A CONCEPTUAL FRAMEWORK FOR A NATIONAL SAFETY GRID AND DATABASE: LESSONS FROM AVIATION SAFETY

NARINDER TANEJA

THE PROBLEM OF AVIATION ACCIDENTS

Aviation accidents have always evoked concern and attention from safety professionals, officials, policy-makers, regulators, aircraft manufacturers, aircraft operators and the travelling public alike. It is, therefore, no surprise that multi-pronged approaches and measures have been instituted to prevent aircraft accidents and improve safety statistics. There were in all 28,442 commercial aviation accidents (civil aircraft) from 1918 through 2022, resulting in 1,58,798 fatalities, with a peak during the 1940s and a gradual decrease since 1978.[1] Safety professionals working on civil aviation safety data indicate a theoretical possibility of aircraft accidents trending to near zero by the mid-2040s.[2] Huge safety has been achieved with technological advancement and innovations over the past many decades, so much

Air Vice Marshal **Narinder Taneja** AVSM VSM (Retd) is currently serving as the Dean of BS Kushwah Institute of Medical Sciences, Kanpur.

1. Kamaleshaiah Mathavara and Guruprasad Ramachandran, "Role of Human Factors in Preventing Aviation Accidents: An Insight," in Zain Anwar Ali and Dragan Cvetkovic, eds, *Aeronautics: New Advances,* (London: IntechOpen, 2022).
2. Ibid.

so that safety professionals believe that it is safer to fly in a commercial aircraft than to drive a car or even walk across a street in the busy New York city.[3] Unfortunately, at the other end of the spectrum of advancements in safety lies the fact that between 70-80 per cent of aviation accidents can be attributed, at least, in part, to human error.[4] This high proportion could also be a reflection of the widening gap in cause factors in aircraft accidents.

Human error in aviation accidents has generally been considered synonymous with pilot error.[5] Pilot error was listed as the primary cause of 78.6 per cent of fatal General Aviation (GA) accidents in the US and as the primary cause of 75.5 per cent of overall GA accidents overall.[6] For scheduled air transport, pilot error typically accounts for just over half of worldwide accidents with a known cause.[7]

It is the understanding of this human error that has continued to perplex everyone connected with aviation safety and remains an area of intense research. The question is, why is this human error so difficult to prevent? The simplistic view is that 'to err is human' and the 'human operator' will continue to err under a given set of circumstances. While psychologists have helped in understanding the nature of human error and human factors involved in aviation accidents and developed targeted and holistic interventions, a lot more needs to be done.[8]

ADVANCES IN AVIATION SAFETY: THE UNDERSTANDING OF HUMAN ERROR AND HUMAN FACTORS

When we discuss human error in aviation accidents, there are generally two schools of thought. The first school of thought, also termed the 'person-centred approach,[9] attributes all accidents to the

3. DA Wiegmann and SA Shappell, *A Human Error Approach to Aviation Accident Analysis: The Human Factors Analysis and Classification System* (UK: Ashgate Publishing, 2004), https://dvikan.no/ntnu-studentserver/reports/A%20Human%20Error%20Approach%20to%20Aviation%20Accident%20Analysis.pdf. Accessed on January 30, 2024.
4. Ibid.
5. Ibid.
6. Ibid.
7. Ibid.
8. Ibid.
9. L. Donaldson, "An Organization with a Memory: Report of an Expert Group on Learning from Adverse Events in the NHS Chaired by the Chief Medical Officer,

actions/inactions/fallibility of the human operator. The consequent recommendations are usually targeted at the operator itself, assuming that the machines are getting more reliable. These could include disciplining, new policies, stricter regulations, etc. However, this isolates unsafe acts from their context, thus, making it very hard to uncover and eliminate recurrent error traps within the system.[10] The concept being that the machine has now become reliable, and the unreliable human is responsible for most of the accidents. Therefore, the human can be trained or punished out of making these errors.

