# DEVELOPMENT OF A WEIGHT SYSTEM TO ASSESS RISK OF HUMAN ERRORS DURING MAINTENANCE USING HUMAN HAZARD ANALYSIS METHODOLOGY

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## ABSTRACT

The goal of the Human Hazard Analysis is to evaluate potential errors that can be performed during maintenance activities in terms of design features, procedures and safety barriers in place, to ensure that such errors are properly mitigated or even prevented by design when deemed feasible and convenient. Indeed, although extensive literature focusing on how human factors, such as fatigue or distractions has been produced, not much information is available on how to analyse the contribution of design to errors from a human factors perspective. A rotorcraft standard promoted by HeliOffshore that sets the high level steps and target outcomes of the Human Hazard Analysis methodology has been the starting point for this work. In this paper it is described a process that integrates the elements considered by the analysis, such as Performance Influencing Factors, error frequency, available barriers - that can both reduce the error safety consequence or its likelihood of occurrence - in a weighted framework that ensures robustness and increased objectivity to the approach.

## NOTATION

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Acronyms

**ALARP** As Low As Reasonably Practical

**ERR** Error Risk Rating

**HH** Human Hazard

**HHA** Human Hazard Analysis

**PIF** Performance Influencing Factors

**PSE** Principal Structural Element

## INTRODUCTION

An efficient and safe air travel system depends basically on three elements: design, operation and maintenance.

Aviation maintenance has changed over the years because newer aircraft contain power plants, electronic subsystems, and materials that did not exist in earlier models. In turn, aircraft maintenance personnel are using increasingly sophisticated equipment and procedures.

However, one important aspect of aviation maintenance that has not changed is that most maintenance tasks are still being performed by human inspectors and technicians that exhibit all of the limitations, idiosyncrasies, and capabilities that are part of being human (Ref. 1).

There are many human factors challenges in aviation maintenance. The primary challenges can be identified under five classifications, as shown in Figure 1.

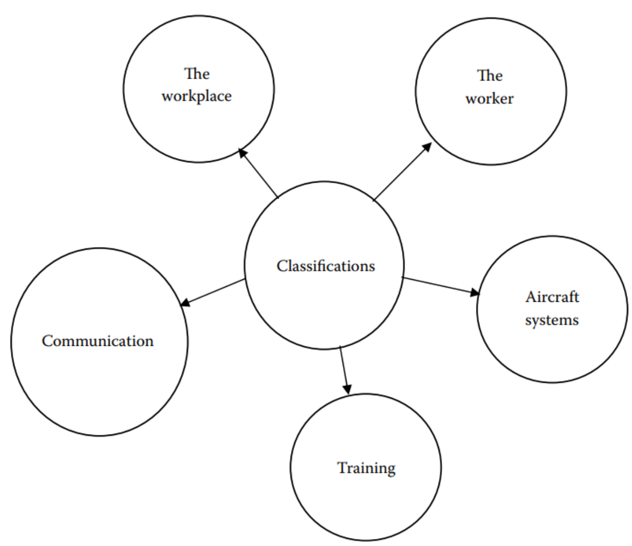


**Figure 1. Five primary challenges of aviation maintenance. Credits: (Ref. 2)**

The classification *the worker* is basically concerned with the availability of adequately qualified aviation maintenance personnel in the future. The classification *the workplace* is concerned with providing an effective workplace to aviation maintenance personnel with respect to factors such as safety, temperature, lighting, work access, and noise. The classification *training* is basically concerned with continuously providing proper training to aviation maintenance personnel with respect to changing aircraft-related technologies. The classification *communication* is concerned with providing timely and accurate maintenance task performance information to aviation maintenance personnel with respect to factors such as "user-friendly" manuals, work cards, and other sources for obtaining inspection and repair-related information. Finally, the classification *aircraft systems* is concerned with, in addition to considering the traditional maintainability-related factors during aircraft systems design, the specific needs of aviation maintenance and inspection manpower at the initial stage of the aircraft systems design.

