HUMAN FIRST (WHEN HUMAN FACTORS AND SAFETY WALK TOGETHER)

T. Rueda (tatiana.rueda@ineco.com, +034-670514299)[1], M. de Mena (maria.demena@ineco.com, +034-628218582)[2], and M. Escalera (maría.escalera@ineco.com, +034-696676935)[3].

[1] *Tatiana Rueda Martínez. Avda. Partenón, 4-6 5ª Floor. 28042 Madrid.*

[2] *Maria Soledad de Mena Serrano. Avda. Partenón, 4-6 5ª Floor. 28042 Madrid.*

[3] *Maria Escalera Rodriguez. Avda. Partenón, 4-6 5ª Floor. 28042 Madrid.*

1. BACKGROUND

INECO is an engineering and consultancy firm involved in developing a safe and sustainable infrastructure in transportation. In particular, the railway and air navigation safety areas have been working for many years in carrying out system risk assessments, ensuring they are safe for operation, as an essential aspect of change management.

Human factors related issues are the cause of most accidents in transportation. But despite the current trend towards automation, human beings are still the key element of all systems and an intrinsic part of their entire life cycle, hence the vital importance of studying the influence of human behaviour on safety. Regulations in some countries already demand analysis of the human factor in addition to conventional safety assessments.

However, in those cases where risk analysis does take the human factor into account, a market deficiency in regard to methods for performing more in-depth analysis means that it generally only does so on a superficial level. Under this premise, there is a definite need for safety studies that take a broader, more comprehensive view of the human factor, or in other words, the human interaction with systems and how it is influenced by different environmental elements, to come up with effective accident prevention strategies.

This fact, and our need for further evolution in safety management, has moved INECO to address the human element more thoroughly and explicitly in safety assessments in order to make system design more fit to human needs.

2. OBJECTIVE

It is time to have a systematic methodology that allows the integration of Human Factors analysis with risk analysis, as well as putting new technologies, data science and the digitalisation of systems at the service of operational safety and the analysis of Human and Organisational Factors (HOF).

Our objective was to obtain more detailed requirements able to improve human performance, as well as using new technologies to take advantage of the knowledge that can be gained from past experience and that can be of great value in learning about the systems and what factors affect them most.

3. METHODS

3.1. METRODOLOGY FOR THE INTEGRATION OF HUMAN FACTORS IN RISK ANALYSIS

Over the course of 6 years, the Ineco innovation project has been working to develop a more thorough and transparent method for handling the human element in safety analyses, which, in turn, will enable us to design systems that are more human friendly. The project analysed proven human-factor methodologies and techniques not generally applied to safety studies and managed to extract, simplify and integrate them into risk assessment processes, therefore, making them universally applicable to any sector of the transport industry.

With the dual objective of taking advantage of the synergies between different transport sectors, as well as making it transversal to other sectors, the project has been conceived from the outset and carried out over time in a fully collaborative manner between INECO's Railway and Aeronautical departments.

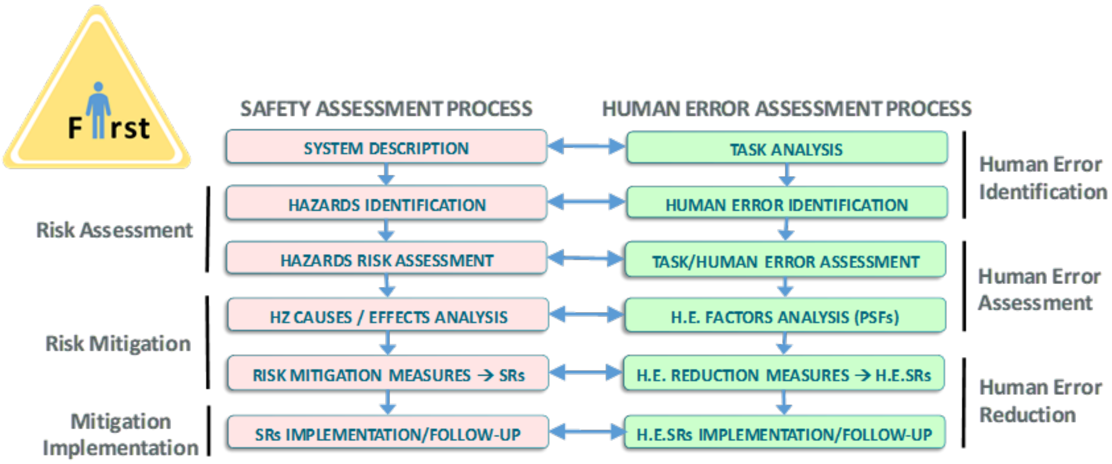
The project began with an exhaustive analysis of human-factor methodologies and science, which were used to begin to extract different tools and techniques and apply them to case studies, while simultaneously developing other own methodologies.