James Reason is credited with moving beyond holding the human operator as the sole cause of an accident.[11] This was a paradigm change in our understanding of the root causes of accidents. He proposed the systems approach to safety, the 'Swiss Cheese' model. The 'Swiss Cheese' model of human error helps in identifying human error in accidents by providing a systematic framework to understand the multiple factors that contribute to an accident. The systems approach "starts from the premise that humans are fallible and that errors are inevitable and errors are seen as being shaped and provoked by upstream systemic factors."[12] The model describes four levels of human failure, each influencing the next. Working backwards from the accident, it depicts the unsafe acts of operators, preconditions for unsafe acts, unsafe supervision, and organisational influences.

One of the key aspects that make the 'Swiss Cheese' model particularly useful in accident investigation is that it forces investigators to address latent factors and failures within the causal sequence of events. Latent failures, unlike active failures, may lie dormant or undetected for a long time until they adversely affect the system. By considering these latent failures, the model helps in identifying underlying issues within the organisation that may have contributed to the accident. The International Civil Aviation Organisation (ICAO), therefore, adopted James Reason's model of

March 6, 2005, The Stationery Office, UK.

10. Ibid.
11. J Reason, *Human Error* (Cambridge University Press, 1990).
12. Donaldson, n. 9.

accident causation in 1993 in an effort to better understand the role of human factors in aviation accidents.[13]

FROM THEORY TO PRACTICE: THE HUMAN FACTORS ANALYSIS AND CLASSIFICATION SYSTEM (HFACS)

Reason's 'Swiss Cheese' model brought a paradigm change in the common views of accident causation. The usability and practical applications of the 'Swiss Cheese' model in accident investigation remained a concern. It was as if accident investigators did not have a taxonomy or names or classification codes for these defences/barriers in the system or the proverbial holes in the cheese. This perceived drawback in applying the model was addressed by Wiegmann and Shappell by developing a new error classification system: the Human Factors Analysis and Classification System (HFACS).[14] HFACS provides a structured approach to understanding and categorising human performance factors that contribute to accidents and incidents. It helps identify underlying causes and systemic issues related to human error, allowing organisations to implement targeted interventions and improve safety.

The HFACS framework put forth the concept that complex systems are inherently prone to failure due to conflicting demands and goals of the various sub-systems. However, it is the human element that forms protective barriers at the levels of operators, supervisors and the organisation, which prevent the system from failing and leading to accidents. Within this human framework, failures may still occur at any level. When these failures occur, they may be at any of the four levels.

The HFACS framework[15] describes human error at each of four levels of failure:

(a) Unsafe acts of operators (e.g. aircrew).
(b) Preconditions for unsafe acts.
(c) Unsafe supervision.
(d) Organisational influences.

13. Barry Strauch, *Investigating Human Error: Incidents, Accidents and Complex Systems* (UK: Ashgate Publishing, 2004).
14. Wiegmann and Shappell, n. 3.
15. Ibid.

Within each level of HFACS, causal categories were developed that identify the active and latent failures that occur. The model surmises that if, at any time leading up to the adverse event, one of the failures is corrected, preventing the failure from aligning, the adverse event will be prevented.

Department of Defence (DoD) HFACS

The US DoD modified HFACS into a DoD HFACS for use across the armed forces and accidents across all domains.[16] This DoD HFACS is a systematic, multi-dimensional approach to error analysis and mishap prevention in the context of human performance. It is used by safety personnel, data researchers, and commanders to identify underlying causes of human error that can lead to mishaps. The original DoD HFACS has also undergone modifications over time.[17]

HFACS offers several benefits in safety analysis, including identification of human error causal factors and detection of latent factors enabling a comprehensive analysis of human failure. It has also proved useful in that it can be used proactively to conduct human factors risk assessment, allowing organisations to identify historical trends in human error and implement targeted interventions to reduce accident and injury rates. The biggest advantage of HFACS is that it has been successfully implemented in various industries, including aviation, transportation, mining, construction, healthcare, and railways, demonstrating its versatility and effectiveness in different contexts.[18]

Some safety professionals believe that in comparison to HFACS, DoD HFACS provides an even more deliberate, cohesive and validated version of HFACS. Both, however, provide an opportunity for their integration across domains.[19]

16. Air Force Safety Centre, "DoD HFACS 8.0," https://www.safety.af.mil/Divisions/Human-Performance-Division/HFACS/. Accessed on January 12, 2024.
17. Ibid.
18. Adam Hulme, et al., "Accident Analysis in Practice: A Review of Human Factors Analysis and Classification System (HFACS) Applications in the Peer Reviewed Academic Literature," Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 2019, vol. 63(1), pp. 1849-1853.
19. Ibid.

