Towards More Integrated Safety Management Tools for Airlines

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Abstract

This article describes a new methodology allowing a combined exploration of experience feedback databases. Based on a small set of data provided by an airline, the study demonstrates the feasibility and the benefit for safety management of this new approach which highlights links between human factor components revealed by crew reports and operational deviations detected through digital flight data. Such a new understanding of the insight of the operations could have a major impact on safety management and contribute to the proactive safety management culture that many airlines try to promote.

1. Introduction

1.1 Applicative challenge

Safety has always been a significant challenge for aeronautical activities. For many years, dedicated experience feedback tools have been developed and implemented by airlines to assess their operational risks. Nevertheless, the last decade shows up a turn of the safety management culture. Worldwide, major's aviation actors are moving from a safety management based primarily on reacting to the last accident or incident to a proactive approach of safety that relies on identification and alleviation of life-threatening conditions and events [1].

This cultural shift leads the aeronautic actors to develop technologies and methodologies to accurately identify plausible accident precursors from normal operational experience ([2], [3]). Improvements have been made in collecting and analysing operational data acquired through several experience feedback channels that may encompass crew reports as well as in flight recorded digital parameters. These evolutions have been accompanied by fundamental changes in the understanding of human errors and their implication in aviation safety ([4], [5]) and also by recommendations in the organisation of safety management in airlines (e.g. [6]).

Nowadays, large commercial airlines store huge amounts of operational data. Each type of experience feedback tool provides a specific point of view on the operational reality. These databases contain many information to improve safety, but the main challenge remains to mine these databases and find these relevant cues before they are revealed by a major incident. Some on-going researches concentrated on the search of atypical situations through digital flight data ([7], [8]) while others focused on the classification of flight crew reports or incident reports [9]. In both case, the challenge is to discover the precursors of the next accident, or in other words to pinpoint new unknown risky situations encountered in operations before they are revealed by a major aeronautic event.

In most of the airlines, the routine operation and the crew reports are both observed and analyzed through distinct channels that produce statistics and trends. Then, the results of these analyzes are combined to acquire a global view of the operations. A major breakthrough could be reached by developing methodologies and tools that better reflect the links between objective elements revealed by aircraft flight data recorders and explanatory elements (operational conditions, threats, errors…) captured by reports. The challenge is to build a more comprehensive view of the operational context by integrating coordinated and heterogeneous data sources (digital in flight data, reports, demographic, weather…). This new type of analysis could impact the understanding of the operational reality and contribute to manage safety.

The aim of the study reported in this paper was to demonstrate the feasibility of such combined analysis on a case study. The work relies on a limited set of flights provided by a commercial airline and uses the Formal Concept Analysis theory which is presented in the next section.

1.2 Theoretical background: the Formal Concept Analysis theory

Formal Concept Analysis (FCA) is a mathematical theory of data analysis. Let us have an intuitive description of this unsupervised machine learning technique. The approach takes as input a representation of the database by a matrix (called the context) specifying a set of objects and their properties (called attributes). Then it generates all the concepts that "make sense" for the given database. A concept is a pair containing both a cluster of objects and a cluster of attributes, these two clusters verifying the following properties: the objects of the concept share exactly the attributes of the concept (and no more) and no other object in the database holds all these attributes.

Let us for example consider the context represented by the following table. It contains four objects and four attributes, the first objects (Obj_1) is described by the three attributes (A_1, A_2 and A_4).

Table 1: Example of context represented by a binary matrix

	A_1	A_2	A_3	A_4
Obj_1	X	X		X
Obj_2		X	X	
Obj_3			X	
Obj_4		X		X

With this context, the pair ({Obj_1,Obj2,Obj_4} , {A_2}) is a concept because these three objects share only the attribute A_2 and A_2 belongs only to these three objects in the matrix. The set of all the concepts derivable from the input matrix can be partially ordered and equipped with meet and join inner operators so as to get a mathematical lattice structure which can be represented as a Hasse diagram. As an example, the lattice structure containing the seven concepts issued from the context of Table 1 is displayed on the Figure 1.

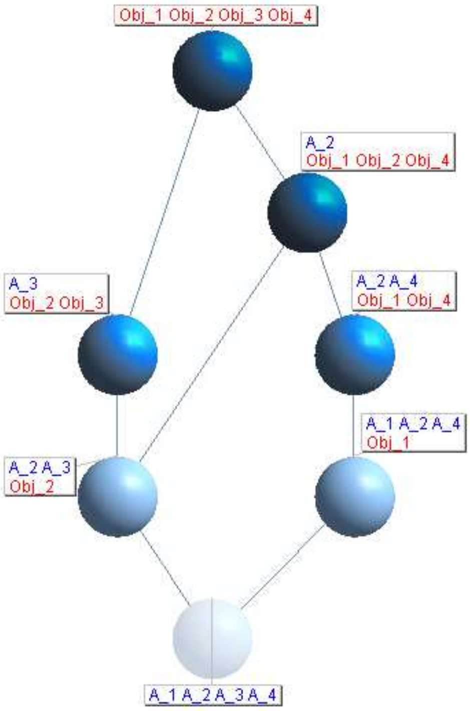

Figure 1: Hasse diagram generated by the Lattice Miner tool [13]

An extended presentation of this methodology (also called “Galois Lattices”) with all the mathematical definitions can be found in [10]. Several tools, often open sourced, implement this theory ([11], [12], [13]) and allow to calculate and sometime to display the set of concepts. Among them, Kontex, developed by ONERA, offers a graphical interface to investigate the content of each node of the lattice structure, to select and display sub-lattices.

