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EXTENDED PRODUCER RESPONSABILITY (EPR) IN AVIATION SECTOR: A NEW RISK ANALYSIS APPROACH

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Abstract

The introduction of Extended Producer Responsibility (EPR) into European legislation will have a significant impact on EU industry. Obviously, in order to make the management of an EPR-based process efficient, it is necessary to define strategic approaches that help companies to be compliant with the European Legislation. Therefore, the objective of this study is to understand whether it is possible to propose a risk analysis model that can help company management to develop an efficient ERP process A possible solution to the research question is to propose a new risk analysis approach in which two widely used methods in the field of risk analysis are combined: the Functional Resonance Analysis Method (FRAM) model of Prof. Hollnagel combined with the Analytic Hierarchy Process (AHP) method proposed by Saaty. The new approach has been applied to the aviation sector, which will be affected by Extended Producer Responsibility in the short term, due to the increase in the number of aircraft at the end of their life cycle and to the evolution of regulations in the aeronautical sector.

Key words: aircraft, end of life, extended producer responsibility, recovery, risk analysis

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1. Introduction

The aim of this research is to apply the principles of Extended Producer Responsibility to the end-of-life management of aircraft. The first step of this article is to define - Extended Producer Responsibility (EPR), placing it in today's industrial reality and taking into account the recent regulatory reforms that have affected this institution. The concept of EPR, introduced in 1990, has been defined by Lindhqvist (2002) as *"a strategy to reach an environmental objective of a decreased total environmental impact from a product, by making the manufacturer responsible for the entire life-cycle of the product and especially for the take-back, recycling and final disposal of the* product". In other words, it is a particular strategy through which the producer of a given good has complete responsibility for his product throughout its life cycle, therefore also during the so-called post-consumer stage (Lifset, 1993; Lindhqvist, 2000). These responsibilities will require the manufacturer to perform several tasks. First of all, the manufacturer must provide customers with all the necessary information for the correct management of potential environmental impacts associated with its products. In addition, those who produce the product have to take charge of the physical and logistical management of the product throughout its entire life cycle, in order to ensure its correct disposal/recovery when it becomes, economically or technically, obsolete. Finally, the manufacturer is responsible for any damage caused by the product to the environment during its life cycle. On closer inspection, this is a very broad responsibility, ranging from the regulatory

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aspect to the technical-o-informational aspect up to affecting the company's credibility towards stakeholders (Lindhqvist, 2000). In recent years, EPR has fully entered the Circular Economy System promoted by the European Union, as a strategic approach aimed at promoting the latter, (Bocken et. al., 2016; Compagnoni, 2022; Jensen et al., 2021). From an operational point of view, this vision has translated into - practical application of the EPR concept in various areas of strategic interest. By way of example, a sector that immediately embraced this principle is the electronic and electrical sector (Directive 2002/96/EC), following numerous pressures from stakeholders who had to effectively manage a constantly growing flow of materials (Compagnoni, 2022; Gui et al., 2013; Huisman et al., 2008; Pérez-Belis et al., 2015; Wasserbaur et al., 2022). To be efficient, an EPR system must start from a system that is able to measure its impacts so as to demonstrate its goodness and technical-economic feasibility. In the aeronautical sector, the application of EPR is a very delicate issue, especially with regard to the correct management of aircraft that are at the end of their operational cycle. Aircraft recovery processes are now becoming increasingly important and this interest will increase in the years to come (Scheelhaase et al., 2022). This statement is confirmed by recent studies carried out in relevant literature (ICAO, 2019; Ribeiro and de Oliveira Gomes, 2015; Scholz, 2022), according to which about a thousand commercial aircraft a year will end their life cycle by 2030. However, determining the real obsolescence of an aircraft is very complex as the *"technical life"* of the aircraft itself does not always coincide with the economic obsolescence. In this sense, - ICAO (2019) estimated that compared to the twenty - six-year average duration of an aircraft from a technical point of view, there could be a significant reduction in its life span from an economic point of view as disassembly activities, if properly managed, could be more profitable than keeping certain categories of aircraft in operation.