By doing so, we were able to design a process that included an adapted HRA (Human Reliability Assessment), based on the HEART method (Human Error Assessment and Reduction Technique), its application to the railway industry through the RARA methodology (Railway Action Reliability Assessment), and also its application to the aviation industry through the CARA methodology (Controller Action Reliability Assessment).

It is important to mention that the aforementioned methodologies use a quantitative approach to the analysis of Human Error, with the consequent difficulties that this approach may entail when there is insufficient data and/or the nature of the data is not very reliable.

The approach adopted in the case of the methodology described in this paper is a qualitative approach, so, based on the phase structure of the methodologies described in the previous paragraphs, we have generated a structure adapted to the needs of integrate into the technical safety analysis.

We have designed a process that includes an adapted Human Reliability Assessment (HRA) to be executed in parallel to the safety assessment, matching each stage in an integrated and traceable manner.



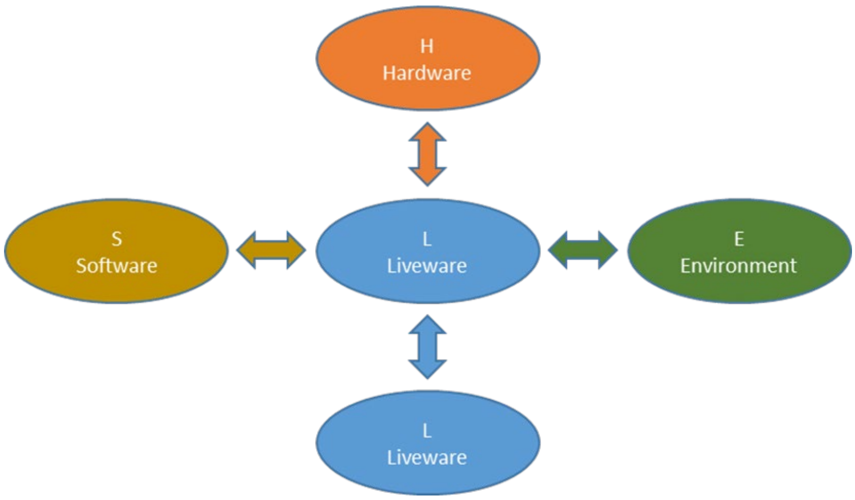
3.1.1. HUMAN ERROR IDENTIFICATION

The process starts with the System Description, in which the system will be studied both from the point of view of the people who have some kind of influence on it, or can be influenced by it, and from a technical point of view, the latter with a level of detail appropriate to the needs of the Human Factor study to be carried out.

The main objectives of the System Description are:

- Identification of the relevant people that have the capacity to interact with the system under study.
- Description of the roles of each of the people identified as relevant.
- Identification of the possible interfaces that may have an influence on each of the identified roles.

One of the key aspects is the identification of interfaces, as people do not work in isolation, but are in an interaction with all the interfaces they interact with, for this purpose, the well-known Shell model has been used, which classifies interfaces into 4 types (Liveware-Software, Liveware-Hardware, Liveware-Environment, Liveware-Liveware).



Then, the process Task Analysis broadens the system description, identifying all the relevant human interventions and where errors can occur.

The objective of Task Analysis is to understand and represent in an orderly and logical way the set of tasks that the human element must perform within the system so that it can be operated normally. By understanding how the human element ideally intervenes in the system, it will be possible in the next phase (Human Error Identification) to analyse the possible deviations that may lead to degradation and thus to a hazard to safety.