Based on previous studies conducted by ONERA ([9], [14]) the FCA theory and the Kontex tool have been selected. The main advantages of FCA for our study are:

- The unsupervised clustering process: no expertise or knowledge about what is looking for is required;
- The lattice structure that allows extracting sub-lattices and studying sub-parts of the data: several point of view on the data can easily be exploited;
- The format of the context (two dimensional table) that allow merging data from different sources;
- The adequacy for small set of data (qualitative data mining);
- The capability of generating contextual rules proved by an inductive methodology;
- The availability of open source dedicated software.

1.3. Structure of the paper

This paper describes a methodology dedicated to combine and jointly mine several sources of data. It has been applied on a small set of commercial flights for which both digital flight parameters and crew reports were available. The article reports the results of this case study, evaluates the feasibility and the benefit of such a new type of analysis for airlines safety department.

Section 2 describes the data available and the principle of the analysis methodology. Section 3 presents the tools used to analyse and store digital flight data and crew reports. Section 4 discusses codification and analyses issues. It points out that several knowledge representation choices are possible and we analyse how they impact the elements highlighted by the analysis process. Then, the choices made to extract and codify relevant elements from the two heterogeneous sources of data are described.

Finally, section 5 presents the results of the study which demonstrates that meaningful correlations between operational markers (such as crew performances) and objective performances (speed events or alignment events) can be discovered by this new type of analysis.

2. Available data and principle of the combined analysis

2.1 Context

The aim of this study is to demonstrate that a combined analysis of digital data recorded during the flight and crew reports could help the airline to better manage flight safety. The work relies on a limited set of flights for which the airline provided both digital flight data recorded in the aircraft and crew reports. Digital flight data give an objective view of what really occurs during flights through the evolution of flight parameters (speed, track of the aircraft, aircraft configuration…) while crew reports describe threats, errors and other more explicative elements (traffic conditions, weather, air traffic controller clearances, passengers issues…) which shape the crew activity. So, these two sources of information are complementary, the digital flight data highlighting what happened during the flight while crew reports reveals more subjective human factor related clues allowing to assess why some deviations occurred.
These two experience feedback channels exist in most airlines but are operated separately. The originality of this study is to feed the data analysis tool with elements providing from both data sources in a way that allows to look for correlations between information produced by these two experience feedback channels.
Such combined analyses are not realized by airlines because firstly their digital flight data system and their reporting system are two separated tools which do not allow to make the link between the data and secondly there is a lack in methodology and tools available in their safety department to conduct an analysis on two different types of data (numerical and textual).

2.2 Available data

This study has been conducted in cooperation with an airline which agrees to manually extract from their operational databases crew reports and the corresponding digital flight data.

Collecting the crew reports is the most sensitive point as it requires the involvement of pilots. In this airline, pilots were asked, over a limited period of time, to systematically report on each safety-compromising event which occurred while on duty. During a few months, these reports in free text have been extracted from the database. Thus a set of 21 relevant reports was produced and sent to ONERA with a complete identification of the flight (date, flight number, departure and arrival airports).

In the same time, the safety department of this airline systematically extracts and analyzes the digital flight data for all the flights. The analysis is made with the tool of the company (AirFASE®[1]) which detects prescribed deviations (called events) and feed a large database. The airline safety officer is in charge to check the operational validity of the events detected by the tool and exploits the database to manage safety. For this study, the safety officer extracted from the database all the events related to the 21 flights and sent them to ONERA with a complete identification of the flight (date, flight number).

The data collection has been achieved with a unique fleet of Airbus's aircraft on a single city pair, over a few months. As only a small portion of flight encountered safety-compromising events, the set of available flights was reduced to 21 flights. This small set is not representative of the amount of data the airline should deal with if applying the methodology to all the fleets on all the destinations but is sufficient to demonstrate the feasibility and the interest of the target analysis.

2.3 Principle of the combined analysis

As stated in the previous section, a set of 21 flights were available with two types of data for each flight. On one hand, the events produced with AirFASE from the flight parameters. On the other hand, the crew reports, in free text. These ones were codified with an Airbus dedicated tool (LOAS® which is described in section 3.2) by Airbus personnel as this tool was not used yet by the Airline. This process produced keywords associated to each report. So, each flight is described by a set of AirFASE's events and a set of LOAS's keywords.

Then, the aim of the combined analysis is to highlight links that may exist in the database between AirFASE's events and LOAS's keywords. For doing this, the Kontext tool was used. As described in section 1.2, it is an unsupervised clustering tool based on the Formal Concept Analysis theory. The principle of this analysis methodology is displayed on Figure 1.