LESSONS FROM AVIATION SAFETY: THE DECADES OF THE 2000s

The realisation by the aviation industry that there was an urgent need to understand human error and human factors better in aviation accidents, as a prerequisite to improving safety, led the industry to adopt the use of a comprehensive, reliable, usable and validated (both theoretical and contextual) error framework such as HFACS. This adoption has provided safety professionals with an understanding of what may be called the 'face of human error' to develop data-driven, evidence-based intervention programmes.

Air forces across the world have adopted HFACS as an error framework to investigate aviation accidents and for *post hoc* analysis of existing databases. Examples include the US Air Force (USAF), US Navy (USN),[20] Indian Air Force (IAF), Republic of China (ROC) Air Force,[21] Royal Air Force (RAF),[22] Royal Air Force of Oman (RAFO)[23] and many more. The application of HFACS to investigate military aircraft accidents is mandated by the IAF. The IAF carried out one of the largest studies analysing 200 aircraft accidents over a 30-year period using HFACS: The HFACS 200 Study.[24] The use of HFACS in aviation accidents and analysis of existing databases has provided safety professionals with a valid, reliable and comprehensive error framework to develop evidence-based, data-driven interventions, thus, leading to improvement in aviation safety records. These are indeed big lessons learnt from the aviation industry's understanding of human error and human factors in aviation accidents and are

20. Wiegmann and Shappell, n. 3.
21. D. Harris and Li Wen Chin, "HFACS Analysis of ROC Air Force Aviation Accidents: Reliability Analysis and Cross-Cultural Comparison," *International Journal of Applied Aviation Studies*, vol. 5(1), March 2005, pp. 65-81.
22. O'Connor and Paul, "HFACS with an Additional Layer of Granularity: Validity and Utility in Accident Analysis," *Aviation Space and Environmental Medicine*, vol. 79(6), June 2008, pp. 599-606.
23. Yousuf Al Wardi, "The Utility of Human Factors Analysis and Classification System (HFACS) in the Analysis of Military Aviation Accidents," *Indian Journal of Aerospace Medicine*, December 31, 2013, https://indjaerospacemed.com/the-utility-of-human-factors-analysis-and-classification-system-hfacs-in-the-analysis-of-military-aviation-accidents/. Accessed on January 30, 2024.
24. N. Taneja, YS Dahiya and J. Aneesh, "The HFACS 200 Study: An Analysis of 200 Cat I Accidents in the IAF using HFACS 2020" (Unpublished Study).

literally becoming a template to adopt in other high-risk industries such as healthcare, nuclear power, and many more.

HUMAN ERROR IN ACCIDENTS: OTHER DOMAINS/ INDUSTRIES

Extensive research and published studies have documented the proportion of human error in accidents in each domain. HFACS in its original or modified form has been utilised in sectors ranging from aviation (including its sub-components such as Unmanned Aerial Vehicles (UAVs),[25] maintenance,[26] Air Traffic Control (ATC),[27] rail, road, maritime, mining, construction, oil and gas, nuclear, shipping,[28] healthcare, and space.[29] This suggests that the contribution, analysis, and understanding of human error and human factors, as well as the development of interventions to minimise accidents and improve safety records, remain areas of concern.

It may not be unreasonable to consider similar proportions of human error accidents in similar industries in our country.