In other words, the choice to keep an aircraft alive depends on numerous variables, which are also influenced by general macroeconomic trends and the competitive positions of the various stakeholders as they operate in the sector (De Brito et al., 2007; Keivanpour et al., 2013; Wong et al., 2020). wanting to deal with the issue of sustainable management regarding the recovery process of an aircraft at the end of its life cycle, the first aspect that must be evaluated is the extreme complexity that characterizes the process of decommissioning an aircraft. As demonstrated in a recent study by ICAO IN 2019, the recovery process of an aircraft tends to be distinguished into two major phases. The first phase concerns the processes apt to obtaining *"reusable"* parts for other aircraft. The second, on the other hand, concerns the pure dismantling and recycling of parts that cannot be used on other means. The distinction between the two phases is very important as the possibility of reusing parts obtained from other aircraft is strictly regulated by the regulations that guarantee the safety of the sector. (Böckmann and Schmitt, 2012; Elsayed et al., 2019; Fera et al., 2020; Maaß, 2020; Scheelhaase et al., 2022). In principle, these components must maintain *"airworthiness"* status before being reused on other aircraft. For this reason, anything that cannot be considered efficient for safe use will have to undergo the recertification process and obtain the relevant authorizations before returning to service (ICAO, 2019). Taking into account this aspect, the pre-eminent objective of any company that intends to proceed with the recovery of one of its aircraft is to remove most of the valuable components, maintaining, given the technical condition, their status of *"certifiability"* so that they can be immediately placed on the market. Having dealt with the recovery process, these have a different value from a purely economic point of view. As highlighted by Scholz (2022), there are two different business models applicable to the sector under consideration. The first concerns the case in which the components obtained from the activities of disassembly remain the property of the owner of the aircraft. The second case, on the other hand, provides for the components obtained from the recovery process to become the property of the recycler. The proposed solutions have important repercussions in terms of determining the trade-off of the recovery process. In fact, if on the one hand the cost of the recovery activities varies according to purely technical aspects such as the class to which the aircraft belongs to or the number of engines present, the value obtained from the disassembly activities is closely linked to the resale of the most valuable components. Therefore, thanks to their correct recovery, more significant results will be obtainable from an economic point of view, both for the owner companies and for the resellers of the components (Zhao et al., 2020).

Taking into account the above, it is clear that there is a need to put in place procedures and reference standards that are able to comply with the characteristics of the economic and environmental sustainability of the disassembly processes provided for by current legislation. In this sense, on the basis of the study conducted by de Brito et al. (2007) several manufacturers have put in place initiatives aimed at ensuring the efficient management of the End of Life, in the light of current legislation. The two main initiatives, led respectively by Boeing and Airbus, have led to the creation of two consortia, AFRA and PAMELA. Without going into - specific merits, - it should be noted that the objective of AFRA (Carberry, 2008) is not to provide for - direct management of the recycling activities but to create standards that are a reference both for the industries in the sector and for the governments that will have to indicate the legislative action. In order to create an EPR compliant management system and to obtain a method of analysis suitable for the objectives of this work, it is therefore necessary to carry out a wide-ranging analysis, that analyzes not only the reference literature in the aeronautical field, but that also analyzes the

EOL methods used by industry leaders (i.e. Boeing, Airbus) for the correct management of the recovery activities associated with their aircraft. Taking into account the above, the present study aims to answer a specific research question: what are the main phases that characterize the dismantling of an aircraft at the end of its life cycle? Moreover, what are the critical steps to be taken into account in order for recovery procedures to be efficient from a technical and economic point of view? To answer these questions, a hybrid approach of risk analysis was chosen. this approach relates to a process based on the combination of two well-known evaluation methodologies - the Functional Resonance Analysis Method (FRAM) model, used in - risk analysis processes of organizational processes, and the Analytic Hierarchy Process (AHP) model useful to better characterize the subjective choices that emerge during the brainstorming phases which are carried out during the analysis of the abovementioned processes. The aim of this study is to answer a specific question: is it possible to set a new risk analysis framework that helps companies to meet the new EPR-related challenges?

2. Material and methods

The present study aims to identify a series of inputs useful for the preparation and updating of these standards. Given the context, it is therefore possible to say that the management of a sustainable recovery system is characterized by the simultaneous presence of heterogeneous elements (i.e. technical, physical, organizational) interconnected with each other. These, therefore, will have to be treated in such a way as to be able to immediately manage any failures, stemming any effects that may cause inefficient conditions to the system. For this reason, the purpose of this research is to create a resilient management process that can effectively respond to any negative event that may harm the technical-organizational efficiency of the recovery process. By embracing what has emerged in the reference literature on resilience engineering (Arcuri et al., 2022; Dinh et al. 2012; Haimes, 2009; Hulme et al., 2019; Patriarca et al., 2020; Sujan et al., 2022), a risk analysis model based on the joint use of FRAM: the Functional Resonance Analysis Method proposed by Hollnagel (2014) and the so-called Analytic Hierarchy Process (AHP) model of Prof. Thomas Saaty (2008), is proposed.

The Functional Resonance Analysis Method (FRAM) is a risk analysis method mainly used for the analysis of so-called socio-technical systems that aims to analyze how the individual activities of a given business process are carried out. Its objective is to understand the real efficiency of the process under analysis rather than the nature of failures that may affect the process itself. The FRAM is based on five steps. First, one must clearly define the purpose of the analysis to be performed, identifying the different functions that characterize the process. Then, for each function, one must understand what relationship exists between this function and the function immediately downstream. Hollnagel (2012), for each function, has identified six elements Input (I), Output (O), Time (T), Preconditions (P), Resources (R), and Control (C). These elements are represented graphically by means of a hexagon. Each function is connected to another function so as to obtain an interconnected network that allows the analyst to immediately visualize the procedural flow related to a given activity. Although FRAM has undoubted advantages in terms of process visualization and adaptability to different organizations, the model under analysis nevertheless has several limitations.