Task Analysis involves the study of what an operator (or team of operators) is required to do, in terms of actions and/or cognitive processes, to achieve a system objective. To do this, there are a set of techniques that help the analyst to collect information, organise it and use it to evaluate or make decisions:

- Data collection methods: Aimed at obtaining the data and information necessary to understand and characterise the tasks being carried out. Examples of information gathering methods are documentation review, walk-through and talk-through interviews, questionnaires, observation of the operation...
- Information representation methods: Dedicated to represent the information previously obtained to facilitate its interpretation in a logical and appropriate way to the objectives of the analysis. Examples of representation methods are Hierarchical Task Analysis, Tabular Task Analysis, Timeline Analysis, Action-Decision Diagrams... (the specific tool for the representation of information shall be selected according to the nature of the system under analysis).

For the identification of human failures modes, the previously performed Task Analysis is taken as input, and the failure modes are identified through Human HAZOP-type techniques. The consequences of the failure modes at a system level are also identified.

For the identification and classification of human failure modes, taxonomies such as Swain and Guttmann’s can be used, which classifies failures into "errors of omission", "errors of execution" and "extraneous acts".

Once the above process has been completed, and as a result of this stage, we will have obtained a System Definition Report, and a Hazard Register that includes a list of human failure modes associated with the system under study.

In the next phase, the identified failure modes will be assessed, taking into account both the ease with which they can be committed and their criticality in terms of the potential hazards they can trigger.

3.1.2. HUMAN ERROR ASSESSMENT

The objective of this phase is to classify the tasks to be carried out by identifying the most critical tasks, and therefore the ones on which special care must be taken, as well as the factors affecting human performance.

One of the key aspects of the methodology developed is that tasks are classified not only according to how easy it is to make a mistake in their performance, but also according to the criticality of the consequences of possible errors (an error whose consequence is a derailment must be treated differently from an error whose consequence is a delay). This classification is made possible by the previously established traceability between tasks, the failure modes associated with each task, and the consequences of these failure modes at the system level.

In order to determine how easy it is to make a mistake in the performance of tasks, a methodology from the nuclear industry has been adapted, in which tasks are classified according to 5 parameters (frequency, time of implementation, complexity, location, change of shift). INECO has developed its own rating system for each of these parameters, so that the tasks can be ranked according to these parameters.

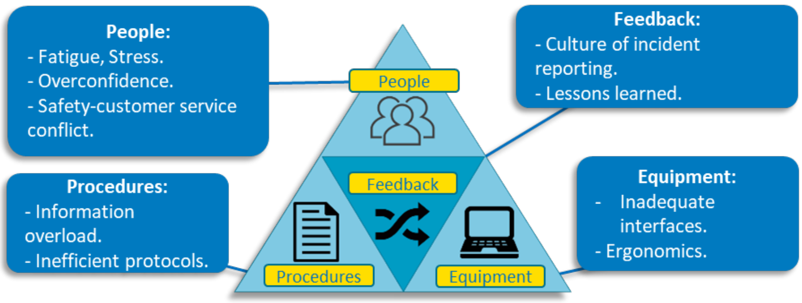
Once the tasks have been parametrised and classified according to the above criteria, the hazards to which they are related, as well as the consequence of these, are included as an additional factor. Taking all these factors into account, we obtain a ranking of the tasks, which allows us to identify the most critical ones.

However, human performance depends not only on the tasks to be performed, but also on the factors that can affect human performance, which we have termed Performance Shaping Factors (PSF).

INECO has developed its own checklist of PSF in which it has been identified the factors that can affect human performance, with the help of the psychology department of the University of Malaga.