POTENTIAL DRAWBACKS IN EXISTING METHODOLOGIES OF INVESTIGATION OF ACCIDENTS AND DATABASES: LESSONS FROM AVIATION

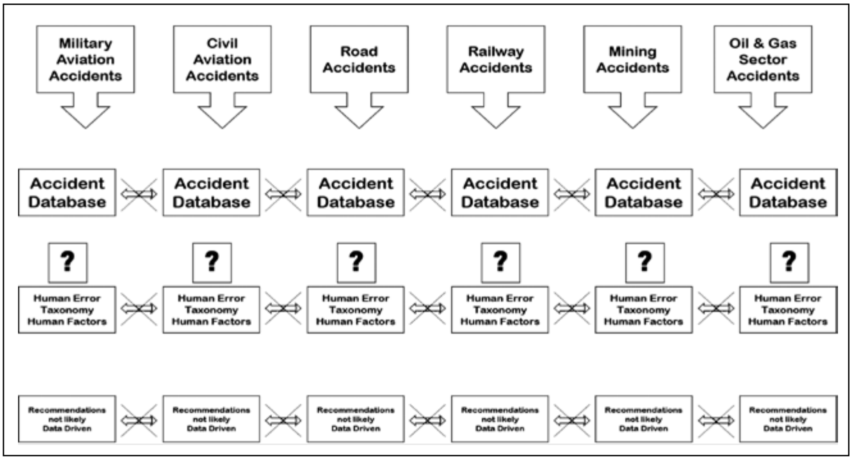
It is presumed that each agency/industry/organisation must mandate the investigation of accidents based on regulations by that particular agency. It is expected that a repository of such accident investigation reports and a database in some form would be maintained by that organisation, e.g. an airline, an oil and gas exploration company or in some cases, ministries or their designated agencies, e.g. railways, civil aviation. Some of them

25. O. Alharasees, M. S. M. Abdalla and U. Kale, "Analysis of Human Factors Analysis and Classification System (HFACS) of UAV Operators," *New Trends in Aviation Development (NTAD),* November 24, 2022, pp. 10-14.
26. Taneja et. al., n. 24.
27. Nikki S. Olsen, "Coding ATC Incident Data Using HFACS: Inter-Coder Consensus," *Safety Science*, vol. 49, Issue 10, 2011, pp. 1365-1370.
28. Hulme, n. 18.
29. Tiffany Miller and Alexander (presenters), "National Aeronautics and Space Administration Human Error Assessment And Reduction Technique (HEART) And Human Factors Analysis And Classification System (HFACS)," PhD Conference: International Association for the Advancement of Space Safety (IAASS), October 18, 2017.

would be in the public domain, e.g. aircraft accident reports on the Directorate General of Civil Aviation (DGCA) website,[30] while others may not be available in the public domain, e.g. military aircraft accident inquiries or databases, for obvious reasons.

While human factors have long been identified as one of the main causes of incidents and accidents across all domains, the utilisation of trained human factors expertise in investigating accidents remains elusive. This is critical and concerning because whereas engineering – and operations – led investigation can highlight what happened and how it occurred, it is increasingly recognised that the integration of human factors into an investigation can help understand why a sequence of events led to an incident or accident. This lack of expertise in understanding the human factors in detail in human error accidents remains a critical element in the search of safety improvements across all domains, in particular, high-risk industries. These have been depicted in Fig 1.

Fig 1: Perceived Drawbacks in Existing Accident Investigation and Safety



Source: The figure has been made by the author.

30. Directorate General of Civil Aviation, "Accident Reports," https://www.dgca.gov.in/digigov-portal/?dynamicPage=AccidentReports/500005/0/viewApplicationDtlsReq. Accessed on January 12, 2024.

DO WE NEED DEDICATED HUMAN ERROR AND HUMAN FACTORS ANALYSIS IN ALL DOMAINS?

If the proportion of accidents attributed to human error ranges between 50-80 per cent across various domains, it is logical to infer that if any significant impact on minimising accidents is to be achieved, we will have to first develop an in-depth understanding of the nature of human error and human factors in accidents in each domain. To develop an in-depth understanding of human factors across all layers of the system or the proverbial 'Swiss Cheese', it is essential that accidents are investigated using a robust error framework by investigators trained in human factors. Along with this, *post hoc* analysis of accident databases should be carried out using a similar error framework.

