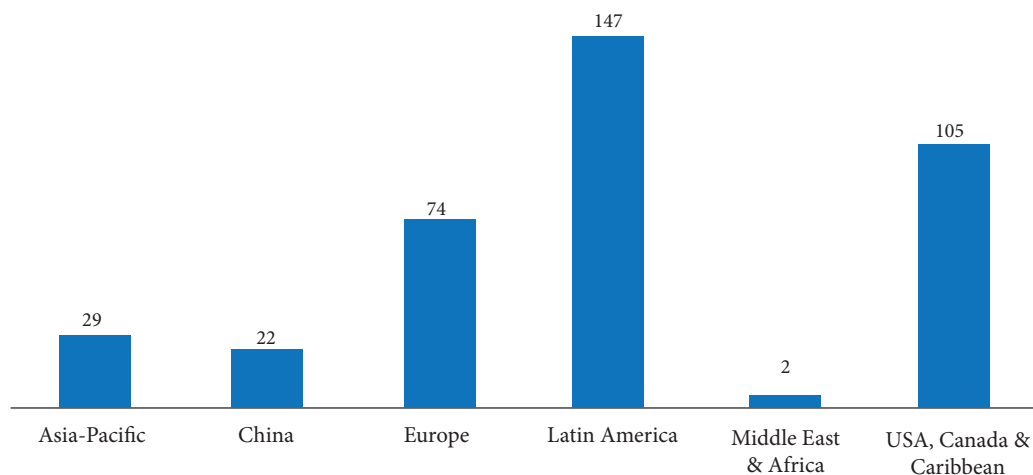
Figure 5. Total amount of suspensions after collected data classification, distributed by region, based on databank of events associated to the selected task execution (Suspensions – 379).
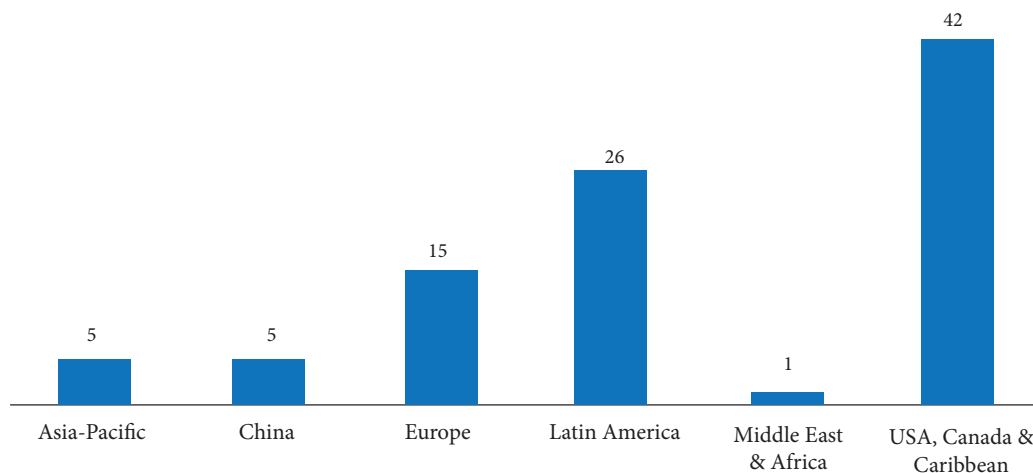

Figure 6. Total failure amount after collected data classification, distributed by region, based on databank of events associated to the selected task execution (Failures – 94).

It was collected a sample of 473 executions of the task (Fig. 4). After data classification, the sample was divided in 379 suspensions (Fig. 5) and 94 failures or findings (Fig. 6).

In order to create the probability function graphic, the Action tool, a MS Excel™ supplement, was used. If it is available to analyze any other more complex statistical tool, it will be possible to evaluate which distribution would be more appropriate based on the collected database and acquire more sophisticated graphics. The Action tool in Microsoft Excel was used because the specific license (beyond Microsoft Office) is not required for its use.