The most important one is that the FRAM is a qualitative analysis model. For this reason, it is necessary to associate the FRAM with an additional method of analysis in order to make FRAM-related choices less ‘subjective’. For this reason, the Analytic Hierarchy Process (AHP) has been associated with the FRAM. This is a multi-criteria decision-support technique used by organizations to select an alternative from those available and to rank a set of criteria according to an order of desirability based on a rational framework of quantitative comparisons (Saaty, 1980). The AHP model proposed in this study is that proposed by Saaty in its general form, constructing a pairwise comparison matrix using linguistic scales where the experts' opinions were used to rate intensity. Compared to the various methods in the literature, the decision to use the AHP is linked to its ease of use by the research team as well as its adaptability to other analysis criteria such as the FRAM.

The FRAM/AHP model, based on the methods and principles of ISO and NIST, aims to make the advantages that derive from the use of the proposed systems its own, while reducing the limits underlying their use. The Functional Resonance Analysis Method (FRAM) theorized by Hollnagel (2014) is a very useful method for managing contexts characterized by a clear predominance of the human/organizational aspect over the purely technical one (Hollnagel, 2017). This ability allows the organization to respond appropriately to adverse events, making it resilient to such situations (Aguilera et al., 2016; Bergström et al., 2015; Bjørnsen et al., 2020; De Carvalho, 2011; Tian and Wasserbaur, R., Sakao, T., & Milios, L., (2022), Interactions of governmental policies and business models for a circular economy: A systematic literature review. , Journal of Cleaner Production, 337, 130329., 2020). However, the FRAM, if used as a model of independent analysis, has the limitation of being strongly influenced by the individual aspect due to the simultaneous presence of several experts, belonging to different professional areas, who, by participating in its drafting, can, with their many individual choices, negatively influence its construction. This, as evidenced by the reference literature, risks reducing its effectiveness as the barriers supporting risk mitigation would be identified exclusively in the face of personal choices and evaluations (Buikstra, et al., 2020; De Carvalho 2011; Rosa et al., 2015). To overcome this limitation, it is therefore necessary to introduce an additional analytical tool to help process actors identify the risk factors associated with the functions identified in the process so that they can identify a priority scale for resolving intervening issues in those functions. To this end, it was decided to build a hybrid FRAM/AHP model, where the AHP method would be used as a semi-quantitative analysis tool capable of reducing the subjectivity underlying the construction of the FRAM model. The model, built on the basis of the methods contained in the International Standards ISO 31000:2018 and NIST Special Publication 800-300 Rev.1 of September 1, 2012, will lead to the creation of a flowgram in which the process under analysis will be divided into interrelated functions that will be evaluated according to two fundamental parameters: Time and Precision. Time and Precision are the subject of particular attention in Saaty's Analytic Hierarchy Process, a measurement method that takes place through pairwise comparisons based on judgments developed by experts in order to obtain priority scales. These scales, appropriately used, will be used to measure *"subjectivity in a mathematically objective way"* (Saaty, 2008). The comparison of the pairs will take place through a particular scale of values, shown below, which represents the intensity that each judgment has in the comparison between these pairs (Table 1).

Table 1. Comparison matrix between pairs (our elaboration taken from Saaty, 2008)

Intensity	*Explanation*
1	Given two activities, they contribute equally to the objective
3	Given two activities, experience and judgment show a slight preference for one over the other
5	Given two activities, experience and judgment demonstrate a moderate preference for one over the other
7	Given two activities, experience and judgment demonstrate a strong preference for one over the other
9	Given two activities, experience and judgment show that one activity is to be preferred without a shadow of a doubt to the other
2,4,6,8	Intermediate Values

From the values obtained from Table 1 we will construct a matrix based on the values contained in this table and their reciprocals. Therefore, when an element *"i"* (a decision) has one of the values in the table, it is compared with another element, called *"j"* (a decision), then *"j"* has a reciprocal value when this is compared with *"i"*. All these elements will be represented in a square matrix *"M"*, where each value of this matrix represents the result of the comparison between the decision criteria of row *"i"* with column *"j"* (Eq. 1). The element will be equal to 1 (= 1), if *"i"* is equal to *"j"*, this means that the factor is equal with respect to itself. Therefore, the main diagonal of this square matrix, where the elements with *i = j* are always present, will always have numerical values of 1, since there is no priority or dominance relationship between closely equal elements.

