A HUMAN FACTORS APPROACH FOR THE ANALYSIS AND THE ENCODING OF AVIATION ACCIDENTS AND INCIDENTS: A VALIDATION STUDY

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Sharing safety information is a key issue to improve aviation safety. Therefore, it appears necessary to have a common way to describe aviation accidents/incidents in order to get consistent data that will be used to produce relevant safety indicators. This implies to use the same taxonomy, the same compatible software to facilitate data sharing, and, more important, a common method to encode occurrences into safety data. The way human factors are taken into account in the database must be improved since statistics usually provided, deal with accident/incident categories and not with their various causes (most of them are human factors related). The BEA in cooperation with the LAA has developed a methodology for the encoding and the analysis of aviation accidents and incidents. This tool has been successfully used during several investigations but still needs to be scientifically validated. This paper aims at putting safety analysis into perspective. It also discusses the methodology that incorporates the Human Factors SHELL model and a validation study.

Introduction

The need for a common and standardized or scientific approach has been highlighted for accident report analysis (Zotov, 2000) and for encoding data from a human factor taxonomy (Casetta et al, 1998). More guidance for reporting has been recently published by ICAO (ICAO, 2003) in addition to what exists in Annex 13. Whereas the facts to be collected are precisely detailed in Annex 13, its appendix only mentions for the analysis: "*Analyze, as appropriate, only the information documented in 1. Factual information and which is relevant to the determination of conclusions and causes*" (ICAO, 2001).

There are several approaches to analyze accidents and incidents. The investigators of the A320 accident of Bahrain (Government of Bahrain, 2002) used a methodology based on the Reason model (Lee and Mulcair, 2003). The Reason model (Reason, 1990) is also used by the US Navy through the Human Factors Analysis Classification System (HFACS) taxonomy to encode occurrences to study error trends across the years to prevent accidents (Shappell and Wiegmann, 2004). A need to validate the results of the encoding process was also taken into consideration (Wiegmann and Shappell, 2001).

The French accident investigation Bureau (BEA), in collaboration with the LAA, has developed an encoding method for occurrence (accident or incident) analysis (Ferrante et al, 2004). This method, which uses the SHELL[1] model (Hawkins, 1987), aims at collecting in an efficient way safety information highlighted during the investigation process and at guiding the investigator into the analysis of the occurrence. The goal is then to be able to disseminate this information through data exchange, safety studies or statistics, mainly focused on human factors and to detect accident precursors. After the development of the method it has been decided to validate it. It consists of verifying the hypothesis that the use of this method harmonizes the determination of causes among investigators and, therefore, increases the reliability of the results that are stored in the database.

This paper summarizes the ADREP causal model structure, the questions raised during an investigation and their associated levels of analysis. It then reviews the methodology stemming from that model and discusses the first results of its validation.

ADREP Causal Model and Associated Levels of Analyses

ICAO adopted the breakdown of an occurrence into a sequence of events which are then described and further explained (see figure 1). This breakdown is useful to classify the different questions that are raised during an investigation and to illustrate the various levels of analysis (Ferrante et al., 2004).

[1] The SHELL model describes a system as the interaction of humans with four elements: Software, Hardware, Environment and Liveware. Each element of the model includes a list of items based on a tree description.

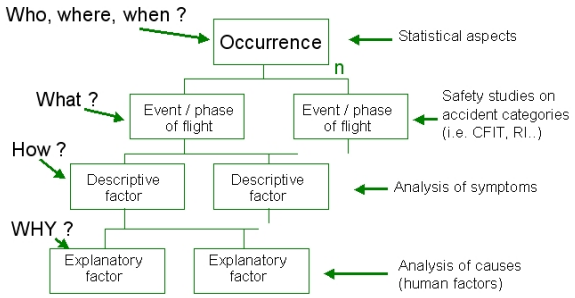

Figure 1. *Four levels of analysis based on ICAO's breakdown of an occurrence*

The first level of analysis covers statistical aspects for different criteria and safety indicators. The first elements gathered right after the notification of an occurrence generally relate to the fields of the flight plan (departure, destination, type of aircraft, date and time). The following questions first asked (who, where, when?) allow to build safety indicators, generally in relation to aircraft, third party damage or injuries. They can be for instance the trend of fatalities in General Aviation or the number of accidents per geographical area. Statistics related to aviation safety are thus mainly based on this type of data, which are only validated during the course of investigations.