PSFs factors have been classified into the following 4 categories:

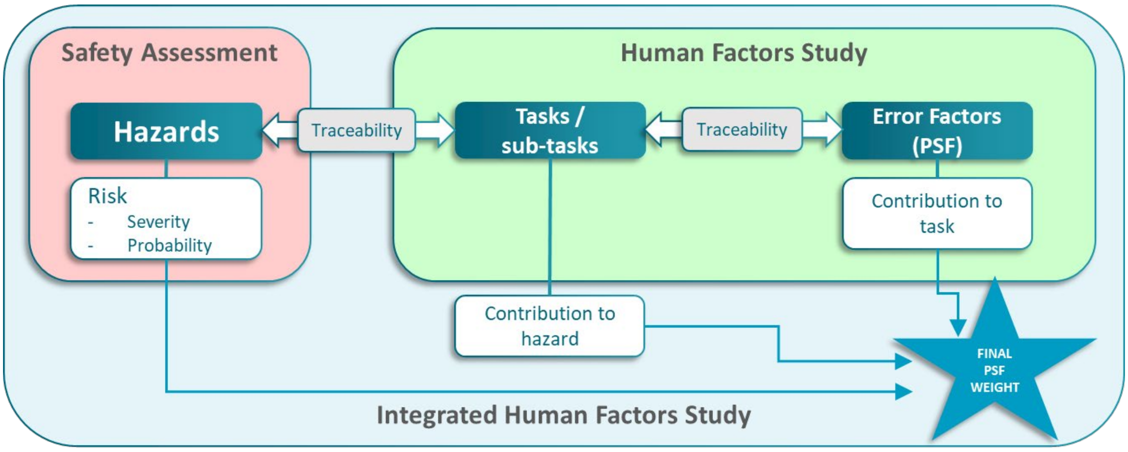
- People: Within this category are factors such as the fatigue, stress, overconfidence, safety-customer service…
- Procedures or standards: Existence of procedures, protocols, communication codes, checklists, regulations... It is taken into account if they exist, or even if they exist in excess.
- Equipment (Hardware and Software): This category takes into account aspects such as ergonomics, physical interfaces with the equipment, process automation...
- Feedback (during operation and after the operation): quality of communications, if there is repetition of orders/instructions, types of supervision, incident reporting culture....



Since people can be affected by different PSFs, and not all the tasks they have to perform are influenced by the same PSFs, each task is assigned the PSFs that can condition its correct development, taking into account both the experience of the Human Factor analyst, but, above all, the support of the experts who operate the systems (the information provided by the operators at this stage is very important for the analysis to be able to reproduce the circumstances in real environments).

To collect information from experts, guided interviews can be carried out, however, in order to obtain information from a significant sample space, questionnaires have been developed as part of this methodology, which can be distributed among a large number of operators, so as to obtain quick and reliable results.

Once the PSFs that influence the correct execution of the tasks have been obtained, they can also be prioritised so that the most critical factors are identified according to both the degree to which each PSF affects the corresponding tasks, and the criticality of the consequences of the hazards to which they may give rise (given that the PSFs are assigned to the tasks, and the tasks are mapped with the possible hazards and their consequences).



As a result of this phase, we obtain:

- A list of tasks to be implemented by operators prioritised according to their impact on safety.
- A list of factors affecting human performance (PSF) for the performance of tasks assigned to operators, prioritised according to their impact on safety.

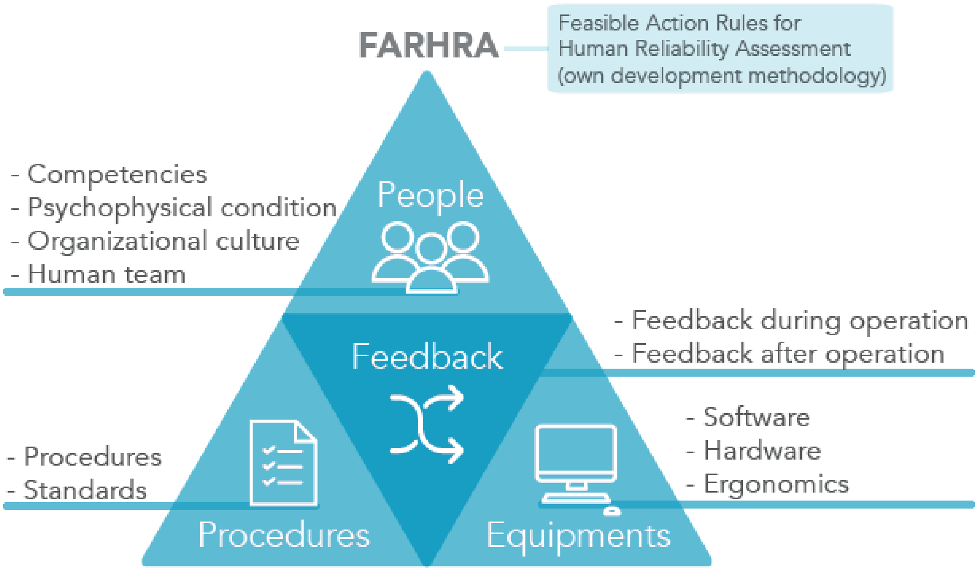
The information obtained in this phase serves as input for the final phase, in which, once the system has been analysed and the most critical elements from a safety point of view have been identified, recommendations should be proposed to help optimise human performance and thereby increase the level of safety in the operation of the systems.