$$M=\begin{pmatrix} 1 & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ \frac{1}{a_{1n}} & \cdots & 1 \end{pmatrix} \tag{1}$$

In addition, the $a_{ij}a_{ij}a_{ji}a_{ij}$ will be the inverse of the element, i.e. = -1. This represents the inverse mathematical relationship that proves the so-called "inverse element opposition". The next step in the model proposed by Saaty (2008) is the determination of - comparison weights between the elements of the square matrix *"M"*. These values are obtained by the partial results of the set *"A"* and $v_i(A_j)$ where $v_i(A_j)$ is the impact value of the alternative *"j"* with respect to the alternative *"i"*. These data represent the numerical representation of the opinions expressed by experts with respect to the proposed alternatives. These results are then normalized through the Eq. (2):

$$\sum_{i=1}^{n} v_i(A_j)=1 \; with \; j=1,\dots,n \tag{2}$$

where: n is the number of alternatives or items compared. Each element of this sum consists of (Eq. 3):

$$v_j(A_j)=1 \; with \; j=1,\dots,n \tag{3}$$

This causes the priority vector of the alternative *"i"*, in relation to the importance criterion, to be defined by the Eq. 4:

$$v_k=(A_i)=\sum_{j=1}^{n}\frac{v_j(A_i)}{n} \; with \; i=1,\dots,n \tag{4}$$

that is, having a square matrix *"M"* to determine the importance weights of each factor in the matrix, it is necessary to add up all the factors and add them together in each column. Then you need to make another *"MRW"* matrix where each of its elements will be the relative weight of each of the elements in the left column, with respect to each of the items in the top row. To do this, divide each part of the *"M"* matrix by the sum of the parts in each column. In this *"MRW"* matrix, the simple weighted average of the elements in each row will give you the relative weight *"RW"* of each element. To validate and ensure the validity of these considerations and calculations, the AHP methodology also involves a consistency analysis of all the processed data. Since the matrix *"M"* is a reciprocal matrix, if all the experts' value decisions were good, it would be possible to verify that all expert value decisions were adequate in all comparisons (Eq. 5).

$$a_{ij}\times a_{jk}=a_{ik} \quad \forall\, i,j,k \tag{5}$$

Therefore, according to this model, the *"M"* matrix would be consistent. Let *"n"* be the number of elements the auto vector of *"M"* and *"w"* the priority vector. If the opinions expressed by the team are all coherent, then λ_{max} (Gomes et al., 2004) (Eq. 6):

$$\lambda_{max} = n \,\&\, a_{ij} = \frac{w_i}{w_j} \tag{6}$$

However, starting from the premise it is always possible to find inconsistencies, these can be evaluated by assuming that the closer the value λ_{max} is to *"n"*, the greater the consistency of opinions. Thomas Saaty (2008) showed that given a matrix "M" one must identify a vector - that - satisfies Eq. (7):

$$A_w = \lambda_{max} \times w \tag{7}$$

and that to obtain the auto vector from this equation, it is necessary to calculate Eq. (8):

$$\lambda_{max} = \frac{1}{n} \sum_{i=1}^{n} v_j \frac{[A_w]_i}{w_j} \tag{8}$$

It is important to note that small variations - imply small variations -, where the deviation of the autovector with respect to n (order number of the matrix) is considered a measure of consistency. Therefore, it can be said that it allows us to evaluate the proximity of the scale developed by Thomas Saaty (2008) with the scale of ratios or quotients that would be used or quotients that would be used if the matrix "M" were totally coherent. This can be done by means of a consistency index (CI). According to Thomas Saaty's (2008) Theorem 1, "M" is consistent if, and only if ≥ n.

That is, if the matrix "M" is consistent, then when calculating the magnitude of the perturbation of the matrix *"M"* using the ratio (Eq. 9)

$$CI = \frac{\left(\lambda_{max} - n\right)}{(n-1)} \tag{9}$$

the CI will have a value of less than 0.1 (Saaty et al, 2012). Saaty proposes the calculation of a Consistency Ratio (CR) based on these issues related to the consistency of matrix data. The Consistency Ratio is defined in Eq. (10):

$$CR = \frac{CI}{RI} \tag{10}$$

where CI is the coherence index calculated from the equation presented above. RI is the Random coherence Index. RI is obtained by square matrices of order *"n"* of Oak Ridge National Laboratory - USA. from Oak Ridge National Laboratory - USA, presented in Table 2 (Saaty, Thomas L., et al., 2012).

The larger the CR, the greater the inconsistency. When n = 1 or 2, the CR is zero; when n = 3, the CR must be less than 0.05; and when n = 4, the CR must be less than 0.08. In general, an inconsistency is considered acceptable, for n > 4, when CR is less than or equal to 0.10. If CR is less than 0.10, judgments will need to be revised. AHP provides an index of consistency for an entire hierarchy. An inconsistency of 10% or less implies that the adjustment is small compared to the actual values of the autovector items (Saaty, et al, 2012). The joint application of the AHP method with the FRAM model will give an objective foundation to the subjective assessments of the variability of the FRAM-obtained Outputs made in terms of time and accuracy.

