

# Towards a classification of state misinterpretation

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## Abstract

Eradicating human error from complex systems is widely accepted as an unattainable goal, since failures in some critical actions, such as state interpretation, can be difficult to detect. State interpretation relies on the operator's perceived state of the system, which depends on: knowing which elements define the system state; accessing all those elements; and correctly interpreting their values. Incident data show that in some cases pilots did not know all the defining variables (9.93% of reported incidents); did not access all these variables (43.4%); or did not interpret the values correctly (8.41%). For ATC operators the figures were 6.64%; 46.3%; and 6.11%. Combining the three factors yields eight possible types of perceived state. It appears that state misinterpretation occurs when the perceived state does not include all the state defining variables. Incident data show that state misinterpretation potentially occurred in 35.0% of reported pilot incidents, and 39.3% of ATC incidents.

## The problem of state misinterpretation

The eradication of erroneous actions—a term describing the manifestations of human error independent of any assumptions about the underlying cause (Hollnagel, 1991)—is widely accepted as an unattainable goal. Although error prevention remains important, it is not always possible. Operators therefore need to learn to manage errors, recognizing them when they arise, and dealing with them accordingly (Frese & Altman, 1989).

The failure to detect and mitigate the effects of an error in dynamic domains, such as aviation, chemical process control and nuclear power generation, can lead to near misses or accidents. These domains routinely employ complex systems, and the ability to cope with the different types of error depends on being able to identify and correctly interpret patterns of system behaviour.

Errors of state misinterpretation, where the operator believes the system state is normal when it is really abnormal, are accepted as having played a role in several major accidents, such as the TWA Flight 514 crash in 1974 (e.g. Reynard, Billings, Cheaney, & Hardy, 1986), and the accident at Three Mile Island in 1979 (e.g. Perrow, 1984). State misinterpretation is difficult to manage because it does not have a readily identifiable unique set of characteristics. It is not one of the logical phenotypes of erroneous actions (Hollnagel, 1991), since it is not a directly observable action; nor is it what reliability analysis call a root cause either, since there may be several possible reasons for a particular instance of state misinterpretation.

The research described here is part of a wider investigation aimed at identifying where state misinterpretation fits in the chain of events which extends from root causes through to erroneous actions. Since state misinterpretation is, by definition, a failure in state interpretation, the first step is to characterize state interpretation. Then, by considering how the characteristics of state interpretation can vary, the different ways in which it may fail can be identified and appropriately classified. The classification can then be used to suggest potential causes of variation in state interpretation, and hence to propose possible ways of managing state misinterpretation.

### **State interpretation and the operator's perceived state**

Complex systems operators<sup>1</sup> perform supervisory control in an iterative manner, using the system state to determine which course of actions to perform (e.g. Kelley, 1968). The system under control can be represented by three different types of state which simultaneously coexist (Boy, 1987):

1. The real state.
2. The perceived state.
3. The desired or expected state.

The real state of the system consists of all the possible facts about the system and its environment. By definition it is infinite, and hence it cannot all

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<sup>1</sup> The term *operator* is used here to describe any person who operates a complex system, including aircraft pilots and air traffic controllers, unless otherwise specified.

be simultaneously accessed by the operator. It would be impossible to keep track of the values of each of the system's thousands of elements individually: the operator would have to continuously take readings of the system variables leaving little time to determine the overall system state and perform appropriate control actions. Complex systems are therefore generally controlled directly on the basis of the perceived state of the system, using a process that has been described as recognition primed decision making (Klein, 1997). Operators take readings of those system variables which define the current state, and synthesize the values to yield the perceived state of the system. This perceived state, which is essentially the result of state interpretation, will be optimally correct when the operator:

- knows which system variables define the current system state;
- accesses the values of all of these variables; and
- correctly interpret the values of these variables.

If the operator recognizes the perceived state as normal, or finds that it matches the expected system state, a set of actions which is consonant with the goal of the current task is executed. If there are discrepancies between the perceived and expected states, the operator analyzes the differences to determine the cause of the variance. When the problem has been diagnosed the operator acts to bring the system to a normal or safe state, as appropriate.

