An Improved System Safety Analysis Method Based on Accimap

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***Abstract*—As a systems-based technique for accident analysis, Accimap involves the construction of a multi-layered diagram in which the various causes of an accident are arranged according to their causal remoteness from the outcome. Though there is systematic research and development for this technique, Accimap is inadequate in terms of the contributory factors identified. This paper presents a modified Accimap by integrating a representative second generation human reliability analysis method(CREAM: Cognitive Reliability and Error Analysis Method) into the traditional Accimap, using the methodology of trace analysis. This paper applies the modified method to analyse the Black Hawk Fratricide Incident from a more comprehensive view of the accident and also for the effectiveness and validation of the method.Within the innovative views of the contributory factors in hierarchy such as the planning, management, and regulatory bodies, the modified Accimap will be more advisable to be used for analyzing accidents in the complex social-technical system.**

***Keywords*-Accimap; System Safety; CREAM; casual factors.**

I. Introduction

A. The Accimap Approach

The Accimap approach was developed by Rasmussen as a means of modeling this socio-technical context to identify the combination of events and decisions that produced an accident. Accimap analyses typically focus on failures across the following six organizational levels: government policy and budgeting; regulatory bodies and associations; local area government planning and budgeting (including company management) technical and operational management; physical processes and actor activities; and equipment and surroundings [1]. For Rasmussen, the Accimap is part of a broader proactive risk management process for generalizing from multiple accidents to devise risk management strategies [2]. The approach has also been used as an independent accident analysis technique in a variety of domains, including aviation, rail, public health, and gas production.

However, the traditional Accimap structure can be problematic. Firstly, the contributory factors in each hierarchy are not comprehensive enough. For example, the physical processes and actor activities level does not specifically deal with failures in cognition of behalf of those involved; rather, flawed decisions are normally represented at this level without necessarily identifying the factors influencing them, such as poor situation awareness or operator mindset of the Accimap. Secondly, since the analysis is entirely dependent upon analyst subjective judgement, the reliability of the method is likely to be limited. Differences in the actual failures identified, the way in which the failures are described, and the level at which they are placed, are likely to emerge across different analysts. A reference is needed to be developed to support identifying the factors in levels of Accimap.

B. CREAM Analysis

Cognitive Reliability and Error Analysis Method (CREAM) is a representative second generation human reliability analysis method. The second generation of HRA method is a method of dynamic reliability analysis, with no strict boundaries and definitions. In general, they also belong to qualitative reliability analysis model, and they more emphasize on explaining human behaviors based on the wholeness of human-computer interaction, as well as the action of the influence of psychological process and environment.

Eric Hollnagel put forward the CREAM method [3] in 1998. It has the following two main features:

- Emphasize the importance of scenario environment for people. This method will be summed up as environment factors, such as performance condition (common performance condition, CPC)
- Present unique cognitive models and frameworks, with functions of two-way analysis of trace and predict. The method not only can trace people mistakenly incident to root cause, but also can give prediction of error probability.

Based on the guidelines for standardized Accimap analysis [4], this paper focuses on enlarging and modifying contributory factors classification for traditional Accimap. The CPC analysis from CREAM contributes to the improvement of analysis in level of technical and operational management and level of company management in an Accimap. The trace analysis from CREAM is used for specially analyzing the level of physical processes and actor activities. A case study applied with the modified Accimap is shown in this paper to verify the technique and to recognize its advantages and disadvantages.

II. The Modified Accimap

The fifth level of Accimap defined as physical processes and actor activities activities mainly includes events directly related with people. And analysis of this level stresses much on the human error. As to CREAM, events of the people are often not just the wrong personnel actions, while the mistake cognition and judgment of surroundings

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as well as wrong decision forced by a specific environment are also included.