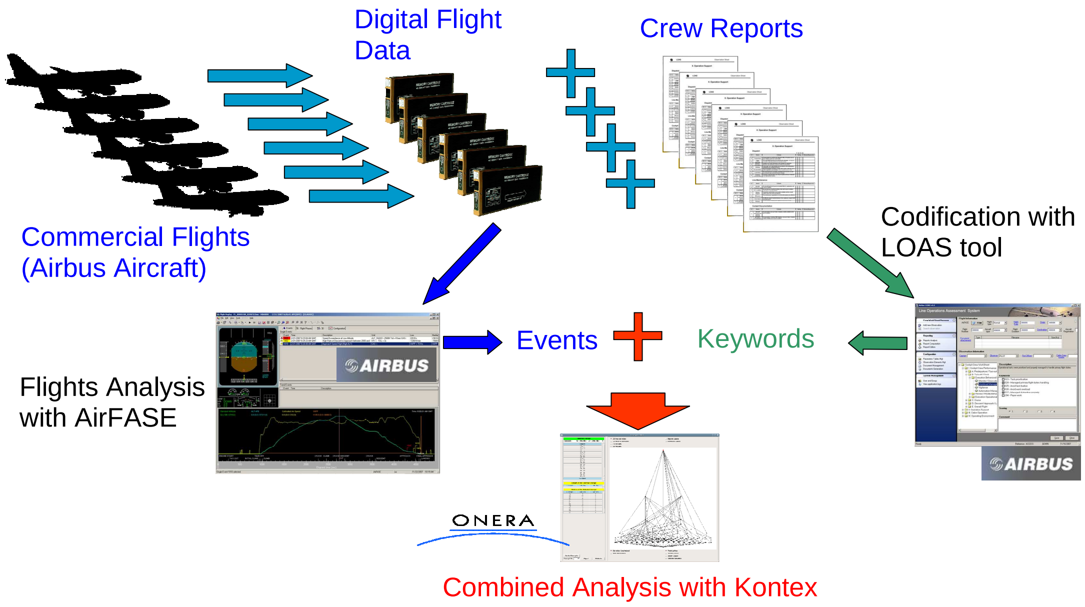

Figure 2: Principle of the combined analysis

3. Description of the used tools

The work has been achieved with the use of three tools: AirFASE for the analysis of the digital flight data, LOAS for the codification of crew reports and Kontex for the analysis of the data. We will now make a brief introduction to the two first tools.

[1] AirFASE®: Aircraft Flight Analysis and Safety Explorer is a measurement, analysis and reporting software tool developed jointly by Teledyne and Airbus.

3.1 AirFASE

AirFASE (Aircraft Flight Analysis and Safety Explorer) is a measurement, analysis and reporting software tool developed jointly by Teledyne and Airbus, which deals with in-flight operational performance of commercial aircraft. This tool, routinely used by over 100 airlines, offers a stable definition of deviations and is used by the airline involved in this study. After the flight, the recorded flight data are inserted in this tool which first analyses the flight parameters, detects deviations from the airline regular profile and then insert the results of the analysis in the airline database. Figure 3 displays the result of a flight analysis where two low severity events (#1010 and #1402) were detected as well as a high severity event (#1005). With this tool the safety officer can quickly access to all the aircraft parameters during the flight and expertise flights with high severity deviations.

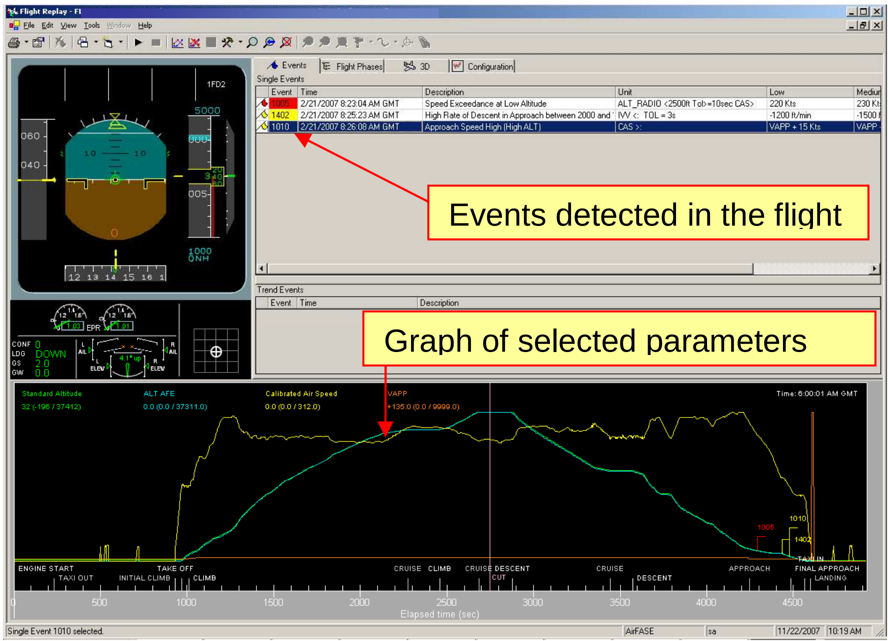

Figure 3: Flight analysis with AirFASE

Within the airline, all the flights are analyzed by the safety department and the high severity deviations are operationally validated. Then, an objective view on the flight operations is build through statistical results on the database. This approach is well dedicated to manage known safety issues.

3.2 LOAS

LOAS (Line Operations Assessment System) is an application dedicated to collect, analyze and archive the observations performed in the scope of the airline flight monitoring program. The tool relies on a codification system which allows to describe elements issued from a narrative with keywords from a structured taxonomy. Figure 4 shows the interface of the tool. The chapters are used to navigate in the taxonomy and access the relevant keywords. Once tagged, a score describing a level of severity can be added to the keywords.