3.1.3. HUMAN ERROR REDUCTION

The main objective of this phase is to define specific measures to improve the human performance, either by acting on tasks, or on Performing Shaping Factors (PSF). These safety measures, will be the specific Safety Requirements for the reduction of human error. Added to the rest of the Safety Requirements (those obtained by other non-human factor specific analyses), they will make up the total set of Safety Requirements for the system.

Combining the three aspects – task potential for error, error criticality and performance shaping factors – we are able to establish orders of priorities for the human error reduction process. Initially, measures were determined using the NARA (Nuclear Action Reliability Assessment) approach (from the nuclear industry), according to which a generic list of types of measures is proposed on the basis of which concrete measures can be determined to address each conditioning factor. In a later stage of maturity, Ineco has developed FARHRA (Feasible Action Rules for Human Reliability Assessment), providing a broader set of generic measures and more aligned with the system view in safety assessment.

Its development was based on guided brainstorming sessions involving a multidisciplinary team of safety and human factors experts from both, the railway and the aviation sectors.



The measures identified are grouped into 4 main clusters:

- People: a set of measures relating to people, both at the individual level and in terms of how they fit into the organisation or company.
- Procedures: measures on the working methods used by people to perform the task.
- Equipment: measures on the equipment, hardware and software used by people and that may assist him/her in the performance of the task.
- Feedback: a group of measures covering people as well as procedures and equipment, specifically acting on the feedback received by the operator during or after the performance of tasks.

Within each group, Generic Areas are established, with two levels of classification and, within each area, a set of generic measures. These generic measures are explained by means of a description and a series of examples.

For each PSF, all generic measures should be reviewed and transformed into concrete measures that can reduce this factor, in the context of the tasks and possible errors to which it contributes.

This is the final phase of the analysis, and its output will be a list of recommendations that will help to improve human performance and that can complete the list of Safety Requirements that are obtained from conventional risk analyses in which the Human Factor is not explored in depth.

3.2. NEXT STEPS

Once INECO has developed its own methodology for the integration of Human Factors in Risk Analysis, INECO has continued to advance to complete and improve the knowledge and development of techniques for the analysis of Human and Organisational Factor (HOF).

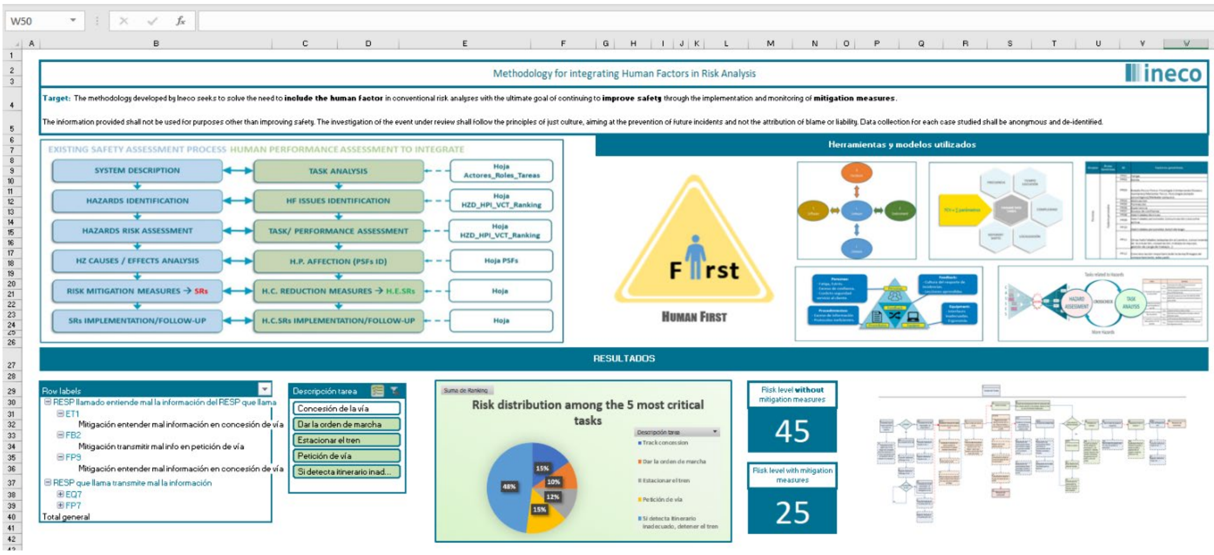
INECO continues to develop new products completing the line of work we have called "**Human First**", which is enriched by including cutting-edge and contemporary approaches in terms of:

- Process automation.
- Use of data science.
- Fatigue management.
- Incident analysis.
- Creation of a comprehensive management tool for Human Factors Analysis.

3.2.1. iHISA TOOL

The iHISA tool has been created in order to assist in the application of the methodology for integrating Human Factors in Risk Analysis described in the previous sections.

In terms of technical characteristics, the tool has been designed in Excel format through programming in Visual Basic language, and consists of 6 excel sheets which are used sequentially as the application of the methodology progresses.



3.2.2. InFact

The analysis of incidents occurring during operation is a very valuable source of information about the system, from which, by performing a Human Factor analysis, information can be obtained about the human behaviours that can trigger dangerous events, which we have called Human Factor Issues (HFI), as well as the factors affecting performance that underlie the occurrence of such behaviours (PSFs).

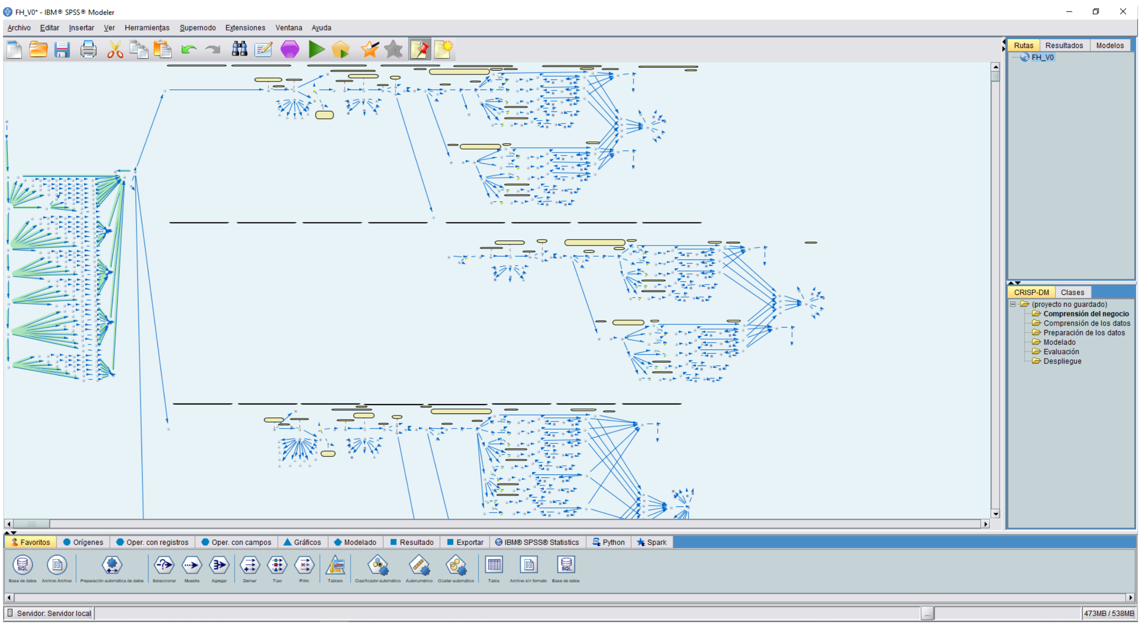
The objective of this tool is to develop a process of analysis of the human factors associated with the incidents produced, from which two types of information are extracted, among others, mainly:

- HFI: Human behaviour that has contributed to the occurrence of the incidence.
- PSF: Factors that have affected proper human performance.