This work concentrates on the *aircraft system* cluster and it has been based on the way proposed by Helioffshore in ref. (Ref. 3) about how human errors can be considered when performing ground aircraft maintenance activities.

The process consists in a systematic method similar to the well-established Failure Mode and Effect Analysis to assess potential errors while performing maintenance activities. It aims to review the design, procedures and safety barriers in place to mitigate the error execution when it can not be avoided at all.

In an ideal world this analysis should be conducted across all systems in the aircraft but in reality, such a process can already provide useful indication focusing on few areas of greatest potential value. Indeed, Human Hazard Analysis considers safety critical maintenance tasks (e.g. installations, removals, scheduled and unscheduled procedures on most relevant / critical components) for additional analysis. It helps to assess the human factors while performing these maintenance operations and indicate what kind of additional protection from human error would be appropriate, if necessary.

The methodology is applicable to new designs under development, both new aircrafts or new design features or kits, but also to the analysis of in-service fleets.

The basic steps in the process are the same, however for existing aircrafts, a more robust assessment can be done due to the full availability of both design details and in service experience. On the contrary, for new designs, a more speculative approach is needed, but it is more effective in terms of preventive action and product lifecycle cost (Ref. 3).

## METHODS

The method is based on setting an Error Risk Rating (ERR) parameter as the measurement of risk used by the Human Hazard Analysis (HHA). It is a numerical value that classifies the error according to the likelihood of the control measures failure and the consequence of the most credible outcome.

It is computed as combination between (see Figure 2):

1. Likelihood that control measures could fail
2. Consequence of most credible accident scenario

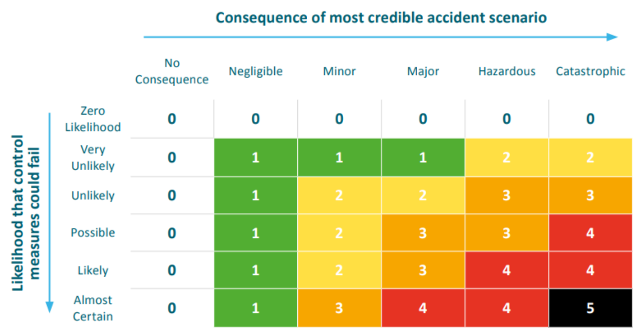


**Figure 2. Error Risk Rating Matrix (Ref. 3)**

A physical interpretation of the Error Risk Rating for each maintenance operation is defined in Table 1.

**Table 1. Error Risk levels definition (Ref. 3)**

| RISK RATING | DEFINITION |
|---|---|
| 1 | No sensitivity to human error (easy to perform, no error risk, or errors cannot progress to significant safety risk) |
| 2 | Limited sensitivity to human error (less easy to perform, limited error risk, error could progress but very unlikely and/or limited safety risk in rare circumstances) |
| 3 | Moderate sensitivity to human error (not easy to perform, moderate error risk, error could progress but moderately unlikely and/or limited safety risk in unusual circumstances) |
| 4 | High sensitivity to human error (challenging to perform, high error risk, error could progress and/or safety risk is material in some circumstances) |
| 5 | Very High sensitivity to human error (interpretation difficult, risk to damage a/c while performing the maintenance, high error risk, error could easily progress and/or safety risk is significant in common circumstances) |

## RESULTS

The work here proposed starts detailing a step by step method followed to perform errors and barrier assessment ("how it should be achieved") and then continues identifying the high-level steps of defining the target outcomes ("what needs to be achieved") through the creation of rating tables.