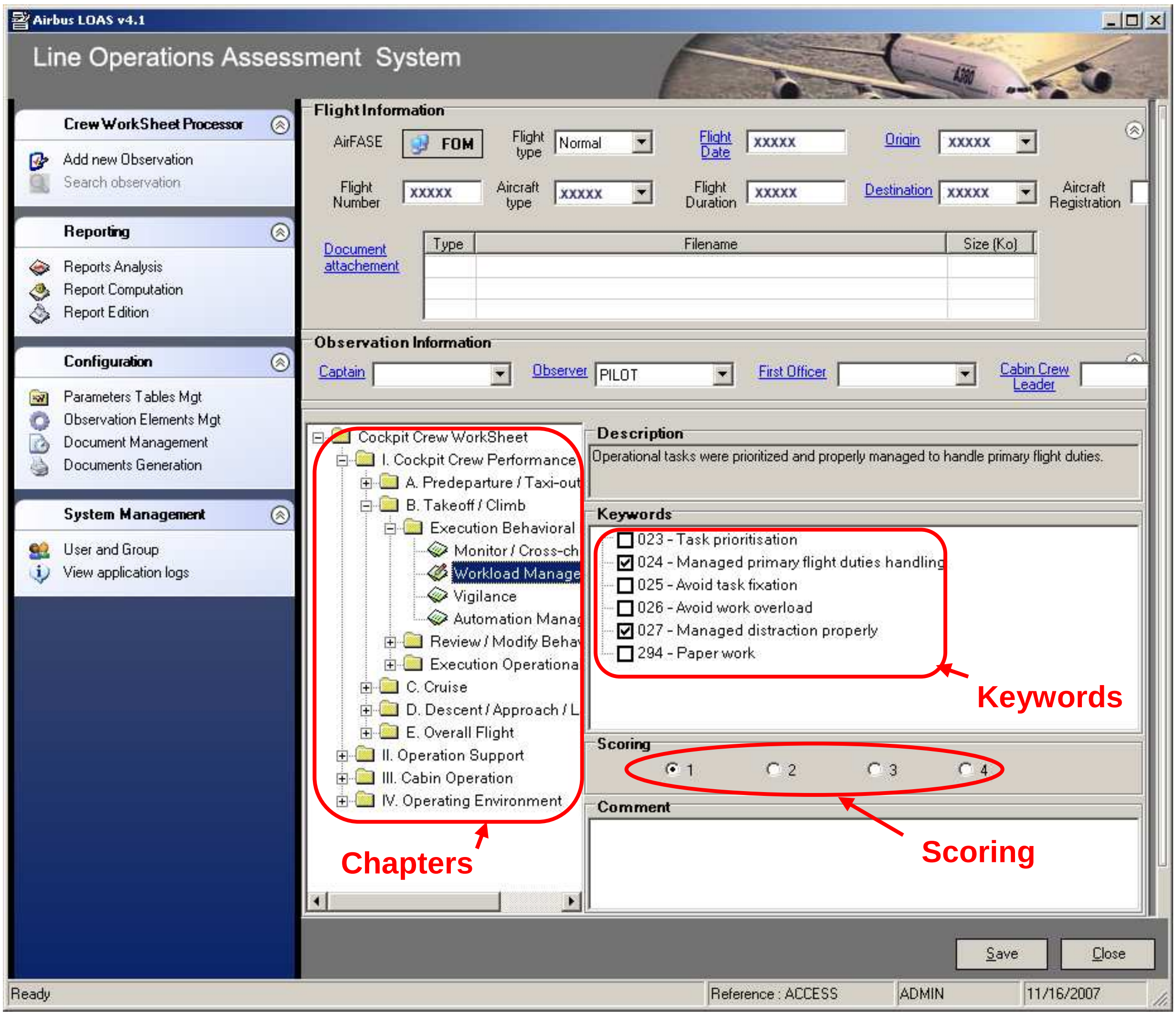

Figure 4: Report codification with LOAS

Then the codified report is inserted in the airline database and statistical analyses can be conducted in order to help the safety department to better manage safety issues encountered in operations.

4. Data codification and generation of the analysis context

4.1 Crew reports codification

Crew reports are reduced to a paper narrative in natural language. A dedicated sheet was given to the participating crew members and was filled after each flight where safety-compromising events had been encountered. Crews were asked to report more specifically threats[2] and errors[3] and to clearly explain what happened, and how and why it occurred. The reports collected were sent by the airline to the Airbus Training team which was in charge of analyzing, codifying and inserting them in the LOAS tool. After that step, each report was described by a set of keywords from the LOAS taxonomy with scoring numbers (1 to 4).

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[2] Threat: An event originating outside the influence of the crew which requires active management to maintain safety. Such an event may increase error potential or become the precursor of an error chain.

[3] Error : an undesirable action or inaction by a member of flight crew which has the potential to compromise the safety of the flight.

Then, the challenge is to build a context dedicated to the Formal Concept Analysis methodology, in which reports are described by attributes derived from the LOAS taxonomy. Several choices were possible. As demonstrated in [15], all information contained in the taxonomy can be captured by the FCA context if attributes are associated to elements of all the levels in the taxonomy: each chapter in the taxonomy and each keyword are represented by distinct attributes in the FCA context.

Nevertheless, such a choice is not always the more efficient for a first analysis of the data: elements from the higher levels of the taxonomy are often too general descriptors while the lower levels can be too selective. The choice of the good granularity for the description of the reports relies both on the number of reports to analyze and their relative diversity.

For the data supporting this study, the more adapted context was finally built by using only the chapters' information. The associated lattice structure reveals that in these 21 flights, 6 can be considered as exceptions (they do not group with other flights) while the 15 other flights can be clustered in 3 well separated classes as shown on Figure 5.