The CREAM method emphasizes that the performances of people in activities are not isolated behaviors, but depending on the surroundings and work conditions(Context)when a person completes a task. The context affects mainly on the person's cognitive control mode and its effect in the different cognitive activities, thus finally give birth to the response behaviors of people. The CREAM method concludes the influence factors into nine categories. Each category means a CPC factor, while each factor has different levels which can produce different influences to the person's performance. This principle of extracting casual factors in an accident from a management level suits much for analysis when using Accimap.

Based on the statements above, this paper puts forward a modified Accimap by adopting principles in CREAM analysis. In this modified Accimap, there are two main changes from the traditional Accimap:

- In Level 3 & Level 4, there is a part of CPC analysis of CREAM to assist getting the organizational and operational factors of the accident. This part is tagged with gray blank in Figure 1.
- In Level 5, this paper divides the factors according to different actors. Each actor needs a trace analysis just as presented in the darker blank in Figure 1.

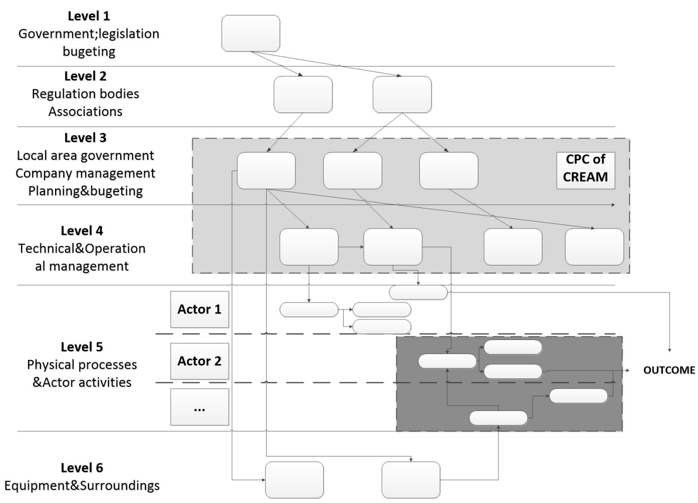

Figure 1. Framework of the modified Accimap

Based on the guidelines for the standardised Accimap proposed by Branford in 2007 [6], this paper presents the adjusted guidelines for using the modified Accimap to analyze an accident.

Step 1: Create a blank AcciMap format on which to arrange the causes: separate the whiteboard or large sheet of paper into the four sections of the AcciMap, with the headings ofthe four levels on the left-hand side and horizontal lines separating each level.

Step 2: Identify the causal factors: on a separate page, make a list ofall causes in the accident data, that is, all factors for which you can say "had this been otherwise, the accident would (probably) not have occurred". If you are unsure as to whether or not a factor is a cause, include it in the list- it can always be eliminated at a later stage.

Step 3: When come to level 3 & 4 and 5,use the trace analysis of CREAM. The steps are showed in Figure 2.

Step 4: Complete CPC analysis and the Actors analysis, draw out of the initial structure of Accimap.

Step 5: Insert the causal links (rearrange the causes in the modified AcciMap so that the causes lie directly above their effects (whether the effects are in the same level or in the level(s) below). Check if the links are completed for each causal factor(each factor should have both income(s) and outcomes(s) in the picture).

Step 6: Go through all the factors and casual links from where the accident occur back to the highest level of Accimap and make sure that anyone reading the Accimap will have no difficulty in making sense of the sequence of events.

III. Case Study

In this paper, the modified Accimap is used for analyzing the Black Hawk Fratricide Incident. The information in the following sections is derived from the accident investigation report issued by the United General Accounting Office.

A. Accident Summary

In April 1991, the United Nations Security Council passed Resolution 688 that demanded that Iraq stop repressing the Kurds in northern Iraq and called on member nations to help meet the humanitarian needs of the region. An emergency relief effort was initiated, named Operation Provide Comfort. Military units from the United States and 12 other countries soon joined the effort as a coalition. The air forces of four coalition members, including the United States, began securing the area of northern Iraq above the 36th parallel, prohibiting Iraqi aircraft from flying north of that parallelłthe no-fly zone. The coalition also established a security zone for the Kurds, inside the no-fly zone, into which no Iraqi military could enter.