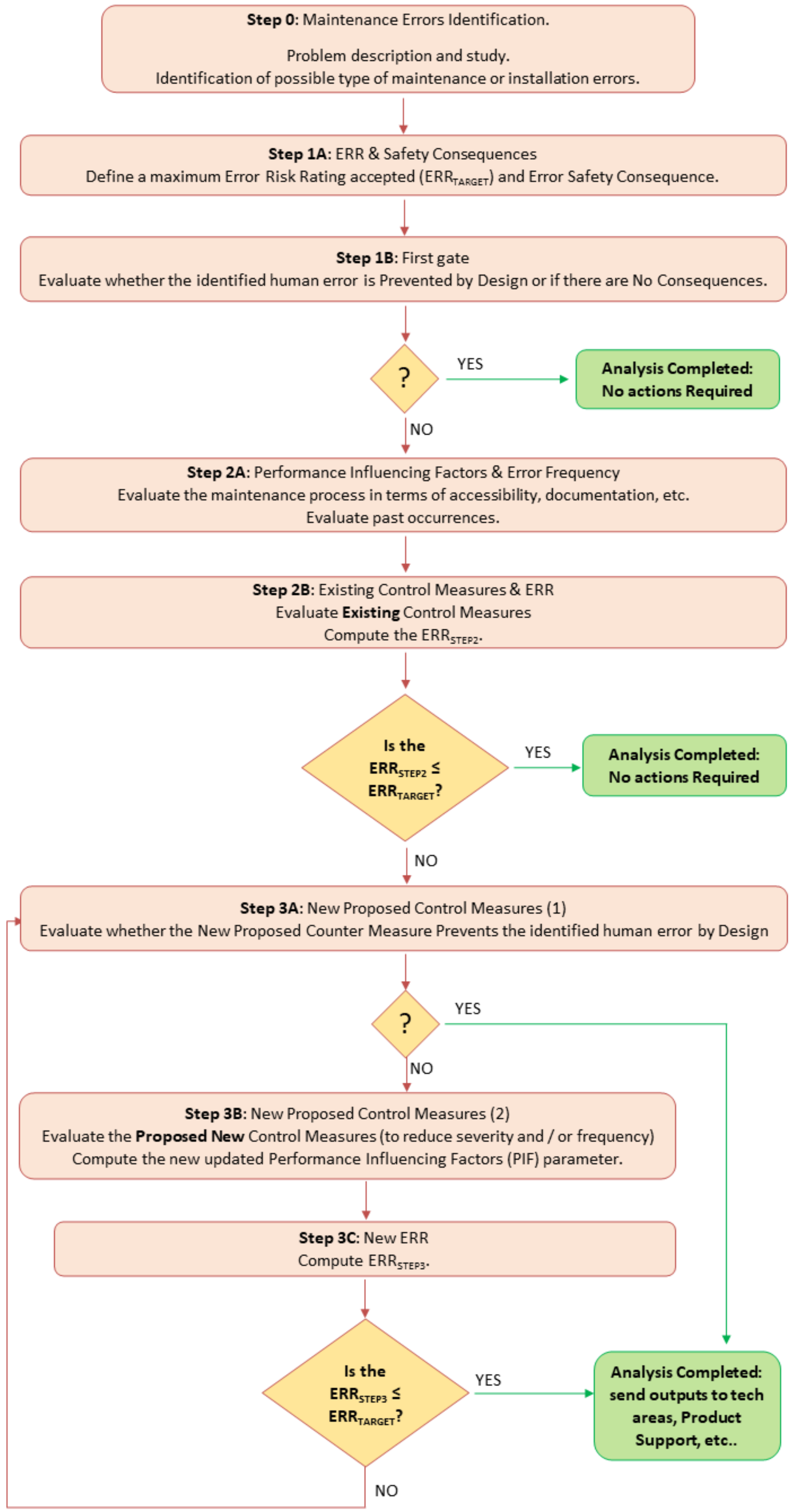


**Figure 3. Human Hazard Analysis Flowchart**

The schematic representation of the HHA process is depicted in Figure 3.