The causal approach breaks down an occurrence into a chain of events. Each event is linked to a phase of flight. The number "n" of events depends on the complexity of the occurrence.

The majority of current safety studies are based on these families or categories of events (events correspond to the question "What?" or "which type of occurrence?"). For example, the BEA issued safety studies on fuel starvation events or mid-air collisions (available on www.bea.aero), which correspond to event categories. ICAO and other organizations carried out safety studies on the category of Controlled-flight-into- terrain (CFIT) accidents in the last few years (Flight Safety Foundation, 1996).

ICAO further refines each event by using descriptive factors. These factors mainly refer to aircraft systems, operational or environmental aspects of each event. They correspond to the question "How?". The associated analyses are thereafter based on these identified symptoms. They allow a first level of mitigation measures generally geared to set up palliative actions.

Each descriptive factor is in turn associated with explanatory factors which, as the name indicates, correspond to the question "Why?". These factors reflect the causes of the occurrence. They primarily relate to human factors. These explanatory factors are classified according to the SHELL model which aims at representing the interactions within the aeronautical system. The BEA safety study on the "get-home-itis" factor is an example of an analysis having as a starting point an explanatory factor pertaining to the SHELL model included in the ADREP 2000 taxonomy.

Use of ADREP and ECCAIRS

This latest taxonomy with its 552 explanatory factors represents the outcome of fifty years of investigations throughout the world (Menzel, 2002). It is the third taxonomy version after ADREP 76 (88 factors), ADREP 87 (142 explanatory factors). This material is helpful in tackling systemic issues during an investigation. The clear separation between events and causes, and the fact of having old causes compiled into a taxonomy, help analytical discussions within a team of investigators (national or international). The likelihood of discovering brand new causes is very remote and the ADREP 2000 taxonomy is a natural tool for exploration since it contains an organized collection of all identified events and factors that have, at one time, led to an accident.

The European Commission decided to implement the ADREP taxonomy into a software, ECCAIRS (European Co-ordination Centre for Aviation Incident Reporting Systems) (Cacciabue, 2000). The latest version (ECCAIRS release 4) incorporates ADREP 2000 (and subsequently the SHELL model). Its objective is to facilitate data exchange for analyses on a higher number of occurrences.

However, in addition to a common taxonomy and a common software (ECCAIRS), it is fundamental to have consistent data to prevent biased analyses. This highlights the need of a common methodology to harmonize safety data. Encoding should reflect the report analysis where descriptive and explanatory factors are discussed to elaborate the conclusions.

Two types of practice are currently undertaken to encode an occurrence into ECCAIRS. The first one is done on achieved investigations based on the analysis and the findings of the published reports. This work is generally difficult because an encoder tends to interpret what the investigator had in mind when he wrote his report. It is recommended to stay as objective as possible in order to avoid entering subjective (biased) data in case of interpretation. This approach alters data quality because it is not the

person who best knows the case that encodes it. The second one, more appropriate, builds the codification as part of the analysis process to help investigators to elaborate the occurrence causal chain based on factual information and to tackle human factor issues. It has been successfully used during several investigations.