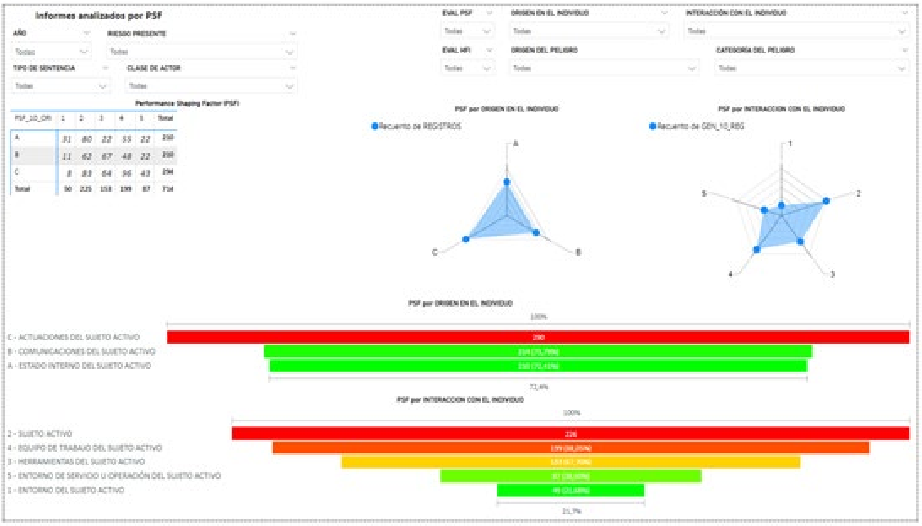
The process developed consists of three main parts:

- Collection of information: in order to automate the incident analysis process, questionnaires have been developed to be completed by the person analysing the incident.
  These questionnaires consist of a series of questions whose answers allow an automated identification of the HFIs and PSFs underlying each incident analysed

- Analysis of the information: From the data obtained from the questionnaires, the HFIs and PSFs from each of the incidents analysed are extracted, stored in a database, and analysed at a global level to obtain statistics on which HFIs and PSFs are most common, and this information can be obtained at a general level, by type of role, by year, by country... This analysis is carried out with the help of the IBM SPSS modeler tool.



- Representation of the information: In order to be able to represent the information obtained in a dynamic way and to be able to select the type of specific information to be obtained, the Power BI tool has been selected.



3.2.3. BioMaF MODEL

When analysing the human element of the system, a depth level of analysis that explains the underlying causes and the contributory factors to the possible errors is needed.

Throughout the years, fatigue has been on the National Transportation Safety Board (NTSB) "Most Wanted List" since the initial list in 1990, so, in order to respond to the need to analyse this fact in more detail, and aligned with ICAO document 9966 that sets biomathematical models of fatigue, as a useful tool that allows the predictive identification of fatigue from work schedules; INECO has developed a Biomathematical Model of Fatigue (BioMaF) which has culminated in the achievement of the following goals:

- **Benchmarking** of classical and contemporary models, from which the requirements to be met by the model were established and review of the most avant-garde literature regarding the use of biomathematical models for fatigue management (FRMS).
- **Algorithm Design**: assessment of model components and establishment of fatigue risk index thresholds (FRI).
- Development of Measuring Instruments for INECO:
    - FIT - **Fatigue Index Tool:** that analyzes and has the ability to compare different shift programs and get the FRI index
    - WAQ - **Workload & Alertness Questionnaire**: questionnaire developed to measure variables such as workload, shift start time or rest quality, based on scales validated and implemented in aviation and railway to analyze fatigue.
    - Volunteer Feedback Report Template, in actigraphy studies (**ActíGraph**), and guide to using the software **ActiLife**

The BioMAF Model allows, on the one hand, the identification of the fatigue risk index (FRI) of safety-critical activity profiles, confirming whether the indices obtained are above the fatigue threshold. In addition, the model correlates these indices with scores derived from subjective fatigue questionnaires. (WAQ) and, on the other hand, it crosses this information with more objective data from actigraphy devices.