The objective of this work has been the improvement of the Human Hazard Analysis as proposed by HeliOffshore (Ref. 3) to increase its robustness and objectivity. In detail the HeliOffshore method suggests to classify the errors and barriers effectiveness based on a qualitative classification executed as outcome of a working group activity through a group consensus approach.

Differently from that methodology this paper proposes a weighted system to evaluate the aspects that influence the final ERR, as Performance Influencing Factors (PIF), countermeasures and frequency of error. In this way different analysts at different times that have to assess the same design with the same barriers are likely to define a unique Error Risk Rating.

**Step 0: Maintenance Error Identification**

As a starting point, it is required to identify candidate items to be analysed in terms of credible errors during any maintenance operations (e.g. installations, removal, scheduled or unscheduled procedures).

Examples of maintenance error categories are:

- Incorrect component installed
- Component / hardware not installed
- Component upside down / inverted / wrongly installed
- Reuse of defective hardware / parts
- Failure to secure
- Wrong or misread torque applied
- Greasing / lubrication mistakes
- Damage not detected / not properly assessed
- Damage induced during installation

**Step 1: ERR Safety Consequence**

Once credible errors are defined, the safety consequence of the most credible scenario that an error can lead to is assessed in a range from ”No Consequence” to ”Catastrophic”.

Then, once the error consequences are identified it is required to define an acceptability criterion for the HH Analysis outputs. Thus, it is required to define the *Error Risk Rating Target*. The analysis results, in terms of ERR will be acceptable only if the ERR will be minor or equal to the *ERR Target*. From past experience applications and considering the error risk rating scheme reported in Figure 2, the most common *ERR Target* used is 2.

To complete *Step 1*, it is necessary to evaluate whether each identified human error is:

- Prevented by Design
- Produce No Consequences

Both these two cases lead to an ERR = 0 (see Figure 2), thus no further actions are required by the process and the analysis can be considered concluded. Otherwise, the analysis continues with *Step 2*.

**Step 2: First Gate**

Once verified that an error cannot be avoided at all, the safety barriers (also called control measures) in place to mitigate its occurrence are listed and divided into two categories:

- Reduce the severity of the error and / or its consequences
- Reduce likelihood that an error can occur

The first category of barriers acts reducing the “consequence of most credible accident scenario” (the columns of the Error Risk Rating matrix, see Figure 2). If an error occurs, such a strategy ensures that the consequence is less than catastrophic (e.g. fail safe analysis or the damage tolerance of PSE items can be considered within this type of barrier). On the other hand, those mitigations that reduce error frequency or allow timely detection of an error are part of the second countermeasure category (the rows of the Error Risk Rating matrix, see Figure 2) aiming to influence the likelihood that an error can occur.

The major novelty of this work has been the development of a weighted system introduced to support the HHA analysts to perform *Step 2* and *Step 3*. A graphical representation of the developed weighted system, applicable to *Step 2*, is shown in Figure 4.

The first part of the activity has been the creation of the link between the Likelihood of Control Measure Failure (from ”Very Unlikely” to ”Almost Certain”) and the new ”Likelihood Rating” that has been created. The authors decided to fix the range of the Likelihood Rating from 0 to 8, where 0 corresponds to ”Almost Certain” and 8 or more to ”Very Unlikely”.

There are three elements that contributes to the ”Likelihood Rating”:

- Performance Influencing Factors (PIF)
- Frequency of Error
- Control Measures

The 5 Performance Influencing Factors (Accessibility, Perceived Task Frequency, Demand On Resource, Documentation and Special Tooling) are at first analysed singularly, with a mark from 1 to 5, in order to define an overall ”Sum of PIF marks” that is linked to the ”PIF Rating” that goes from 0 (overall negative PIFs evaluations) to 2 (overall positive PIFs), as shown in Table 2.