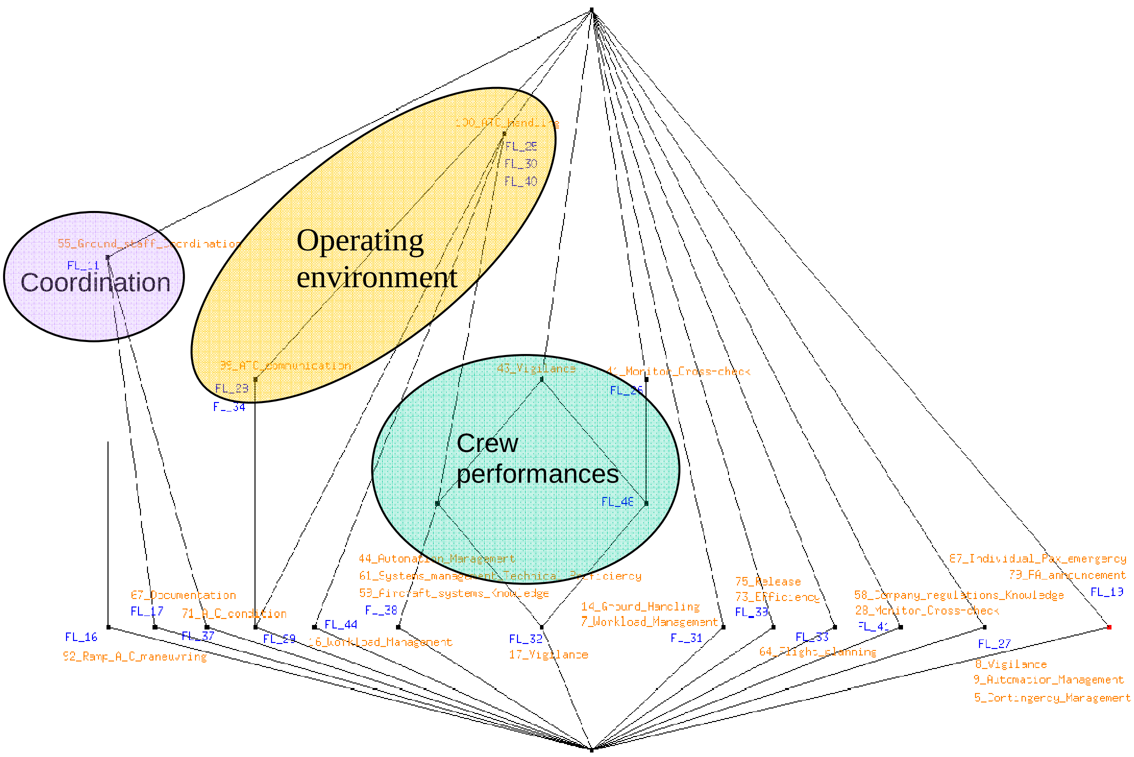


Figure 5: FCA Lattice structure for LOAS attributes

The relevant level of description for the LOAS markers being determined, let us now focus on the AirFASE events codification.

4.2 AirFASE events codification

Each flight is analyzed with AirFASE in order to find prescribed deviations. This process allows us to describe each flight as a set of events (the deviations found) with their respective level of severity (1 to 3). Once again, different options are possible so as to derive a FCA context from these events. The best choice mostly depends on the data available. Here are some possible options:

- Each type of event is associated to an attribute, the severity level is not codified;
- The use of a first order logic codification: Event(severity) is used and then the equivalent FCA context is derived according to [15];
- Only severity 3 events are kept as often airlines concentrate their analysis on this class of events;

- Classes of events are defined and used as attributes.

As we only have a limited number of flights for this study, the more adapted codification system was the one based on classes of events in order to define more general attributes. Such classes can be defined easily using the AirFASE identification of the events [16]. Indeed, the 2 first digits of the event reference number indicate the type of the event with the following meaning :

10: speed events
11: pitch events
12: roll events
13: height events
14: vertical rates events
15: acceleration events
16: configuration events
17: thrust events
18: alignment events
19: warning events
20 and 22: Level 2 : risk detection events

Hence, we decided to use these classes of events for defining the attributes of the flights. The lattice structure generated by the new FCA context becomes:

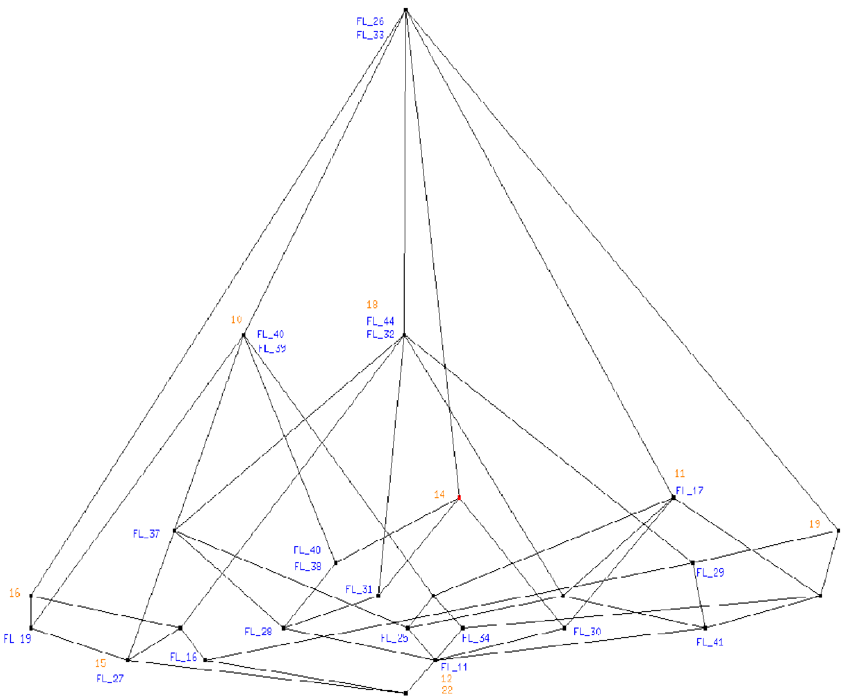


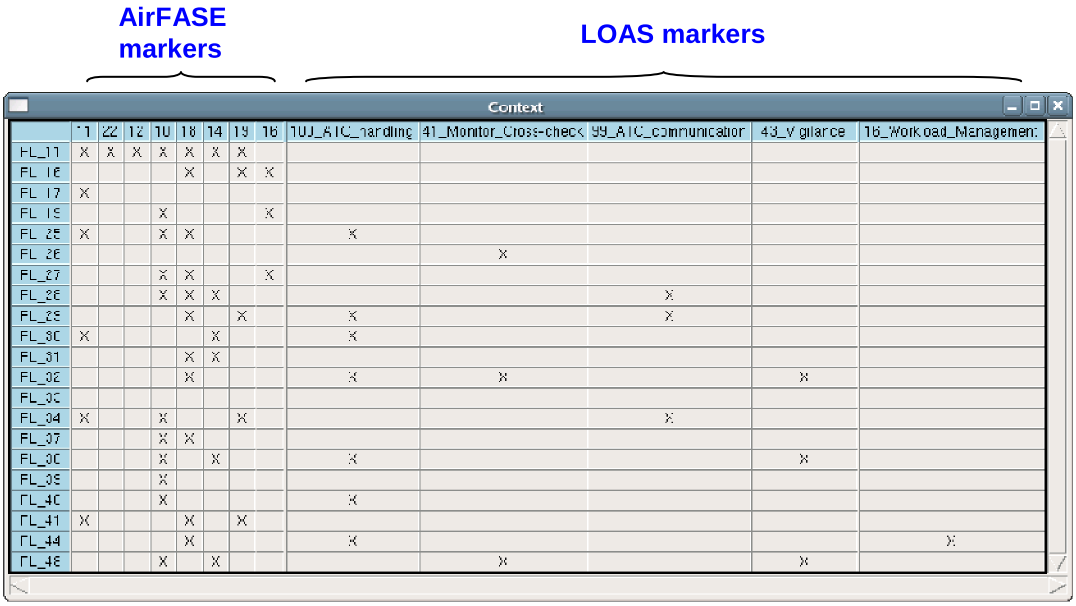
Figure 6: FCA Lattice structure for AirFASE events

It indicates that classes of events #10 (speed events) and #18 (alignment events) are the ones which generate the bigger clusters.

We can now combine the LOAS attributes and these AirFASE attributes in order to build and analyze the complete context.

4.3 Building the FCA context for the combined analysis

The FCA context used for the global analysis has to combine in a single binary matrix the information provided by the two experience feedback channels. This step is easily done by joining the attributes describing LOAS reports with the ones describing AirFASE events in a single FCA context. Figure 7 displays one part of this context (some of the LOAS markers are missing in the table for lack of place).



	11	22	12	10	18	14	19	16	100_ATC_handling	41_Monitor_Cross-check	99_ATC_communication	43_Vigilance	16_Workload_Managemen
FL_11	X	X	X	X	X	X	X						
FL_16					X		X	X					
FL_17	X												
FL_19				X				X					
FL_25	X			X	X				X				
FL_26										X			
FL_27				X	X			X					
FL_28				X	X	X					X		
FL_29					X		X		X		X		
FL_30	X					X			X				
FL_31					X	X							
FL_32					X				X	X		X	
FL_33													
FL_34	X			X			X				X		
FL_37				X	X								
FL_38				X		X			X			X	
FL_39				X									
FL_40				X					X				
FL_41	X				X		X						
FL_44					X				X				X
FL_48				X		X				X		X	

Figure 7: Excerpts from the global FCA context for the combined analysis

So, the methodology used to build the context underlying the combined analysis is based on a two steps process: (1) for each experience feedback channel, select the relevant attributes that characterize the flights, and (2) join the attributes of each channel in a single binary table. This process can be applied to a large number of data sources and allows to merge all the descriptions. For instance, one could add information extracted from a weather database in order to study the impact of weather conditions on the flight safety.

5. Results of the combined analysis

Based on the context given by the binary matrix, the lattice structure is processed (see Figure 8). The graphical representation of the lattice which shows all the clusters of flights that are generated by the unsupervised analysis method is going to guide the exploitation of the results. In the Figure 8, the level of the concept in the graph is directly linked to the number of flights it contains.

Firstly, the graph highlights two concepts that appear to be higher in the lattice structure. These two concepts allow identifying attributes that generate big clusters of flights. In our case, these two attributes are "Speed events" and "Alignment events". So both of them come from the digital flight data analysis and describe type of deviations. For these two attributes, we will now search if we have some links with other attributes by studying the associated sub-lattice (section 5.1).

Second, the graph points out one flight which cannot be clustered with other flights (FL_33 on Figure 8). This flight is atypical in the database and will be studied separately. In our case, a crew report has been generated because of flight planning issues that disturbed the preparation of the flight by the crew. Nevertheless, at least for this flight, there were no direct impact on the prescribed deviations.

Third, the lattice structure allows to identify a flight that can be clustered with nearly all the other flights (FL_11 on Figure 8). This flight will also be studied separately (section 5.3).

Finally, the lattice structure will allow to find clusters related to the three main attributes identified in section 4.1 and evaluate if there are correlations between these human behavioural attributes and prescribed deviations (section 5.2).

