Center for Research in Economics, Management and the Arts

A Systematic Approach to Safety Incidents in Public Health – Applying the Human Factors Analysis and Classification System to COVID-19

Working Paper No. 2020-13

CREMA Südstrasse 11 CH - 8008 Zürich www.crema-research.ch

A Systematic Approach to Safety Incidents in Public Health – Applying the Human Factors Analysis and Classification System to COVID-19

Steve J. Bickley[1,2] and Benno Torgler[1,2,3]

[1]School of Economics and Finance, Queensland University of Technology, Australia

[2]Centre for Behavioural Economics, Society and Technology (BEST), Australia

[3]CREMA – Centre for Research in Economics, Management, and the Arts, Switzerland

Abstract

In this article, we argue for application of the Human Factors Analysis and Classification System (HFACS) to *proactive* incidence prevention in the public health system response to COVID-19. HFACS is a framework of causal categories of human errors typically applied for systematic retrospective incident analysis in high-risk domains. By leveraging this approach proactively, appropriate, and targeted measures can be quickly identified and established to mitigate potential errors at different levels within the public health system (from frontline healthcare workers to regulatory and statutory decision makers).

1 Introduction

Principles of behavioural change (West et al. 2020), human factors, and ergonomics (Gurses et al. 2020) have the potential to contribute significantly in controlling the spread and minimising the health and socioeconomic effects of coronavirus. We argue that proactive incident prevention in the public health response to COVID-19 could be achieved by leveraging the Human Factors Analysis and Classification System (HFACS) (Shappell and Wiegmann 2000), which is a framework of causal categories of human errors that cause adverse outcomes. Typically applied for retrospective incident analysis in high-risk domains such as aviation, maritime, oil and gas and construction, the HFACS framework provides a systematic method to investigate the active and latent failures of humans in organisational contexts as well as the causal pathways through which errors propagate to incident causation. The Oil and Gas Industry variant (HFACS-OGI) (Theophilus et al. 2017) has been adapted to the public health domain (HFACS-PH) and includes statistically significant causal pathways identified in the literature review to enable proactive incident management. This expands on previous adaptations to healthcare service delivery in hospitals (Diller et al. 2014, Hughes et al. 2013), surgery operating rooms (ElBardissi et al. 2007, Cohen, Francis, et al. 2018), analysis of anaesthesiology incidents (Neuhaus et al. 2018), trauma care (Cohen, Cabrera, et al. 2018), and in patient safety studies (Hoffman et al. 2013).

2 Background

The World Health Organisation (2019) suggests that the increasing complexity in healthcare settings make humans (doctors, nurses, surgeons, anaesthetists and so on) more prone to preventable mistakes and highlight the obvious major concerns for patient safety. de Vries et al. (2007) find that nearly one in ten patients are affected by adverse events during hospital admission, with the majority of these adverse events resulting from preventable errors. Further, Vlayen et al. (2010) find that anywhere from 17-76.5% of adverse events resulting in admissions to an Intensive Care Unit (ICU) are preventable. Examples of preventable errors in healthcare include medication errors, healthcare associated infections, unsafe surgical procedures, unsafe injections practices, diagnostic errors, unsafe transfusion practices, radiation errors, sepsis, and blood clots (World Health Organisation 2019).

Clearly, taking a proactive (as opposed to reactive) approach to incident prevention in healthcare settings would be of major benefit to patient safety. This is particularly true in the current COVID-19 pandemic, where public health systems have experienced a significant surge in demand, combined with staff absences of up to 20% due to illness or self-isolation (Willan et al. 2020), placing further stresses on already overloaded public healthcare systems.