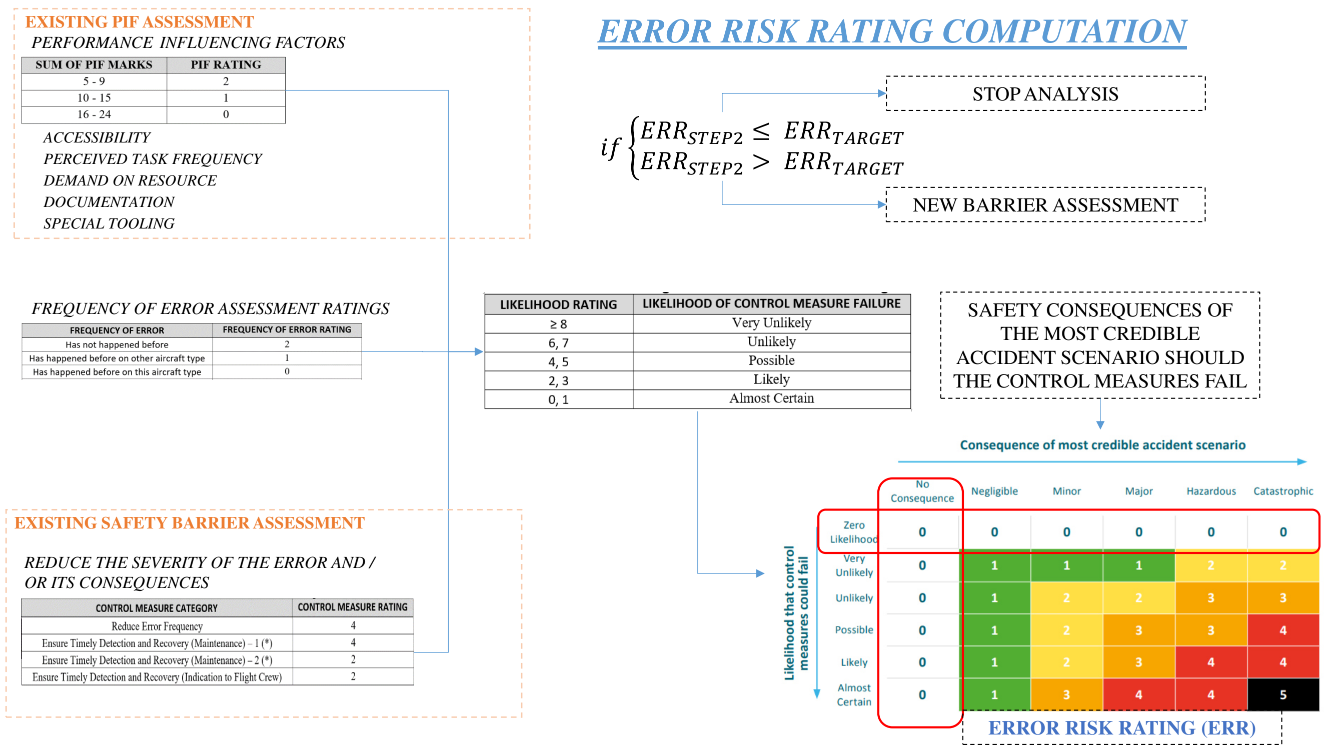


**Figure 4. Step 2 graphical representation**

**Table 2. PIF marks and rating relationship**

| SUM OF PIF MARKS | PIF RATING |
|---|---|
| 5-9 | 2 |
| 10-15 | 1 |
| 16-24 | 0 |

**Table 3. Frequency of error ratings**

| Frequency of Error | Frequency of Error Rating |
|---|---|
| Has not happened before | 2 |
| Has happened before on other aircraft type | 1 |
| Has happened before on this aircraft type | 0 |

Following the same logic, also the Frequency of Error Rating has been discretized in 3 levels: 0, 1 and 2 considering if the error has already happened on this aircraft type, on another aircraft or never happened (See Table 3).