The U.S. Commander in Chief, Europe, directed the creation of a Combined Task Force with all coalition members. By September 1991, the Combined Task Force organization, headed by U.S. and Turkish co-commanders, included a Combined Task Force staff; a Combined Forces Air Component (CFAC); and a Military Coordination Center. The CFAC Commander exercised daily control of the Operation Provide Comfort flight mission through his Director of Operations (CFAC/DO), as well as a ground-based Mission Director at the Combined Task Force headquarters and an Airborne Command Element aboard the AWACS. The CFAC/DO was responsible for publishing guidance, including the Airspace Control Order, for conduct of Operation Provide Comfort missions. (The Airspace Control Order was a directive to all Operation Provide Comfort aircrews that provided rules and procedures governing Operation Provide Comfort flight operations.) The Military Coordination Center monitored conditions in the security zone and was supported by a U.S. Army helicopter detachment.

On the day of the incident, two Black Hawks and their crews were transporting officials inside the TAOR. Although the AWACS crew flying support for the days mission package were aware that the Black Hawks were in the area, the two F-15 pilots sanitizing the area were not aware of their presence. The F-15 pilots received two radar contacts (helicopters) and stated that they attempted unsuccessfully to identify them by electronic means. They twice reported their unsuccessful attempts to the AWACS but were not informed of the presence of the Black Hawks in the contact area. As required, the F-15 pilots attempted a visual identification of the helicopters. However, their attempt, involving a single pass each, was at speeds, altitudes, and distances at which it was unlikely that they would have detected the helicopters markings. This resulted in the lead Pilots misidentification of the helicopters as Iraqi Hinds and the subsequent shootdown of the Black Hawks.

B. CREAM CPCs of The accident

CPC(Common performance conditions) analysis is to use the limited factors and influence factors to adequately describe environmental conditions. According to the official accident investigation report, as well as some basic knowledge of aviation passenger transport, the accidents CPC results are shown in Table I.

Table I
CPC (Common performance conditions) analysis

CPC Name	Evaluation	Expectation effect of performance reliability
Organization	integrity	invalid Reduce
working conditions	Match	No significant
Integrity of the man-machine interface (MMI) and operation support	Temporary not fully	Reduce
availability of procedures/plan	Not appropriate	Reduce
number of targets	Match	No significant
On duty time zone	Daytime	No significant
The adequacy of training and experience	Temporary	not fully Reduce
Quality of team members cooperation	Bad effect	Reduce

According to assessment results of CPCs, the natural conditions outside of the flight are nearly normal. It is the organizational coordination and communication that affect the accident. Mainly reflected in these areas: low organizational integrity, inappropriate procedures and plan availability, inadequate training and experience, poor team members cooperation. According to the results, the detailed causal factors in Level 3 & Level 4 of Accimap which can be easily used for drawing the big picture of the accident are provided in Table II.

C. Tracing Analysis in Accimap

Firstly, this paper begins with an analysis on the error model of the two actors: F-15 actor and Black Hawk actor. The following table shows the wrong operation and the corresponding error model. Then this paper presents separately tracing analysis for both actors, which can be used directly in drawing part of the whole Accimap of the accident.

Table II
Accimap analysis based on CPC

CPC Name	Level	Cause factors	Detailed cause factors
Organization integrity	4	ACE Human Resources inadequate & insufficient	Entourage is not monitored
			No Black hawk control transfer
			En route controllers not timely and effective track and report black hawk flight path
			ACE term understand error
Integrity of man-machine interface & operation support	3	Human-computer interaction and operation support inadequate	Black hawk radar speed, IFF, keep as the original path
The adequacy of training and experience	3	Training inadequate & insufficient	Inadequate awacs simulation training
			Inadequate new shift ROE training
			Inadequate training in visual recognition
Availability of procedures/plan	3	Two versions of the ATO in air force and army	
		No helicopter transition process	
Quality of team members cooperation	4	Communication and Information	ASO and SD not timely and effective communication; Not complete tracking black hawk
			Entourage is not monitored
		Task & discipline not strict	