For example, an accident report to a Boeing B737-200 at Tamanrasset (Government of Algeria, 2004) and a serious incident report to a MD83 at Nantes (BEA, 2004), were based on the encoding method. The analyses of these occurrences were undertaken in parallel with encoding and highlighted human factors and systemic issues. In the case of the Tamanrasset accident, this methodology provided tangible material for supporting teamwork, within an international team with people of different backgrounds. It greatly helped putting together the different pieces of the puzzle in the analysis. The main advantage stemmed from the visual tree description of events and factors that illustrate the depth of the investigation. It was thus a powerful and convincing incentive to tackle root causes and their underlying systemic factors.

Principles of the Encoding Method

The main steps of the method are presented in Figure 2 (Ferrante et al, 2004).

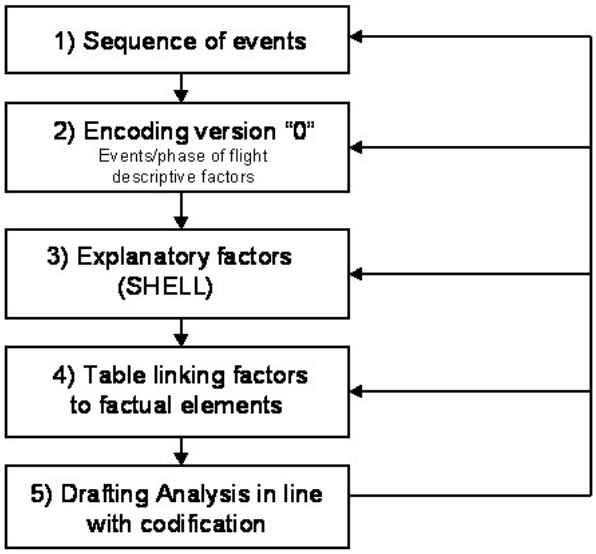

Figure 2. *Main steps of the encoding method*

The first step consists in determining the events leading to the accident/incident. Flight Data Recorder (FDR) and Cockpit Voice Recorder (CVR) data, radar tracks, witness statements and all other information available during the investigation process contain key elements (action, omission, decision, failures, etc.) which will be used to elaborate the sequence of events. Each event is then associated with a phase of flight. A collective approach allows reducing the loss of information and helps dealing with subjective elements, like a witness statement that can be conflicting with factual information.

The descriptive factors precise each event and describe the technical facts and the decisions made by actors which might be later considered as symptoms. One (or more) modifier qualifies each descriptive factor.

The explanatory factors, as they represent the human factor aspects, are chosen within the list given by ADREP 2000, based on the SHELL model. The tree-lists are used as checklists and the explanatory factors are determined after a systematic check. The creation of a table linking the factors to factual elements proved to be very helpful for the justification of the final codification and subsequently the writing of the analysis.

Validation Method for Data Consistency

To validate the encoding method, it is necessary to ensure that it is applied the same way by different investigators.

The validation purpose is to assess the variability of the encoding. Expecting zero variability seems unrealistic. Nevertheless, two investigators using the same method and the same tools should produce similar encoding. The study of the variability of this encoding process should lead to identify the reasons why variability exists. Afterwards, it should be possible to adjust the encoding method by adding enhanced “rules of encoding” to keep the variability as low as possible.

Assessing Variability

To assess encoding variability, the following protocol was applied:

- production of several codifications (sets) per occurrence,
- comparison of the different codifications related to the same occurrence.

A higher number of codifications per occurrence and more occurrences make it easier to bring to light the origin of variability. Therefore it was decided to start with general aviation occurrences, since they are less complex than public transport occurrences and consequently easier to encode in high numbers.

Obviously, this protocol will have to be considered, in a second step, on public transport occurrences, since ADREP 2000 is more dedicated to commercial aviation. The first step, however, consisted of defining criteria to compare different codifications, thus producing initial results.

Production of Several Codifications

During the analysis and encoding steps, two processes can create variability :

- investigators may diverge on the analysis of the same factual information, or
- they may draw the same analysis (same scenario and causes) but without selecting the same elements from ADREP 2000 taxonomy to encode it.