As far as regard control measures, they have been divided in categories depending on their effectivness in reducing the probability of an error occurrence, and thus assigned a rating from 2 to 4. If more than one barrier is present, the analyst should sum the ratings assigned to each of them (see Table 4).

In the end, the sum of the PIF, frequency of error and control measure rating defines the "Likelihood Rating" (see Table 5).

The "Likelihood that control measure could fail" combined

**Table 4. "Reduce likelihood that an error can occur" Control Measures ratings**

| Control Measure Category | Control Measure Rating |
|---|---|
| Reduce Error Frequency | 4 |
| Ensure Timely Detection and Recovery (Maintenance) – 1[a] | 4 |
| Ensure Timely Detection and Recovery (Maintenance) – 2[a] | 2 |
| Ensure Timely Detection and Recovery (Indication to Flight Crew) | 2 |

[a]Within the "Ensure Timely Detection and Recovery (Maintenance)" a large amount of actions can be included (e.g. barriers as daily/routine checks, post installation/inspection verifications or vital point requirements). However, not all of them have the same impact on finding and rectifying the error. For this reason, two different levels for the same category have been created.

with the "Consequence of most credible accident scenario", that takes into consideration the initial safety consequence evaluation (defined in *Step 1*) and any possible barriers that may reduce the severity of the error or its consequences, defines the Error Risk Rating of the existing design (*ERR Step2*). Only if the *ERR Step2* is equal or minor of *ERR Target* (defined in *Step 2*) the analysis can be considered concluded and no further actions are required.

Otherwise, the analysis continues with *Step 3*.