The result of the human performance analysis, due to the fatigue to which these profiles are subjected, will provide the organization with an indicator for a preventive management of fatigue within its Safety Management System (SMS or FRMS).

After the completion of all the activities described above and in view of the statistical results obtained after the application of the biomathematical model to the sample of selected aviation and railway personnel, during a period of two moths, it can be concluded that:

The model reaches a reliability index of 0.80, this index confirms a high internal consistency between the components, so it can be said that the parameters: alertness/sleepeness levels, Workload and sleep quality, provide high coherence with each other; while the inclusion of other parameters such as, for example: shift start, fatigue index (FRI), or sleep hours, etc. provide a complementary measurement of attributes associated with fatigue.

So it can be said that the first objective is met, since the questions of the questionnaire measure the construct Fatigue or aspects associated with it.

Finally, it is important to mention that the analyses have been carried out without tools that Data Science could provide and that would greatly help the processing of massive data and would facilitate the extraction of relevant information about the rest and activity patterns of these personnel who perform critical tasks in operational safety.

3.2.4. GFA TOOL

INECO is developing a comprehensive management tool for Human and Organisational Factors Analysis named GFA Tool. It is based on the generic safety risk management processes and the Human Factors analysis methodologies developed at INECO. Thus, by means of this tool it will be possible to monitor, analyse and consult key performance indicators, metrics and fundamental data that make it possible to track the Human Factors status in an organisation within a safety perspective.

As an embedded information management tool, GFA is being conceived to have a future dashboard-like interface that complies with the principles of being an application: customisable, visual, practical and accessible.

Among the main objectives of GFA Tool are:

- To know and manage the status of Human and Organisational Factors (HOF) in a functional system. In a general way as well as in a specific way through the results and synergy of the different INECO products that cover, among others, the following studies: change management, incident analysis, fatigue studies, and operational scenario analysis.
- Definition of objectives and decision making. The analysis of the integrated data of this tool supports a management system and allows the definition of strategic metrics that provide results on secondary problems with a new approach.

- Development of a generic repository of Human and Organisational Factors (HOF) studies in several industries. This tool provides a standardised and synchronised database that will facilitate the comparison of information, forecasting and indicators definition.

Both the design of this tool and its future application enable the strengthening of the safety management of an organisation by identifying and analysing the influence of Human and Organisational Factors (HOF) on safety, their characteristical components and their interaction with the rest of the elements of the system. Consequently, GFA Tool will guarantee an effective integration of Human Factors in Risk Analysis.

CONCLUSION

'If you cannot measure it, you cannot improve it.' That is a quote from Lord Kelvin. This statement in terms of a socio-technical functional system indicates that it is crucial to take into account human performance and its interaction with the rest of the elements (people, procedures, equipment) in order to improve the performance of an organisation with critical operations.

In this regard, INECO's growing experience in the development and application of Human Factors products is enriching safety cases and aligning them with new trends in safety management. In particular, this means evolving towards a more proactive safety management that not only integrates the systemic approach, but also the Human Factors discipline in systems management.

As proof of the above, this article has summarised products that INECO has developed (and continues to develop) in the field of Human and Organisational Factors Analysis:

- Methodology for the integration of the Human Factor in the Risk assessment: Comprehensive and systematic methodology for the analysis of factors affecting human performance in the tasks people have to carry out, as well as identification of the most critical tasks from a safety point of view.
- iHISA tool: tool for assisting in the application of the human factor analysis methodology developed.
- In-FACT: methodology for analysing incidents and obtaining statistics.
- BioMaF: offers a consolidated service for fatigue analysis.
- GFA-Tool: tool for the integrated management of the different products developed by INECO.

Keywords: Human and Organisational Factors; Human Reliability Assessment; HEART; RARA; CARA; Shell model; Task Analysis; Human HAZOP; Performance Shaping Factors; Human Performance; NARA; Human First.