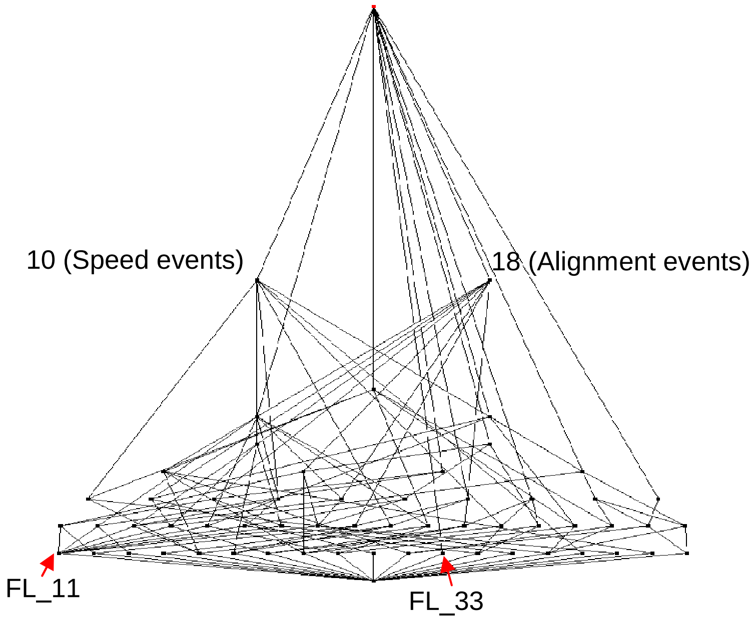


Figure 8: Lattice structure for the combined analysis

5.1 Study of the main clusters of flights

Let us focus now on the two higher nodes below the top of the graph. They identify the two more general attributes in the lattice which are in this case AirFASE's classes of events (speed events and alignment events). So "speed events" and "alignment events" are the two main classes of events that emerge in this database. We will now look at these two clusters in order to determine if these types of events are linked to the occurrence of other attributes.

Speed events:

If we select and display only the speed event node and its children nodes (Figure 9), we find that this class of event is mainly related to alignment and pitch events (the higher children nodes). The first two LOAS attributes in this sub-lattice are the two related to ATC (90_ATC_communication and 100_ATC_Handling).

Thus speed and alignment events are often correlated, pitch events are also correlated to speed events but usually to a lower level. The issues related to the air traffic controller (ATC), which are revealed by LOAS attributes, seem to be one cause of the occurrence of speed events.

Alignment events :

The alignments events are mainly correlated to speed events, which is the higher children node, and to ATC_Handling issues.

So the study of the two concepts that cluster most of the flights demonstrate that one cause of the more usual deviations is linked to the interaction between the crew and the air traffic controller.

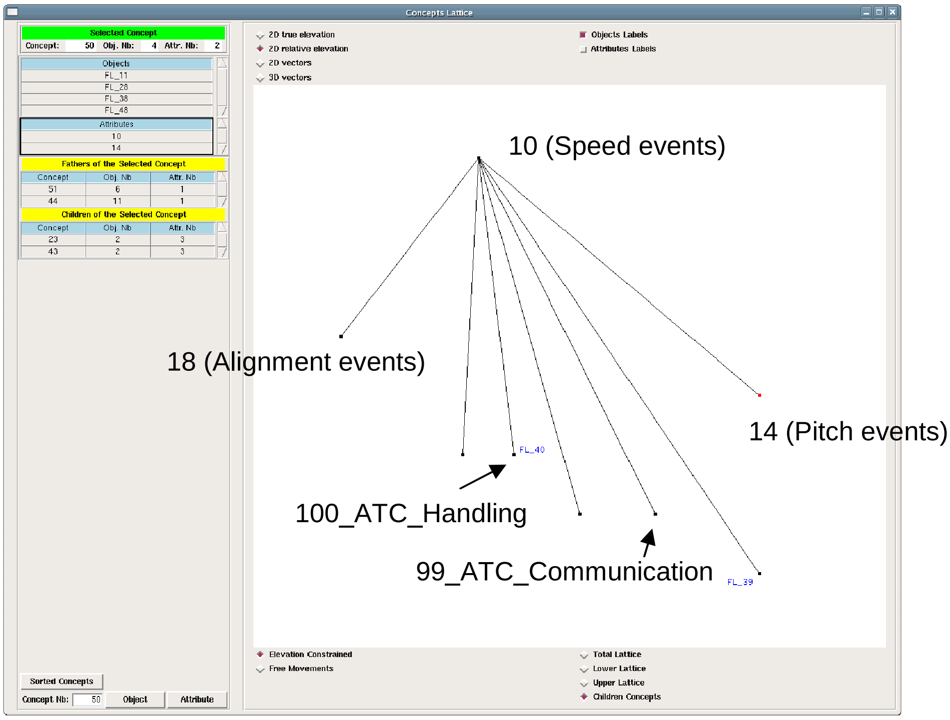


Figure 9: The speed events node and its children nodes

5.2 Study of the main LOAS markers

Let us now have a look on the three main type of LOAS issues found previously (Coordination, Operating environment, Crew performances). If we extract the sub-lattice dealing with ATC handling issues (Figure 10), we can see that the two higher nodes are the AirFASE's classes #10 and #18. So ATC handling issues mainly infer alignment and speed events. This result is coherent with the one found in section 5.1.