In order to evaluate system without collecting maintenance intervention data from all fleet, it is possible to measure some parameters using normal distribution (as per central limit theorem). Normal probability distribution, in this case, describes when it is expected to have a failure (in aircraft flight hours) and it is presented in Table 1, where average is the value obtained by adding all maintenance accomplishment quantity and dividing the sum by the number of failures (statistical assumptions: normal distribution, consider n ≥ 30; confidence interval = 95%; reliability: 75%).

The mean time to failure (MTTF) value is presented in Index table (Table 2). Standard deviation is the value used to measure the amount of variation or dispersion (how sample collected is spread from its mean), quartiles are the values adopted considering events (population), from the lowest value to the highest and which splits distribution into four equal parts. First quartile is the number

that keeps 25% of events below and 75% above the median. the median keeps 50% of population below mean and 50% of the population above mean. All values must be read by aircraft flight hours.

Table 3 presents the percentage of how failures would be distributed (10% of the fleet would have a failure on this system with 8,534 hours, 90% of the fleet would have this failure on 30,175 hours).

Table 1. Reliability overview.

Parameter	Estimates	Standard Deviation	Inf. Lim.	Sup. Lim.
Averages	19354,65	805,35	17776,19	20933,11
Standard Deviation	8443,05	566,53	7332,68	9553,43

Table 2. Index table.

Index	Value
MTTF	19354,7
Standard Deviation	8443,1
Median	19354,7
1st Quartile	13659,9
3rd Quartile	25049,4

Table 3. Failure destribution.

Percentages (%)	Estimates	Standard Deviation	Inf. Lim.	Sup. Lim.
10	8534,4	636,0	7287,9	9781,0
50	19354,7	805,4	17776,2	20933,1
90	30174,9	1395,3	27440,1	32909,6

The value indicated for the task, according to the assumptions adopted, is approximately 15,000 hours and is presented in Fig. 7. It was selected as a premise of 75% reliability (which means the time that 75% of the fleet would be able to reach, according to the sample data evaluated).

Table 4 must then be fulfilled with the task intervals recommended by each information source. Group 1 herein represented considers MTBF and CMM recommendation from another aircraft. In this case, the information collected considers how long the fire extinguisher system takes to failure in other aircraft and what is the interval the supplier recommends to test this system in other aircraft (any other aircraft analyst has information available). Group 2 information presents how long the fire extinguisher system takes to failure, how long it takes to remove main components in the system (consider lower value among components)
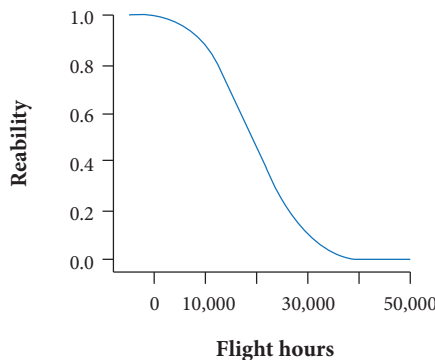

Figure 7. Reliability function – normal distribution of collected sample.

and interval this system's supplier recommends to test. Group 3 in this table presents results from statistical analysis accomplished on this paper presented method.

Table 4. Task intervals recommendations, task 26-21-00-001 analysis.

Information source	Recommended value	Group
Recommended MTBF through theoretical data	6,000 FH	1
Equivalent system's (in operation in different fleets) CMM (not considering the manufacturer)	8,000 FH	1
Recommended MTBF by supplier for similar system	15,000 FH	2
Field MTBUR for similar system	12,000 FH	2
Supplier recommendation for your own system	-	2
MTBF based on supplier tests for components under development	-	3
MTBUR of components of identical system in operation	12,000 FH	3
Task interval of identical/similar system stated in the MRBR or optimized according to the interval optimization procedure	15,000 FH	3
Task interval recommendation made by the development engineering	-	3
Task intervals between tasks executions used in order to certify the system with regulatory authorities	-	3

MBTF: Mean Time Between Failure; CMM; Component Maintenance Manual; MTBUR: Mean Time Between Unscheduled Removal; MBBR: Maintenance Review Board Report.