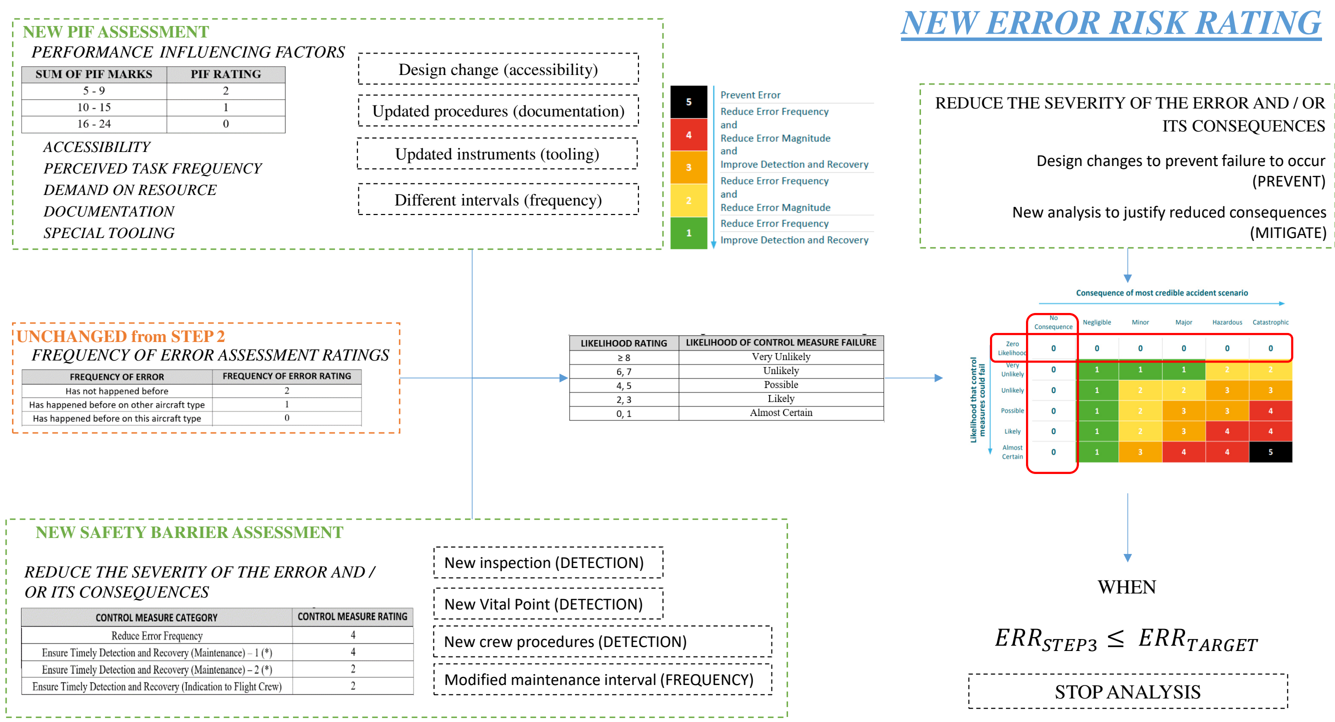


**Figure 5. Step 3 graphical representation**

**Table 5. Likelihood ratings and ERR matrix association logic**

| Likelihood Rating | Likelihood that control measures could fail |
|---|---|
| $\geq 8$ | Very Unlikely |
| 6, 7 | Unlikely |
| 4, 5 | Possible |
| 2, 3 | Likely |
| 0, 1 | Almost Certain |

### Step 3: New Proposed Control Measures

Similarly to what has been developed for *Step 2*, also in *Step 3* a weighted system rating has been prepared following the same logic and a graphical representation is shown in Figure 5.

Indeed, the aim of this section of the analysis is to evaluate which new design barrier (single or multiple) may be implemented to further reduce the ERR to an acceptable level (equal or minor to the *ERR Target*). The choice for the most appropriate new proposed control measure should be driven by the ALARP philosophy, where ALARP stands for “As Low As Reasonably Practical”, in order to achieve the most cost effective solution to reduce risk at an acceptable level.

After the identification of the new control measure it is necessary to reassess the following parameters:

- Whether the error has become Prevented By Design (e.g. for the implementation of a dedicated design change). In this case the analysis can be considered concluded (*Step 3A*)
- Whether the new barriers identified in the cluster of those that can “Reduce the severity of the error and / or its consequences” have been introduced and thus consider the new updated “Consequence of most credible accident scenario” (*Step 3B*)
- Whether the new barriers identified in the cluster of those that can “Reduce likelihood that an error can occur” have been introduced and thus consider the new updated “Likelihood that control measure could fail” parameter (computed as shown in Table 4, *Step 3B*)
- all the 5 PIF marks, considering the new control measure implemented (as shown in Table 2, *Step 3B*)

At this point, information to revaluate the “Likelihood that control measure could fail” considering the new barriers put in place are available while the Frequency of Error Rating remains unchanged.

The updated rating of ”Likelihood of Control Measure Could Fail” (defined as in Table 5) combined with the ”Consequence of most credible accident scenario”, defines the *ERR Step3* of the new proposed design changes.

If the new updated *ERR Step3* is equal or minor of *ERR Target* (defined in *Step 1*) the analysis can be considered concluded and the new proposed control measure can be implemented by the relevant technical discipline or technical publication department.

Otherwise, if the new updated *ERR Step3* is not equal or minor of *ERR Target* (defined in *Step 1*) it means that the new proposed control measure is insufficient to reduce the error risk. Thus, the analysis should further be updated repeating *Step 3* either proposing an additional control measure or changing the one proposed with an alternative control measure of a different category.

## CONCLUSIONS

1. There are many human factors challenges in aviation maintenance as aircraft maintenance personnel are using increasingly sophisticated equipment and procedures. The work confirms that a systematic method, similar to the well established Failure Mode and Effect Analysis, supports in the identification of design features, procedures and safety barriers in place to mitigate human error execution during maintenance.

2. This paper offers a Human Hazard Analysis methodology based on a weighted system that ensures increased robustness in respect to errors and barriers assessment.

3. Using the described approach, different analysts at different times that have to assess the same design with the same barriers are likely to define a less arbitrary Error Risk Rating.

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