2.1 Human Error

Reason (2000) introduces the human error problem through two paradigms of thought – the person approach and the system approach. The person approach tends to view unsafe acts (errors and procedural violations) as resulting from human-related processes such as physical and cognitive constraints, mistakes in decision making, errors in implementation, lapses in concentration, negligence, and general carelessness. In the person approach, blame is generally attributed to errors made by frontline workers and penalisation dealt similarly. In contrast, the systems approach views unsafe acts as arising from systemic weaknesses in the organisation. In the systems approach, safety barriers or countermeasures are implemented by an organisation at various levels (management, supervisory, environment and staff) with the aim of preventing exposure to the hazardous conditions through which errors may occur.

The person approach points towards the recognition of bounded limits (physical and cognitive) on human decision-making capabilities in complex environments and uncertain problem spaces – similar to those in medical settings. To reduce the computational requirements to perceive and respond to complex tasks, humans rely on cognitive processes such as recognition (from stored skills, knowledge and experience), decision making rules or heuristics (domain-specific or generalised rules backed by experience), and pattern-recognition (detection and extrapolation of recursive or hierarchical structures in information) (Simon 1990). The systems approach highlights an organisational pursuit for continual improvement in incident prevention and risk management. This pursuit is constrained by the processes of organisational adaption which balance the exploitation of competence in current working methods and procedures with the exploration of potentially more beneficial and hence, safer alternatives (March 2003). Organisational knowledge which defines day-to-day operations is embedded in networks of people (Stenvall and Virtanen 2017). People who are themselves, rationally bounded by physical and cognitive limits and thus, leading to the reasonable deduction that organisations are also rationally bounded. To explain a system which is bounded rationally, the system's processes and the environment in which it is embedded (and hence, to which it adapts) must first be understood (Simon 1990). With this in mind, this article will recognise that macro-level social phenomena are implemented through the actions and minds of (rationally bounded) individuals (Castelfranchi 2000) and take the view of healthcare systems as dynamic, complex and adaptive systems (Miles 2009, Lipsitz 2012, Sturmberg, O'Halloran, and Martin 2012, Kopach-Konrad et al. 2007, Martin 2017).

2.2 Human Factors Analysis and Classification System (HFACS)

The majority of complex human, natural and artificial systems are hierarchical in structure, with the efficiency of the whole as some function of the sub-systems' efficiencies and their interactions (Simon 2001). It therefore makes sense to view incident causation through a similar lens. Shappell and Wiegmann (2000) provide a formalised taxonomy of human errors based on Reason's (1990) Swiss-Cheese model, leveraging his four hierarchical levels of human error. This supports the system-oriented approach to incident causation via a taxonomy of hazard sources and the hierarchical interactions between various decision-making levels of any complex human system as proposed by Rasmussen (1997).

A brief description on each level of the HFACS Framework is provided in the sections below.

2.2.1 Unsafe Acts

Unsafe acts are termed as active failures and are differentiated from latent conditions by their locality to the safety incident and the relatively short time it takes to show their adverse effects. Unsafe acts can be broadly classified into two categories: errors and violations Shappell and Wiegmann (2000). Errors are further categorised into decision (relating to knowledge, experience, or informational deficiencies), skill-based (relating to the execution of routine activities) and perceptual (relating degradation or impediment of sensory inputs). Violations are related to departures from organisational procedures, rules and regulations and can be either routine (habitual) or exceptional (one-time departures). Both errors and violations often represent the cognitive shortcuts of human decision-makers (Simon 1990) and their bounded and biased representations of context, task, and environmental conditions (Castelfranchi 2000).

2.2.2 Preconditions for Unsafe Acts

Preconditions for unsafe acts refer to the underlying latent conditions that most directly relate to the occurrence of unsafe acts (Reason 1990) and thus, provide the greatest prediction power for unsafe acts (Baldissone et al. 2019, Harris and Li 2019). This level comprises of conditions of operators, environmental factors, and personnel factors (Shappell and Wiegmann 2000). Conditions of operators are categorised by adverse mental states (e.g. mental fatigue, stress, distraction or loss of situational awareness), physiological states (e.g. intoxication, illness, injury or physical fatigue) and physical/mental limitations (e.g. physical strength, cognitive capacity or chronic illness/disease). Situational factors are categorised by physical environment (relating to operational setting, workstation design or ambient environmental conditions) and technological environment (relating to enabling tools and technology such as computers, software, and checklists). Personnel factors are categorised by crew resource management (e.g. shift planning and team pairing) and fitness for duty (e.g. training and physical readiness).