It was first decided to assess the second type of variability, meaning to assess the use of ADREP 2000 by investigators more as an encoding tool than an analytical tool.

Consequently ten occurrences extracted from the General Aviation Bulletin (factual information, analysis and causal factors already available) published by BEA, were given to three separate groups, each composed of one investigator and one human factor specialist. Each group encoded separately these occurrences and highlighted the textual information contained in the report justifying their choices. Doing so, the three sub-levels of codification were covered: events, descriptive and explanatory factors. Then, a comparison of the three resulting codifications was performed in order to quantify and qualify differences.

Comparison of Different Codifications

The next step was to compare the three codifications produced for the same occurrence.

For each occurrence, each pair explained to the others the rationale of encoding the occurrence. During the debriefing, the three groups agreed on a final codification. A significant finding is that the collective approach for encoding helps, as expected, to reduce variability between individuals' interpretation and to produce an agreed final codification.

The following example represents three different codifications and the final one for an accident to a Diamond DA-40 that encountered a power loss during its initial climb. The pilot made a forced landing. The BEA established that the cause of the accident was due to inadequate design of the fuel system. This occurrence was followed by a service bulletin and an airworthiness directive (BEA, 2003). These findings were encoded as illustrated hereafter:

Group 1:

- Power loss in a reciprocating engine due to non-mechanical failure , during Initial climb. {Occurrence}
  - Aircraft fuel system : Faulty
- Forced landing , during Emergency landing or off-runway landing. {Occurrence}

Group 2:

- Power loss in a reciprocating engine due to non-mechanical failure , during Initial climb. {Occurrence}
- Powerplant fuel system related event , during Initial climb. {Occurrence}
  - Fuel filter/strainer
    - *Aircraft manufacturing design staff., Non-flight deck/cockpit aircraft equipment : Inadequate design*
- Forced landing , during Emergency landing or off-runway landing. {Occurrence}

Group 3:

- Engine mechanical failure , during Initial climb. {Occurrence}
  - Aircraft fuel system : Air in
    - *Aircraft manufacturing design staff., Task demands due to technical problem/failure*
- Forced landing , during Emergency landing or off-runway landing. {Occurrence}

Final codification:

- Power loss in a reciprocating engine due to non-mechanical failure , during Initial climb. {Occurrence}
  - Aircraft fuel system : Air in
    - *Aircraft manufacturing design staff., Non-flight deck/cockpit aircraft equipment : Inadequate*
- Forced landing , during Emergency landing or off-runway landing. {Occurrence}

Figure 3. *Comparison and integration of three codifications*

For a given occurrence like the Diamond DA-40 case, all the ADREP 2000 items selected by any of the three groups were listed. For each item, the agreement was scored as follows:

- if selected only by one group, then a "no agreement" was considered,
- if selected by two groups, then a "partial agreement" was considered,
- if selected by the three groups, then a "total agreement" was considered.

Figure 4 shows the results of the agreement between the three groups broken down into the three encoding levels: events, descriptive and explanatory factors.

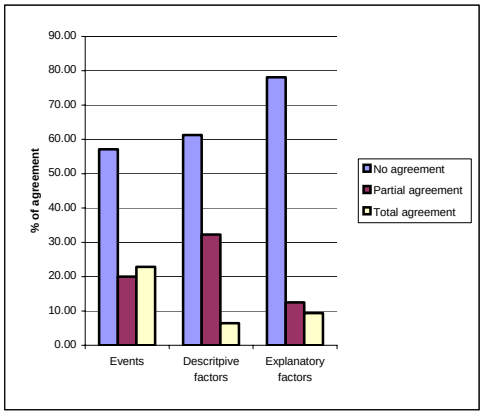

Figure 4. *Percentage of the encoding agreement for three groups*

This comparison shows that variability is higher for explanatory factors than for events and descriptive factors. The nature of the report itself could be a limitation to this validation study since based on a limited analytical narrative.