5. Results and discussions

The case study of this work has been drawn up in compliance with the ISO 9001:2015 standard *"Quality Management Systems",* where it is provided that, for the executive execution of an End of Life project such as the one proposed, it is necessary to preliminarily frame:

1. Who are the subjects and which processes are involved in the EOL process of an aircraft with clear identification of the existing interrelationships between them;
2. Define the roles, tasks and responsibilities of the parties involved, in order to avoid any process inefficiencies
3. Build a risk analysis model capable of identifying the main project tasks and any issues related to this path

The three elements described will lead to the construction of a project plan, drawn up in accordance with the provisions of paragraph 8.3 of the ISO 9001:2015 standard which, once validated by the Management, will constitute the operational framework of the entire process (Fig. 1).

The first result that the team has obtained, through the application of the FRAM/AHP model, is a complete reformulation of the disassembly process of an aircraft at the end of its life cycle. It is demonstrable, in fact, that with an adequate brainstorming activity, the team was able to rework the flowgram proposed by ICAO (2019) (Fig. 2) INTO a *"dynamic"* scheme (Fig. 3), where, for each downstream function, a specific condition capable of characterizing the upstream function is defined.

Table 2: Random Consistency Index (R.I.) Source: Saaty and Vargas (2012)

N	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Random consistency index (R.I.)	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

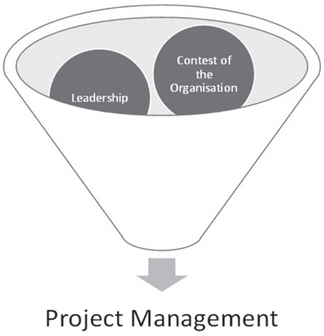

Fig. 1. Operational flow chart of the model (our processing)

Another very interesting result related to the application of the FRAM model derives from the fact that, through - analysis of the *"Technological, Organizational, Human"* characteristics of the identified functions, it is be possible to obtain a classification, in terms of the two variables proposed by Erik Hollnagel in 2014: *"Time"* and *"Precision"*. These two elements, according to the author, are fundamental in order to define the degree of criticality of the functions of the process in question, as their presence is able to characterize the degree of variability that these have and how this variability influences the interactions between the functions downstream and upstream of a given process. through the analysis of the *"Time elapsed for the realization of the activity"* and the "Precision used for the realization of the activity", the working group analyzed the different functions that characterize the disassembly process of an aircraft at the end of the life cycle, arriving at the identification, through an internal brainstorming process, of the following functions considered critical for the performance of recovery functions (Table 3).

The highlighted functions are considered critical by the research team because they have a high capacity to influence the efficiency of downstream functions. In particular, according to the team's analysis, the 'critical' functions affect downstream activities for two reasons: the first is related to the fact that, given the accuracy required to carry out disassembly activities, the time that operators will have to devote to such activities could be prolonged beyond what is expected, creating bottlenecks all along the way. Secondly, possible misunderstandings between operators may generate errors in the identification of parts, leading to delays along the recovery line.

The other functions, although important in the economy of the process, are not considered critical by the team because, from the evaluations carried out, their inefficiency could be easily managed through the down streaming of the functions. The analysis process carried out with the FRAM method was therefore supported by the AHP method, through which the working group intended to "confirm its evaluations by purifying them, as much as possible, from the subjective assumptions that allowed the graphic realization of the FRAM model, Starting from the so-called Common Performance Condition (CPC) theorized by Woltjer Rogier and Erik Hollnagel (2008) and adapted to the recovery process, it is possible to establish that time and precision are respectively functions of the following CPCs Eq. (11) (Table 4 and Table 5).

$$f_{TIME}=\left(T_1;T_2;T_3;T_4;T_5\right)$$
$$f_{ACCURACY}=\left(P_1;P_2;P_3;P_4;P_5\right) \tag{11}$$

From the characterization of the c.d. Priority matrix of the variables under analysis, two different matrices have been created, one for the Time variable and the second for the Precision variable. Subsequently, the working group examined how the individual variables are able to influence the functions considered critical through FRAM analysis by constructing two matrices, one for priority and one for the determination of the score associated with the analyzed variable with respect to the examined function. The data obtained have been summarized in the following table and graph (Table 6) (Fig. 4).