Figure 8 shows the result of the application of the first part of the interval definition procedure. In order to define the analyzed task interval to be adopted in the fire protection system under development, it was performed the evaluation of the project characteristics related to:
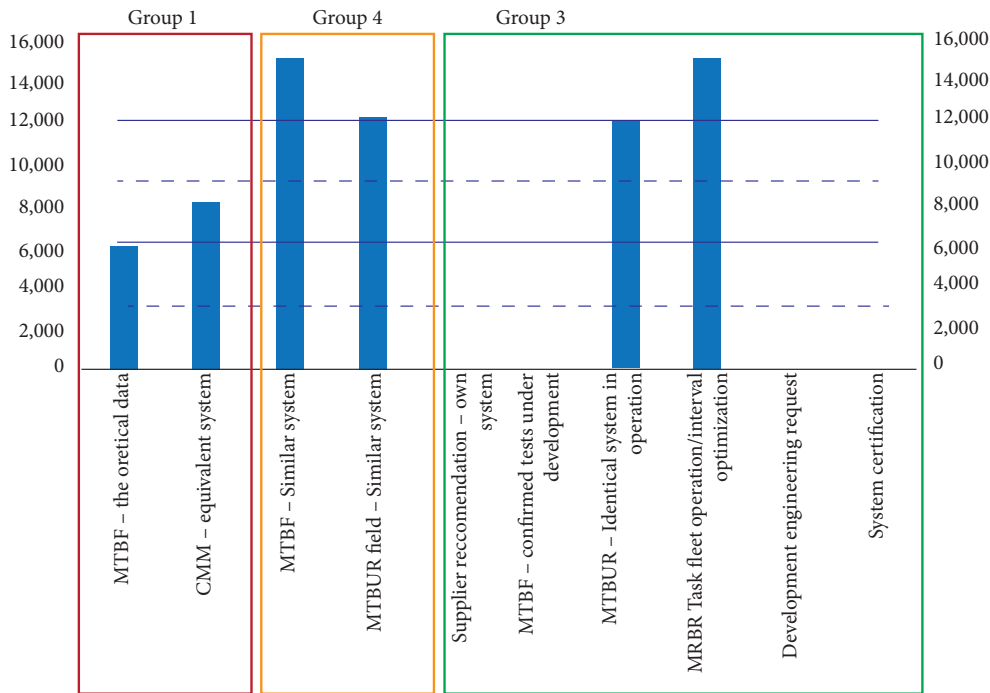

Figure 8. Result achieved by the partial application of the MRBR task interval definition procedure for a new system under development Recommended intervals' values (in flight hours, FH).

- Function: there is no change in the engines' fire extinguisher subsystem function for the product under development.
- Specification and performance: the amount of the components in the subsystem under development is equivalent. However, some part numbers are expected to represent improved reliability.
- Part Number (PN): some PNs numbers were modified, however, with no modifications in the final design. The pressure sensor was improved only to increase the system reliability. The bottle with the extinguisher agent and the cartridge are the same ones used in the operating aircraft.
- Components' material: there is no difference in material, coating, thermal treatment or manufacturing processes of the components.
- Mechanical components' geometry: there was no modification in the mechanical components' geometry.
- Product assembly: some components were relocated. However, the subsystem's characteristics of the aircraft in operation were maintained.
- Other aspects were not mentioned because they were considered irrelevant.