Table III
The Possible error model for accident actors

Actor	Faulty operation	Error mode
F-15 pilot	Took a black hawk helicopter as female deer and helicopter shot down in Iraq	Error (similar) target
Black hawk pilot	No change in both IFF code & frequency after entering into the no-fly zone	Time (missing)
	identification system not open	Time (missing)

1) F-15 Tracing: Given the trace analysis of F-15 pilots in the process of the whole event, we can know pilot error factors causing accidents mainly include the following points

- The pilot didn't get message about black hawk from superior, this means the transmission of information is inadequate between American army and air force;

- F-15 pilot made mistakes on both remote signal recognition and close visual recognition of the helicopter;
- Not in accordance with the provisions of ROE, no confirmation of hostile intentions before opening fire on the helicopter;
- No report to ACE before launching missiles;
- No waiting for wingman pilot's identity, no question to fuzzy response.

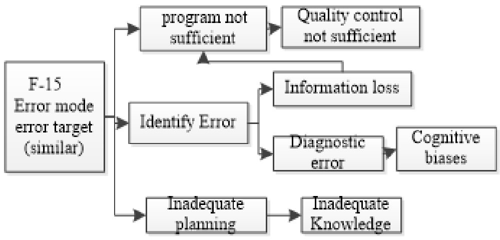

Figure 2. Tracing Analysis for F-15 actor

2) Black Hawk Tracing: For Black hawk, the pilot's error is one of factors leading to the accident:

- Black hawk pilot did not change the IFF code: All friendly aircraft used code 42, and code in the no-fly zone was 52, which do not match the rules of the army and air force;
- No change to the frequency of the no-fly zones;
- Black hawk pilot for some reason closed IFF system.
- Entering the no-fly zone before Air force do the clearance.

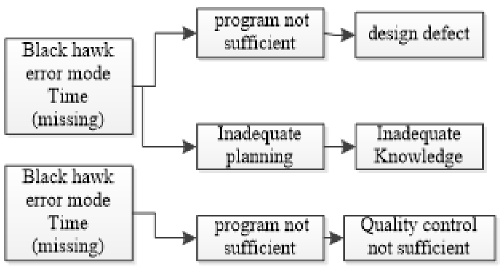

Figure 3. Tracing Analysis for Black Hawk actor

D. Explanation and discussion of the modified Accimap of Black Hawk Accident

After all the steps of drawing the big picture of the Black Hawk Accident, illustration of the final result as shown in Figure 4.

The flow of important boxes is elaborated by the text underneath.

- Level 1 and 2: The governmental policy linked with the accident includes the internationally accepted certifications and the regional aviation regulation.Both inadequate communication and enforcement contribute to the tragedy.
- Level 3 and 4: Based on the previous CPC analysis, this paper presents a better review. The authorities and companies linked with the accident include C-FAC and MCC, air traffic management(AWACS) and ground control operators, airlines, and so on.
- Level 5: In this part of modified Accimap, two direct actors are separately and clearly showed in the picture. The casual factors are extracted by the tracing analysis in last section.
- Level 6: Equipment and surroundings in this accident involve radar and IFF system and the mountain conditions.

The cause of the accident is likely to be technical system operator error (both the pilots and AWACS staff) if the specific events of the accident are only focused on. In fact, the air force research team, which is made up of more than 120 people, concluded that there are two key failures: Firstly, AWACS personnel did not provide accurate airspace images to F-15 pilot.Secondly, F-15 pilot mistook the friendly target for the enemy.