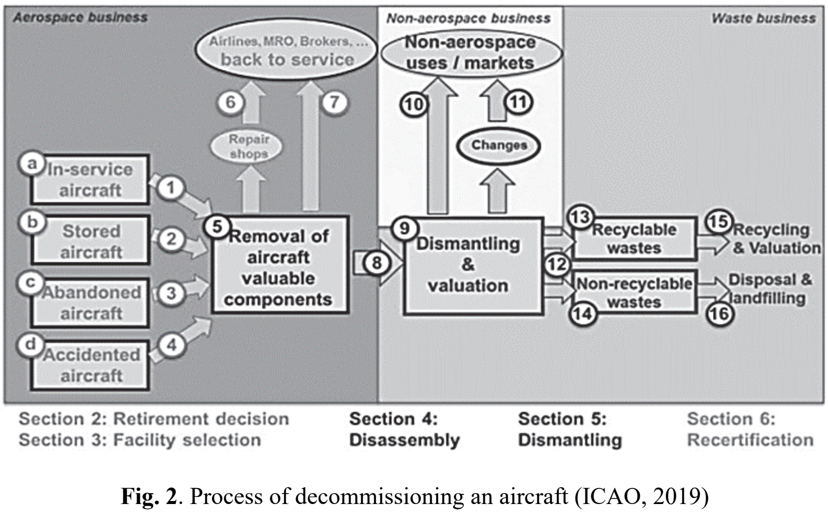

Fig. 2. Process of decommissioning an aircraft (ICAO, 2019)

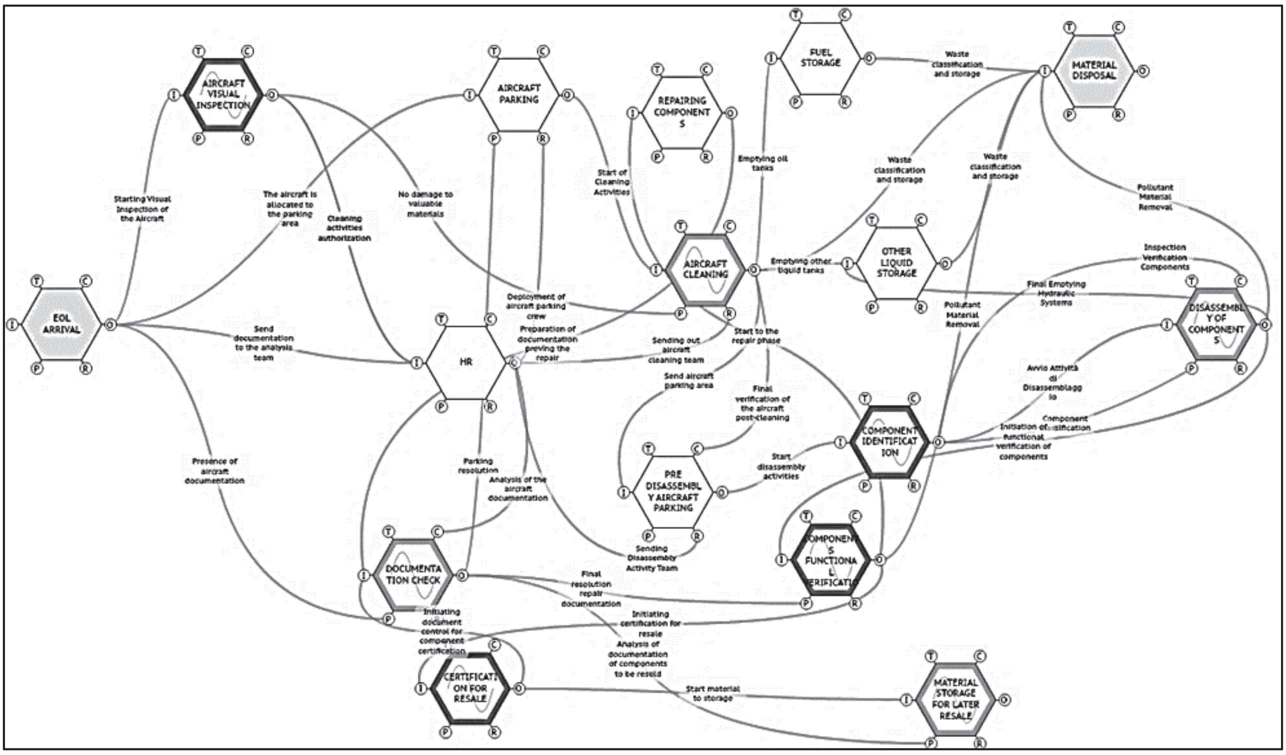

Fig. 3. FRAM representation of decommissioning of AN aircraft (our processing)

Table 3. Critical functions of the decommissioning process of an aircraft (our processing)