### **Data collection and analysis**

Collecting valid data is a general problem in human error research (Hollnagel, 1993). One solution, adopted here, is to make use of archive incident data. The incident database used here is the CD-ROM (DOS Version 97-2) of the NASA Aviation Safety Reporting System (ASRS) (Reynard, et al., 1986). The caveats of using such voluntary incident data are well documented (e.g. Chappell, 1994), and have been taken into account in interpreting the results.

Incidents in the ASRS database are classified using Federal Aviation Administration (1998) categorizations. The scope of the work presented here is restricted to incidents attributed to air traffic control personnel (FAA operator deviation and operator error categorizations), and incidents attributed to pilots (FAA pilot deviations). Although air traffic control and piloting an aircraft are both critical tasks in the aviation system, they are considered separately because of the different types of skills involved.

### **Search 1: Failures in factors determining the perceived state**

If the operator notices a failure in any of the three factors which determine the perceived state this should be reflected in the incident report. So, for example, a failure to access all the defining state variables might be described by the phrases "did not check", "failed to check" or "did not read".

For each of the three factors, a logical disjunction of textual phrases which could be used to report a failure in that factor was constructed. These sets of phrases were used to interrogate the ASRS database to find out how many incidents involved a reported failure for each of these factors.

#### *Search 1 results and discussion*

The results of the initial search of the ASRS database for reported failures in the individual factors that determine the perceived state are shown in Table 1. The figures show that the most commonly reported problem for both pilots (43.4 per cent out of a total of 34,560 reports) and ATC operators (46.1 per cent out of 5,525 reports) is that of failing to access all the state defining variables. A lack of knowledge about which variables define the system state, and a failure in interpreting the values of these variables are reported much less frequently for both pilots and ATC operators.

The figures in Table 1 present a general picture of the overall pattern of reported incidents stored in the ASRS database. The picture is somewhat oversimplified, however, in that incidents are counted once for each of the three factors for which a failure is reported. So, for example, an incident involving a failure in knowledge and access will appear in the figures for both of those factors. Furthermore, the figures for each of the factors are shown separately, whereas in reality the operator's perceived state of the system depends on the combination of these factors. In order to rectify these discrepancies, a second search of the ASRS database was carried out.

**Table 1.**  
**Reported Failures in the Dimensions of the Perceived State**

<u>Aspect</u>	<u>Pilots</u>	<u>ATC Operators</u>
Knowledge	3,431 (9.93%)	354 (6.41%)
Access	15,007 (43.4%)	2,546 (46.1%)
Interpretation	2,906 (8.41%)	298 (5.39%)

## Identifying different types of perceived state

Each of the three factors that determine the operator's perceived state can be considered as binary dimensions, in that they are either true or false for any particular situation. By combining the truth values for the three factors, eight different types of perceived state can be identified, as shown in Table 2.

The table illustrates the major difficulty in defining and identifying state misinterpretation: none of the different types of state will definitely lead to problems. Aircraft pilots can, for example, successfully fly their aircraft even when their perceived state is not optimally correct, as suggested by rows three and four in the table. If the pilot does not access all the required variables, the perceived state may be coincidentally correct in that all the variables that have not been accessed are within process limits. If the pilot accesses too many variables, then the perceived state may still be correct, but the pilot will simply have wasted effort in accessing and interpreting the additional data.

There is a fundamental assumption here that any lack of knowledge about the state's defining variables precludes the ability to generate the correct perceived state. This assumption is based on the fact that operators need to know which variables define the system state in order to be able to distinguish between normal and abnormal states. So, for example, pilots and ATC operators have to demonstrate advanced levels of knowledge and competence before they are allowed to fly an aircraft or control real traffic. Pilots and ATC operators should therefore know the state defining variables, so the expected number of reported incidents where the state defining variables are unknown (rows five to eight of Table 2) should be close to zero.