ERROR FRAMEWORK: OPTIONS

Different frameworks have been utilised to investigate accidents in different domains, some of them tailored to the needs of that particular industry. Some of the many error frameworks commonly in use include the 'Swiss Cheese' model, HFACS and Heinrich's Domino Theory.[31] Various researchers mandate that the error framework should be comprehensive, reliable, usable and demonstrate both theoretical and contextual validity.[32]

HFACS and DoD HFACS have both been extensively evaluated and validated by different research groups. With HFACS proving to be an effective error framework that can be applied seamlessly across industries and domains, it can be inferred that, by and large, the nature of the human error and human factors across domains is similar. If the cause factors are similar, the intervention programmes will possibly also have similarities. It is with such a hypothesis in mind that the concept of a National Safety Grid and Database is being proposed.

NATIONAL SAFETY GRID AND DATABASE: A CONCEPTUAL FRAMEWORK

Let us hypothetically assume that it is mandated that all accidents across all domains will be investigated using a common error

31. H.W. Heinrich, *Industrial Accident Prevention (1941) Technology* (New York and London: Mcgraw-hill Book Company Inc., 1941).
32. DA Wiegmann and SA Shappell, "Human Error Perspectives in Aviation," *International Journal of Aviation Psychology*, vol. 11(4), October 2001, pp. 341-357.

framework. It is feasible that such a human error and human factors database could seamlessly converge and formulate into a National Safety Grid/Database. This is schematically depicted in Fig 2. To implement such a concept, a framework may have the following components and more (Fig 3).

Fig 2: National Safety Grid and Database

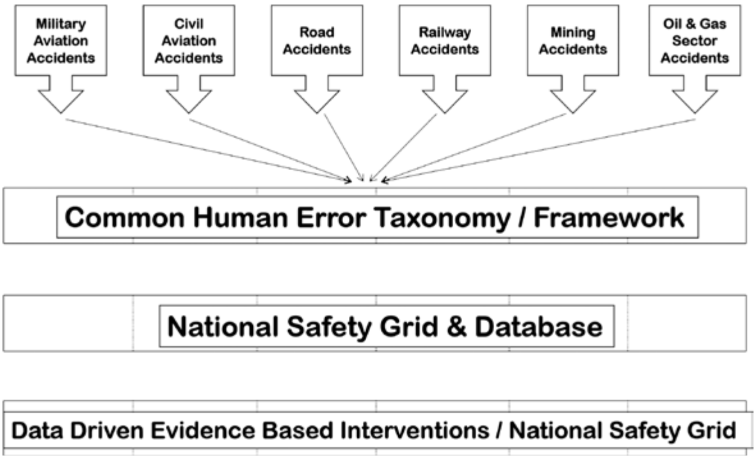


Fig 3: Conceptual Framework and Components: National Safety Grid Database

Issue No.	Functionary / Location	Envisaged Functions	
Issue 1	Coordinating Agency	▪ Policy formulation, Implementation, Monitoring ▪ Obtaining periodic feedback. ▪ Formulating Recommendations & guidelines for training ▪ Could have various verticals / working groups	
Issue 2	Central Database	▪ Partnership between various stakeholders ▪ Requirement of domain expert from each Ministry ▪ Human Factors database / framework ▪ Research are to be trained in Human Factors ▪ Can be merged with iRAD or ▪ Could be any IIT	
Issue 3	Participating Ministries	▪ Road Transport ▪ Mining ▪ Urban Affairs ▪ Oil & Gas ▪ Shipping ▪ Railways ▪ Highways	▪ Create a Nodal office of Human Factors. ▪ Responsible for Human Centred Design (e.g. Road Signs) guidelines. ▪ Responsible for Human System (HS1) Integration. ▪ Training of staff in Human Factors. ▪ Education – Human Factors. ▪ Training of potential accident investigators in HFACS/Error Framework.

Source: The figure 2 and 3 have been made by the author.

THE WHAT, WHY, WHO, AND HOW OF NATIONAL SAFETY GRID AND DATABASE?