Function name	***Description***	***Function type***
AIRCRAFT VISUAL INSPECTION	The Work Team provides an initial inspection of the aircraft waves and retrieves the accompanying flight documentation	Human
CERTIFICATION FOR RESALE	The product to be resold undergoes re-certification by the relevant agencies to be remounted on the aircraft	Human
COMPONENTS FUNCTIONAL VERIFICATION	Components are tested for subsequent reuse	Technological
COMPONENT IDENTIFICATION	Components to be disassembled are first identified and classified	Technological
DISASSEMBLY OF COMPONENTS	Components are disassembled from the aircraft and destined for functional testing	Technological

Table 4. CPC considered as a function of time (our processing)

Time-assessed CPCs	
Resource availability	T1
Training and experience of the resources involved	T2
Type of fastner/connection	T3
Component manipulation	T4
Working conditions	T5

Table 5. CPC considered as a function of precision (our processing)

CPCs rated for accuracy	
Resource availability	P1
Training and experience of the resources involved	P2
Quality of internal/external communication	P3
Working conditions	P4
Quality of collaboration between team members	P5

Table 6. Summary table of the results obtained through AHP (our own processing)

Critical Function	*Time*	*Precision*
AIRCRAFT VISUAL INSPECTION	0.386	0.367
CERTIFICATION FOR RESALE	0.329	0.355
COMPONENTS FUNCTIONAL VERIFICATION	0.132	0.134
COMPONENT IDENTIFICATION	0.102	0.096
DISASSEMBLY OF COMPONENTS	0.061	0.046

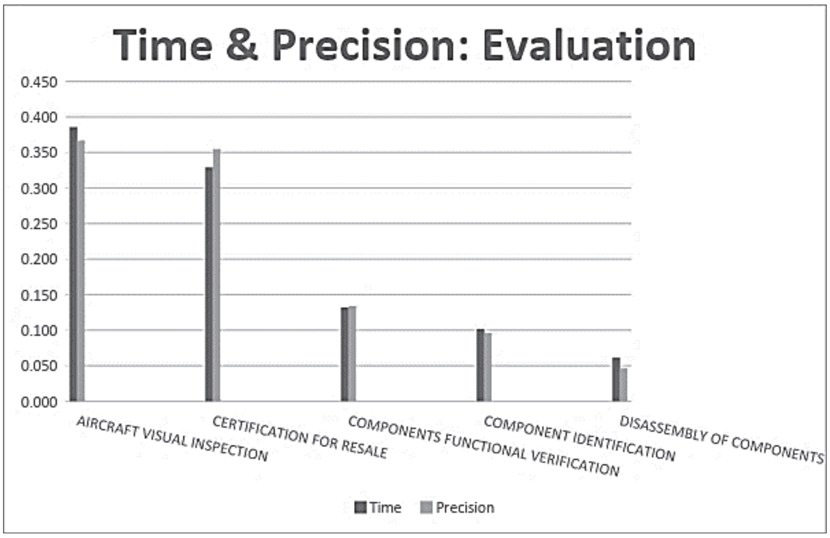

Fig. 4. Time and accuracies evaluated according to the AHP method (our own processing)

As can be seen from the data obtained (Fig. 4), the application of the AHP model to the case examined substantially confirmed what emerged during the application of the FRAM model, namely that the visual inspection function of the aircraft and the certification of the components recovered for subsequent resale/reuse on other aircraft requires particular attention from the workers. Going into the details of the results obtained, the visual inspection of the aircraft sees a prevalence of the *"Time"* factor (Fig. 5) compared to the *"Precision"* variable (Fig. 6).

This data is confirmed by the operational experience in the field, where the on-site verification of the condition of the aircraft requires adequate timing by the operators in charge who will have to identify any damage to the external elements of the aircraft that make the analyzed element unsuitable for immediate reuse. The second aspect of attention is that of certification for resale. Looking at the *"Time"* factor and the variables that most influence its performance (Fig. 7), the AHP method has shown how, for the work group, the availability of manpower connected to the technical capacity of the resources involved in the analyzed function are fundamental for the performance of efficient and effective performance.

Now let's look at how the *"Precision"* function is affected (Fig.8); according to the results collected and processed with the AHP method, we note a very important novelty compared to the case dealt with for the analysis of the *"Time"* function: For the *"Precision"* function, in fact, in addition to the skills and availability of the workers, the work team gives high importance to the communication aspects both between the members of the group responsible for managing the certification of the components and that between the latter and external parties (i.e. deputies issuing of certifications, public authorities).

The evaluation proposed by the team finds, in this case as in others, its correspondence in operational practice. in fact, any element that is susceptible to reuse from a technological point of view must necessarily be accompanied by all the necessary documents in order to be authorized for use by the competent authorities.

By deepening the analyses in reference to these two functions *"critical for the disassembly process",* the AHP analysis has allowed us to understand how to improve the performance of the variables *"time"* and *"precision"* as a function of the variables being evaluated. with regard to the *"time"* function, the inspection of the aircraft requires, in order to be efficient, an adequate number of operators dedicated to the purpose.