**Table 2.**  
**The Dimensions of The Different Types of Perceived State.**

State Variables			Perceived state
Known	Accessed	Interpreted	
True	True	True	Optimally correct
True	True	False	Incorrect
True	False	True	May be coincidentally correct
True	False	False	May be non-optimally correct
False	True	True	Incorrect
False	True	False	Incorrect
False	False	True	Incorrect
False	False	False	Incorrect

## Search 2: Incidents reported for the different types of perceived state

The appropriateness of the classification of perceived states into different types can only be assessed by examining how reported incidents fit into the different classes. A second interrogation of the ASRS database was therefore performed using combinations of the search terms used in Search 1, and their negations, for each of the eight different types of perceived state listed in Table 2.

### *Search 2 results and discussion*

The results of the second search are shown in Table 3. Row one shows that almost half of the reported incidents occurred when the perceived state was optimally correct. This simply shows that half of the reported incidents cannot be attributed to the operator's perceived state being incorrect, or to failures in state interpretation. The inherently biased nature of voluntarily reported incident data makes it difficult to quantify the incident rate directly attributable to state misinterpretation. Table 3 does, however, show the minimum numbers of reported incidents for each type of perceived state.

The most striking result is that more than one third of the reported incidents arise when the perceived state does not include all of the values of those variables which define the system state (row three). It was suggested earlier that this type of perceived state can appear to be correct, when it is really only coincidentally correct. If operators only ever encounter conditions in which a

**Table 3.**  
**Reported Incidents For Each Type of Perceived State**

	Perceived System State Factors			Pilots	ATC Operators
	Knowledge	Access	Interpretation		
1	True	True	True	16,531 (47.8%)	2,719 (49.2%)
2	True	True	False	1,423 (4.11%)	121 (2.19%)
3	True	False	True	12,119 (35.0%)	2,173 (39.3%)
4	True	False	False	1,053 (3.05%)	156 (2.82%)
5	False	True	True	1,392 (4.03%)	133 (2.41%)
6	False	True	False	206 (0.60%)	5 (0.09%)
7	False	False	True	1,609 (4.66%)	200 (3.62%)
8	False	False	False	223 (0.65%)	15 (0.27%)
Reported Incidents				34,556 (100 %)	5,522 (100 %)

subset of the state defining variables can be used to determine the real state of the system, they will learn to rely on that subset of variables. In other words, the operators generate homomorphic mental models of the system in which only a subset of the real state is represented (Moray, 1987). The net effect will be that incidents (or accidents) may arise in situations where the unread variables play a critical role in distinguishing a normal system state from an abnormal one. The figures in row three of Table 4 show that this problem may have arisen in 35.0 per cent of reported incidents attributed to pilots, and 39.3 per cent of those attributed to ATC operators. A more detailed analysis of the incident reports is required to determine whether the incident occurred because an abnormal system state was wrongly identified as a normal one.

## Discussion

The simple analysis of state interpretation presented here offers a useful insight into the conditions that can give rise to state *mis*-interpretation. State misinterpretation may occur when the operator has not accessed all the state defining variables, or when the interpretation of some (or all) of the values of those variables is incorrect, or both. Data from ASRS incident reports suggest that state misinterpretation occurs most often when the operator does not access all of the state defining variables.

The results are based on a coarse search of the ASRS database, and naturally include a number of false positive reports—incidents satisfying the search criteria, but not involving state misinterpretation. These reports will be removed during a detailed analysis of the incidents. The problem of identifying false negative reports—incidents involving state misinterpretation which do not satisfy the search criteria—is more difficult to resolve however.

The ASRS database is really composed of several different homogeneous populations of pilots (general aviation, military, commercial air carriers and so on), and air traffic controllers (ground, departure, tower, and so on). In order to further explore the ideas presented here, the heterogeneous data needs to be partitioned into homogeneous sets and re-interrogated using the criteria applied to the second search. A preliminary analysis suggests that the distribution of reports for one homogeneous group—experienced commercial air carrier pilots, with over 1000 hours of experience, and flying passenger missions—has the same shape as the overall distribution for pilot reports.

Future work will include a retrospective causal analysis of the selected incident reports using a version of Hollnagel's (1998) Cognitive Reliability

Error Analysis Method (CREAM), adapted for the aviation domain. Once this causal analysis is complete, it should be possible to identify common patterns of events surrounding state misinterpretation in the selected incidents, and hence to propose how it may be appropriately recognized and managed.

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