Coordinating Agency: Such a concept of a National Safety Grid and Database will have to be mandated by a policy/regulation through a central agency such as the Niti Aayog. Alternatively, one ministry could be designated as the nodal ministry for inter-ministerial coordination and synergy. Guidelines will have to be established for reporting accidents, near misses, and incidents to ensure consistent documentation of relevant details. This could include standardising reporting formats, data collection methods, and information-sharing protocols. Each in itself, such as incident reporting, will require a dedicated group to work on. The potential envisaged functions of this coordinating agency, which may comprise many verticals, could include:

- Policy formulation, implementation, and monitoring.
- Obtaining periodic feedback.
- Formulating recommendations and guidelines for training.

Central Database: Policies formulated by, and emanating from, the coordinating agency would identify a location for maintaining a Central Human Factors Accident Database. Protocols will have to be created to identify:

- Partnership between various stakeholders.
- Requirement of domain experts from each ministry at the central database management site.
- Human factors framework to be utilised for the database.
- Researchers to be trained in human factors.

It is possible that such a database could ride on the existing Integrated Road Accident Database (iRAD) at the Indian Institute of Technology (IIT), Chennai,[33] or one of the central institutes can be identified to develop a robust central database architecture.

33. Centre of Excellence for Road Safety, "Integrated Road Accident Database," https://ed.iitm.ac.in/~vb/rbg/Research/PublicPolicy/iRAD.html. Accessed on January 14, 2024.

Participating Ministries: Any ministry under whose purview accidents can happen can participate in the National Safety Grid and Database. Some representative ministries include:

- Road Transport.
- Mining.
- Urban Affairs.
- Oil and Gas.
- Shipping.
- Railways.
- Highways.
- Civil Aviation.

Each participating ministry will have to create a dedicated structure for human factors education, training and research. Besides the contribution of human factors in accident investigation, this structure could be, in addition, responsible for:

- Developing human centred design (e.g. road signs) guidelines.
- Human System Integration (HSI).
- Training of staff in human factors.
- Training of potential accident investigators in HFACS/Error Framework to standardise the quality of accident investigation.

INVESTIGATION OF ACCIDENTS

Policies will have to be formulated for the investigation of accidents. They will define a step-by-step process for accident investigation and will outline roles, responsibilities, and procedures. This could include conducting site visits, collecting evidence, interviewing witnesses, analysing data, and identifying contributing factors. The Indian Air Force, for example, has a dedicated Air Force Order (AFO) stipulating the entire spectrum of activities and responsibilities of various agencies/stakeholders in accident investigations.

These policies will have to address issues pertaining to the training of potential investigators in human factors. This training could be carried out at centralised institutes like the Institute of Aerospace Safety (IAS), which is currently engaged in imparting such training or getting officers trained in human factors on deputation from the armed forces for initial periods. The duration for such initial training could be modelled on existing templates in the IAF.

Data Analysis and Statistics: A consensus will have to be reached regarding either a centralised analysis of data or a decentralised approach at the level of each ministry, or even a potential hybrid model combining both centralisation and decentralisation for data analysis. Guidelines will have to be formulated for implementing methods to analyse accident data and identify trends, patterns, and common contributing factors across industries. This will permit the identification of systemic issues and the development of targeted preventive strategies across industries.

Lessons Learned and Recommendations: The biggest gain of such a National Safety Grid and Database would be data across domains, providing in-depth understanding and data-driven programmes. Sharing lessons learned from accident investigations and disseminating recommendations for preventive measures across domains will improve safety by leaps and bounds.

CONCLUSION

This concept paper presents an oversight of the potential of human error and human factors investigation in accidents across sectors in our country. While each industry may mandate systematic and detailed investigation of such accidents, including human error, it is possible that such investigations are carried out by not-so-experienced human factors investigators and using a not-so-reliable, comprehensive and valid error framework. The nature of human error and human factors shares commonality across domains. It may be feasible to develop and implement data-driven, evidence-based interventions at a pan-nation level across domains. Developing a National Safety Grid and Database could be a huge first milestone in our efforts to make our systems safer. By implementing a common error framework for accident analysis, we can foster a culture of safety, facilitate knowledge exchange, and drive continuous improvement in accident prevention and mitigation efforts across industries. It will help establish consistent approaches to accident investigation, analysis, and prevention, resulting in improved safety outcomes and the protection of human lives and well-being.