Apart from the four "errors omissions and failures" in the "chain" of accident summed by the defense minister according to the accident report, this paper presents a more comprehensive explanation including causal factors in each level of the social-technical system based on a modified Accimap:

- Both the regulations and its execution are not sufficient;
- Inconsistent and inaccurate information (ATO);
- Inadequate coordination and communication;
- Overlap control and cross section in responsibilities of staffs;
- Lack of monitoring when performing adjustment of the process;
- Inadequate training in higher levels of the system.

All these results differed from the report comes from the modified levels in Accimap, ranging from the direct actors such as F-15 pilots to the operational and company management including superior staffs.

IV. Conclusion

This paper presents a more comprehensive Accimap by adopting principles of a HRA method. Compared with the traditional standardised Accimap, this modified method reorganized the level of physical processes and actor activities in a more clear and detailed way, and it also makes some enrichment in casual factors in level of management. The application of Black Hawk Incident highlighted the capacity of this modified method to incorporate factors stemming both from level of management and level of direct actors in an accident.This paper verifies the method and discovers more details than the accident report through the application. This modified Accimap is more suitable for accidents involving several actors and more caused by human factors.

Some limits of this paper and further research are presented as these: 1)The 9 CPCs in CREAM cannot completely describe the casual factors in management level of Accimap. Further research can be combined with other methods (HFACS, etc.) for the cause analysis of

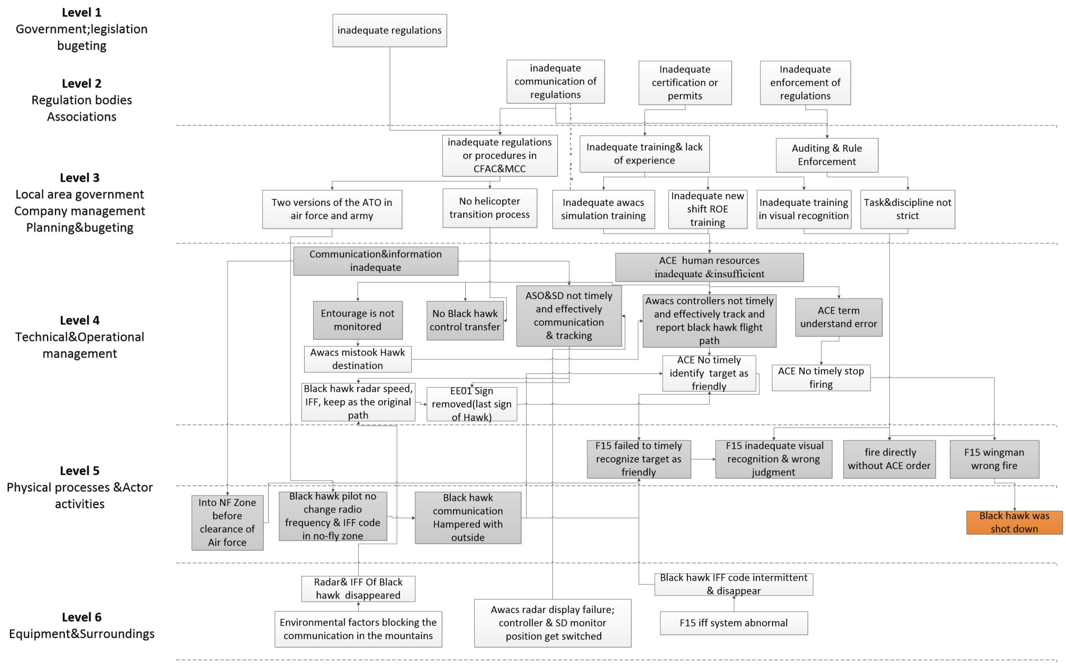

Figure 4. Modified Accimap of Black Hawk

hierarchy. 2)There still remains problem of subjectivity when doing tracing analysis in the modified Accimap, and results may range in a certain degree. Therefore an adoption of traditional fault tree principles can be considered. 3) The standardization of the modified Accimap analysis steps and related application instructions need to be strengthened.

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