In addition, this comparison method does not take into account:

- the tree description of ADREP 2000 that leads to score a difference if the items are not strictly identical, although they may belong to the same branch (see figure 5). It would be worth assessing this "proximity" and taking it into account in a further comparison; and
- that a single explanatory factor can be present in two different codifications but without being linked to the same descriptive factor and event. For example, the item "fatigue" can be related to different factors and events.

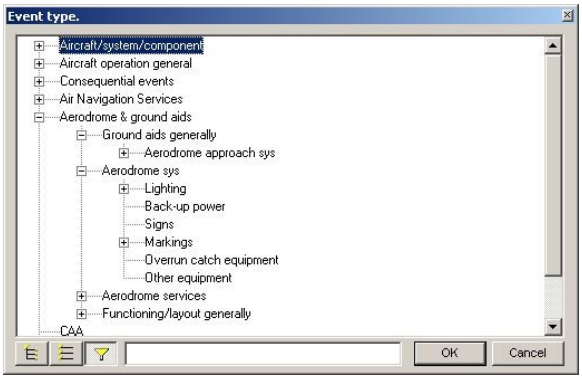

Figure 5. *Tree-list of ADREP events*

This disembodiment of human factor data (Decker, 2001) has to be integrated in an improved comparison process.

These initial results highlight that there are several ways to study differences between codifications. Significant and acceptable differences must be defined. The next step would be to generate a more suitable comparison process. This is still being undertaken.

Initial Explanations and Supplementary Results

The list of points or questions that follows gives initial explanations for this variability, which is related to the use of ADREP 2000 taxonomy through ECCAIRS:

- Investigators do not always check the definition of the ADREP term they select. Therefore, these shortcuts, related to sometimes ambiguous terms, can lead to different interpretations. The on-going learning process has an additional impact on variability.
- A given fact can sometimes be encoded as an event or a descriptive factor.
- Should the breakdown of an occurrence into a chain of events highlight the chronological order of the events or the causal link between events ? This question was answered by placing the causal link as early as possible in the sequence of events, in line with prevention strategies that aim at detecting as early as possible any precursors before they lead to an accident.
- The events and factors section of ADREP 2000 is made of 493 events, 1550 descriptive factors and 552 explanatory factors. Although these numerous elements allow to precisely encode any occurrence, it is sometimes difficult to choose the term that suits the best. Moreover, all investigators do not have the same knowledge of this extended taxonomy.
- When the report is precise enough about a given human factor (e.g. get home-itis, channelized attention, fatigue/alertness), there is generally no variability. When the report does not formally identify a human factor but hints at it, the variability increases because investigators tend to interpret it.

Many of these points are related to training on the use of the method and knowledge of the ADREP 2000 taxonomy. The on-going validation study allows to streamline the methodology and obtain more consistent data.

Conclusion

This pre-validation study has covered a limited number of occurrences from the General Aviation Bulletin where the results of investigations are given in a concise way. On these rather simple cases, a validation protocol was developed. This approach, initially limited to published reports, needs to be enlarged to the direct analysis of factual information, as foreseen for the production of codifications. This represents a time-consuming task for the various groups. It will be even more cumbersome on more complex investigations (with a higher number of events), which generally involve public transport aircraft. This on-going validation study already brought supplementary results to fine-tune the encoding methodological process.

The encoding methodology showed its usefulness on several cases, where a consensus was found for the final codification and for the report analysis. The step by step/iterative approach greatly contributes to its

practical use as a tangible support for teamwork. It gives a clear visual understanding of the accident sequence and the associated causes. Investigators have a different knowledge of the extended ADREP 2000 taxonomy. It introduces variability in some codifications and highlights the need for training on the events, descriptive and human factors to share a common understanding of the ADREP definitions.

In the long run, if everybody shares the same concepts, definitions, tools and methods, future prevention measures could be based on standardized and validated results from different countries.

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