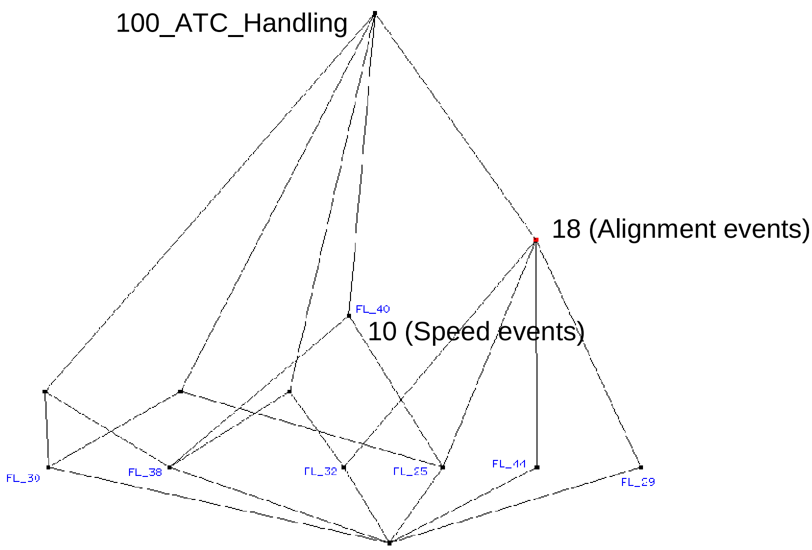


Figure 10: Sub-lattice for ATC_Handling node

The sub-lattice of the 43_Vigilance attribute (Crew performance issue in LOAS) shows that it could infer the co-occurrence of speed and vertical rates events (the two events appear on the same node, Figure 11). These two classes of AirFASE's events seem to be more correlated when a vigilance problem is reported than otherwise.

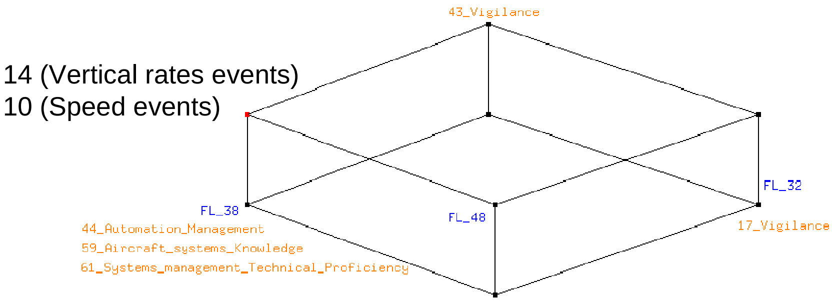


Figure 11: Sub-lattice for Vigilance node

The results of the analysis for the three groups of LOAS markers can be summarized as follow:

Crew performances (Vigilance, Cross-check) are more linked to:
- Speed events
- Vertical rates events
- Co-occurrence of these 2 types of events

Operating environment (ATC) are more linked to:
- Alignment events,
- Speed events

Coordination (ground) are more linked to:
- Alignment events,
- Pitch events

The results related to the Crew performances and the Operating environment clusters make sense for an operational point of view. On a bigger set of data, it could be interesting to make the analysis by phase of flight in order to see if we have a time connection between these LOAS and AirFASE attributes.

The third result is primarily more difficult to interpret. Why coordination problems on the ground (for these flights at the beginning of the flight) can have consequences on pitch values or alignment events? Of course, this analysis, based on a small set of data, can only give some clues on this issue. We will just have a look on the flight #11 which belongs to this group in the following section.

5.3 Study of a specific flight

The flight #11 was identified in section 5 as a special one in this database because it belongs to many concepts. Let us have a look of both the LOAS and AirFASE descriptions of this flight.

Summary of the LOAS report: The crew had to return to stand to offload 6 irate passengers and wait 30 minutes to get someone on board to handle the situation.

Summary of AirFASE events: “bad” approach and landing phase with 9 events: 3 of high severity level, 2 of medium severity level .

This flight is the one with the more severe deviations on the AirFASE data, but also one with a severe stressing and unusual situation for the crew at the beginning of the flight. Maybe the “bad” approach and landing can be considered as a consequence of the initial situation?

This example flight emphasizes the fact that such a global analysis can reveal unsuspected relationships between events and it highlights situations were the safety can be involved. A analysis of the LOAS report alone will allow to identify the airline organisation issues but will not reveal the real impact on safety and all the consequences of such a situation. The analysis of AirFASE events alone will not allow to go back to the origin of the safety problem. Of course, due to the limited set of data from which these results are extracted, one must be very careful with their generalization and a larger study should be made to obtain more reliable results.

6. Conclusions

This study proposes a methodology and tools to combine data provided by different experience feedback channels and acquire a more global understanding of the safety issues for aeronautical operations. It demonstrates the feasibility, on a reduced set of flights, of a combined analysis of crew reports and safety events extracted from digital flight data. The results showed that some events reported by crews may have immediate impacts on deviations detected by the FOQA program while others have indirect but severe consequences on the flight safety. The study shows that this new methodology allows to highlight links between human factors component (revealed by crew reports) and objective operational deviations. These links remains hidden when the available experience feedback are mined separately. Also, such a combined analysis could help the airline safety department to get a better understanding and measurement of the consequences of the threats encountered and managed by the crews.

With the increase of data stored in airlines, it becomes of prime necessity to improve the safety management tools available. The way opened by this work relies on the building of a better view of the operational reality by a combined exploitation of several experience feedback channels. The development of more integrated suite of safety management tools should help the emergence of this combined analysis in industrial software. Other complementary data mining methodologies, such as the statistical research of atypicalities [17], or automatic analysis and classification of reports [18], are also under studies. The complementarities of all these new approaches should allow the airline to make a new step for a more proactive management of safety.

Acknowledgments

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