Considering that functional failure and the failure effect are classified as category 8 in the MSG-3 analysis, the task selection is mandatory. In this way, and after perform project characteristics analysis, the task interval selection can be made by maintenance opportunity defined during the development process. For this aircraft under development, maintenance tasks are concentrated in multiple intervals of 3,000 and 6,000 hours (aircraft under development in this paper has the same multiple interval checks of aircraft under operation). As a conclusion, according to this analysis, the recommended interval is 12,000 hours.

DISCUSSION

While performing the proposed method application analysis, it is possible to observe the following:
- Fleet operation under control by customer support is able to generate important information to fill the product development process. Reducing costs, bringing customers closer, improving products reliability and availability is essential in aeronautic industry to aim greater competitiveness. All these items can be considered as part of intangible results because, despite there are some comparison tools among manufacturers (important aviation magazines, for example), it is actually not possible to measure all these referred parameters, except for costs reduction. Using systems' operational data as a benchmark for development can be considered an important tool to reach excellence in products and services offered to customers.
- Maintenance tasks interval optimization is a term used in the aviation industry to refer to an adequate interval. Adequate means: an interval which avoids unscheduled maintenance events (that could lead to flight delays and cancellations) and prevent over maintenance (when maintenance action creates the failure in aircraft). The optimum interval would also be able to allow the DMC value to reach an acceptable value in the aircraft category (limited by aircraft design, engine and fuel cost and many other items related to aircraft characteristics).
- There are available in the market DMC comparison researches (for example, B&CA, Conklin & de Decker) to provide operators (the airlines) average DMC values parameters. Despite manufacturers provide results based on their parameters, how each task contributes to DMC result is considered to be confidential information – the reason why it is not possible to include that result in this paper. In addition, it would be complex to include this calculation in this paper, considering that there are many other premises and concepts involved.
- The great difference between the presented method and the practice currently used among the manufacturers is the information used in decision-making, which is associated to similar systems. With statistical analysis and real operational data, it is possible to observe the behavior of each system and take decisions that are more accurate. It is fundamental to structure this information when product development is very complex and involves different departments' processes.
- The validation of the results will only be possible after the system under development Entry Into Service in a new fleet and monitoring the system during the fleet operation. This is a continuous process and already expected by MSG-3 systems. Therefore, since the assumptions for systems similarity are well established, a satisfactory result is expected.

- The most fragile assumption within the task intervals optimization procedure is one that does not question the integrity and quality of the collected data. This is due to the fact that is not possible to guarantee that all the aircraft operators' representatives and MRO service centers adequately follow each one of their processes. A possible approach to reduce this risk is the execution of periodic visits to the operators and MRO centers in order to know their respective processes and way of working. The more optimization exercise is done, the higher will be the analyst's ability to recognize procedure mistakes and possible in data integrity failures.

CONCLUSIONS

The presented procedure to achieve the objective of optimizing maintenance task intervals and defining more accurate intervals to new aircraft under development is more comprehensive and accurate than the ones currently available in the market. The resultant information of maintenance task interval optimization procedure, once structured in a simple and adequate way, represents several benefits in the integrated product development – such as greater customer satisfaction with the manufacturer and the increase of manufacturer and operators' competitiveness by reducing maintenance costs, for example.

For the method application in the case presented in this paper, the task interval of the aircraft fleet in operation is 6,000 hours, and after applying the proposed interval definition procedure, it was possible to approve, for the fleet under development, the interval of 12,000 hours. This represents an increase of 100% in the task interval, which would not be possible to discover without the method presented herein. The greatest benefit of the application of the presented method is to start the operation of the aircraft fleet with scheduled maintenance with tasks at intervals that decrease the number of unscheduled interventions for the operators. Therefore, the operators' final benefit is lower unexpected maintenance costs. However, there are cases where the method application indicates decreased task intervals, and in such situations, a cost benefit analysis must be performed. Finally, it is possible to conclude that the more accurate the intervals between scheduled runs, the lower the amount of unscheduled events.

AUTHOR'S CONTRIBUTION

Both authors contributed equally in this manuscript.

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