As far as *"precision"* is concerned, here too the aspect related to the skills of the staff is highly relevant compared to the other variables. with regard to the other critical function, that of "certification for resale/reuse", the *"time"* and *"precision"* functions are also influenced by the presence of an adequate number of people appointed for the purpose and who are adequately trained to manage the operational activities related to the activity analyzed.

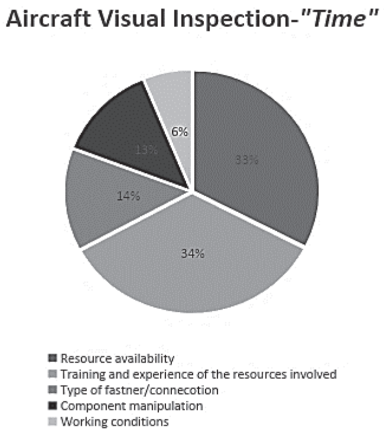

Fig. 5. Aircraft Visual Inspection - Evaluation of Weather Incident Variables (our processing)

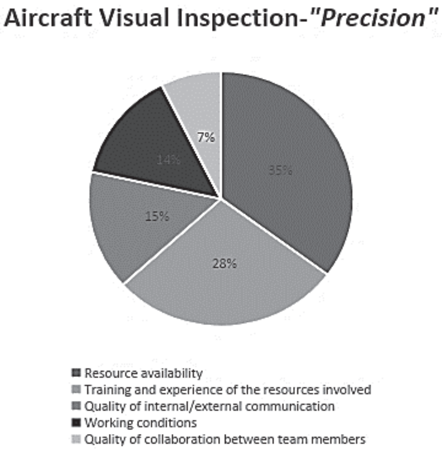

Fig. 6. Aircraft Visual Inspection - Evaluation of Accuracy Variables (our own processing)

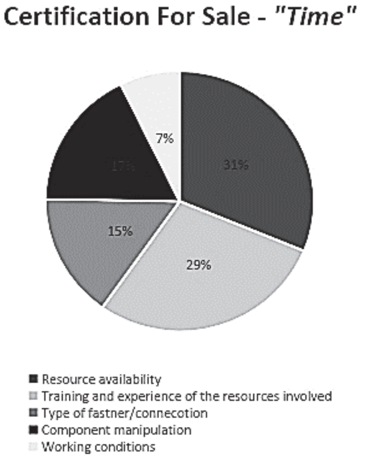

Fig. 7. Certification for Sale- Evaluation of Variables Affecting Time (our elaboration)

6. Conclusions

The aim of this study was to present a methodology designed to support companies involved in the disassembly of aircraft at the end of their life cycle, ensuring efficient recovery activities that align with the principles of extended producer responsibility.

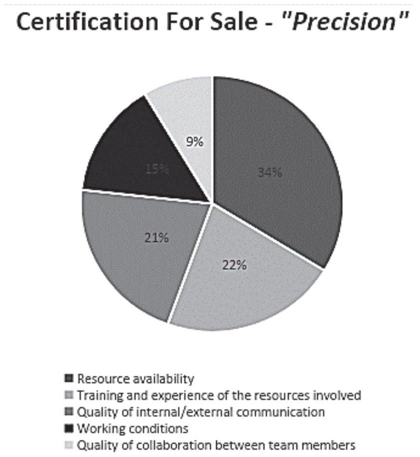

Fig. 8. Certification For Sale - Evaluation of variables affecting Accuracy (our elaboration)

Following a brief review of relevant literature, the study introduced a process analysis methodology combining FRAM and AHP models. This approach facilitated the identification and validation of key outcomes by the team responsible for managing the various phases of disassembly necessary for the recovery of aircraft components for reuse and recycling. The decision to develop this methodology stems from the observation in the literature that there are few models available for managing aircraft disassembly at the end of their life cycle. This highlights the novelty and developmental stage of this sector. Additionally, the evolving regulatory framework for extended producer responsibility adds complexity and opens avenues for further research.

The analysis emphasized the critical importance of "time" and "precision" factors, which, when defined through specific variables, must consider the human and organizational elements. These include the availability of resources and the requisite skills of the actors involved in the recovery process, both of which are essential for achieving outputs that are economically viable for companies. The economic evaluation of the presented process is proposed as a future area of research to provide comprehensive decision-support models that enhance the economic and environmental sustainability of the aviation sector. The proposed risk analysis model aligns with current evidence and studies.

However, ongoing regulatory and technological advancements in the aviation sector will necessitate further refinements. The authors anticipate that future work will confirm the validity of the proposed approach. Additionally, the methodology will need to be expanded to include cost-benefit analyses aimed at improving the efficiency of critical functions identified. This will involve the application of economic analysis methods, which are currently under review and will serve to further support the decision-making processes in aircraft recovery at the end of their life cycle.

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