2.2.3 Unsafe Supervision

The causal chain of events (Reason 1995) in incident causation can be traced up the supervisory and management chains of command, creating the initial (pre-)conditions for the unsafe acts of workers. The third level of HFACS, unsafe supervision (Shappell and Wiegmann 2000), is broken down into inadequate supervision (relating to failure to provide adequate guidance, leadership and training opportunities for frontline workers), planned inappropriate operations (relating to management and assignment of work including risk management and operational tempo), failure to correct known problems, and supervisory violations (conscious disregard for rules, regulations, regulations and standard operating procedures).

2.2.4 Organisational Influences

Shappell and Wiegmann (2000) break down organisational influences further into resource management, organisational climate, and organisational process. Resource management relates to the allocation and maintenance of organisational resources including personnel, finance, and equipment/facilities. Organisational climate relates to the broad class of organisational variables which affect worker performance and satisfaction including culture, command structure and policies. Organisational process relates to the procedures and methods which govern the everyday activities of the business and enable management oversight over operations including production quotas, incentive schemes, schedules, standards, work instructions, safety programs and measurement/review of key performance indicators.

2.2.5 Contexts of Application

The HFACS framework has been applied in retrospective incident analysis across numerous high-risk, high-reliability industries including aviation (Wiegmann and Shappell 2003, Zhou, Zhang, and Baasanuren 2018, Li and Harris 2013, Li, Harris, and Yu 2008), maritime (Yıldırım, Başar, and Uğurlu 2019, Chauvin et al. 2013, Griggs 2012), rail (Reinach and Viale 2006, Madigan, Golightly, and Madders 2016, Baysari, McIntosh, and Wilson 2008), mining

(Patterson and Shappell 2010, Lenné et al. 2012), oil and gas (Theophilus et al. 2017, Gholam Abbas et al. 2018), and construction (Sun et al. 2011, Xia et al. 2018, Ye et al. 2018). More recently, HFACS has been applied in the context of healthcare service delivery in hospitals (Diller et al. 2014, Hughes et al. 2013), surgery operating rooms (ElBardissi et al. 2007, Cohen, Francis, et al. 2018), analysis of anaesthesiology incidents (Neuhaus et al. 2018), trauma care (Cohen, Cabrera, et al. 2018), and in patient safety studies (Hoffman et al. 2013). HFACS has also been extended to the *proactive* management and prediction of incidents through causal pathway analysis in the mining (Lenné et al. 2012), process (Baldissone et al. 2019), aviation (Liu, Chi, and Li 2013, Inglis et al. 2010, Li, Harris, and Yu 2008), oil and gas (Theophilus et al. 2017), and construction (Sun et al. 2011, Ye et al. 2018) industries. Neural networks have also been used to predict the unsafe acts (level 1 errors) from preconditions of unsafe acts (level 2 errors) (Harris and Li 2019). In the health domain, causal pathways have been quantitatively identified in the analysis of adverse drug events (Min-Chih 2019) and qualitatively in the analysis of adverse events in cardiovascular surgery rooms (ElBardissi et al. 2007). A multi-industry, meta-analysis of latent failure pathways provides benchmark standards for HFACS causal pathways (Berry 2010).

2.3 Public Health Framework Adaptation (HFACS-PH)

Figure 1 illustrates the proposed HFACS-PH framework which includes 5 levels at which errors eventuate. Each higher-level influences the next downward level except for external influences (e.g. global PPE shortages) which can influence all levels. The causal relationships identified in the literature cited in section 2.2.5 have been overlayed onto the HFACS-PH framework (in orange) to enable proactive management of potential error pathways before incidents occur.

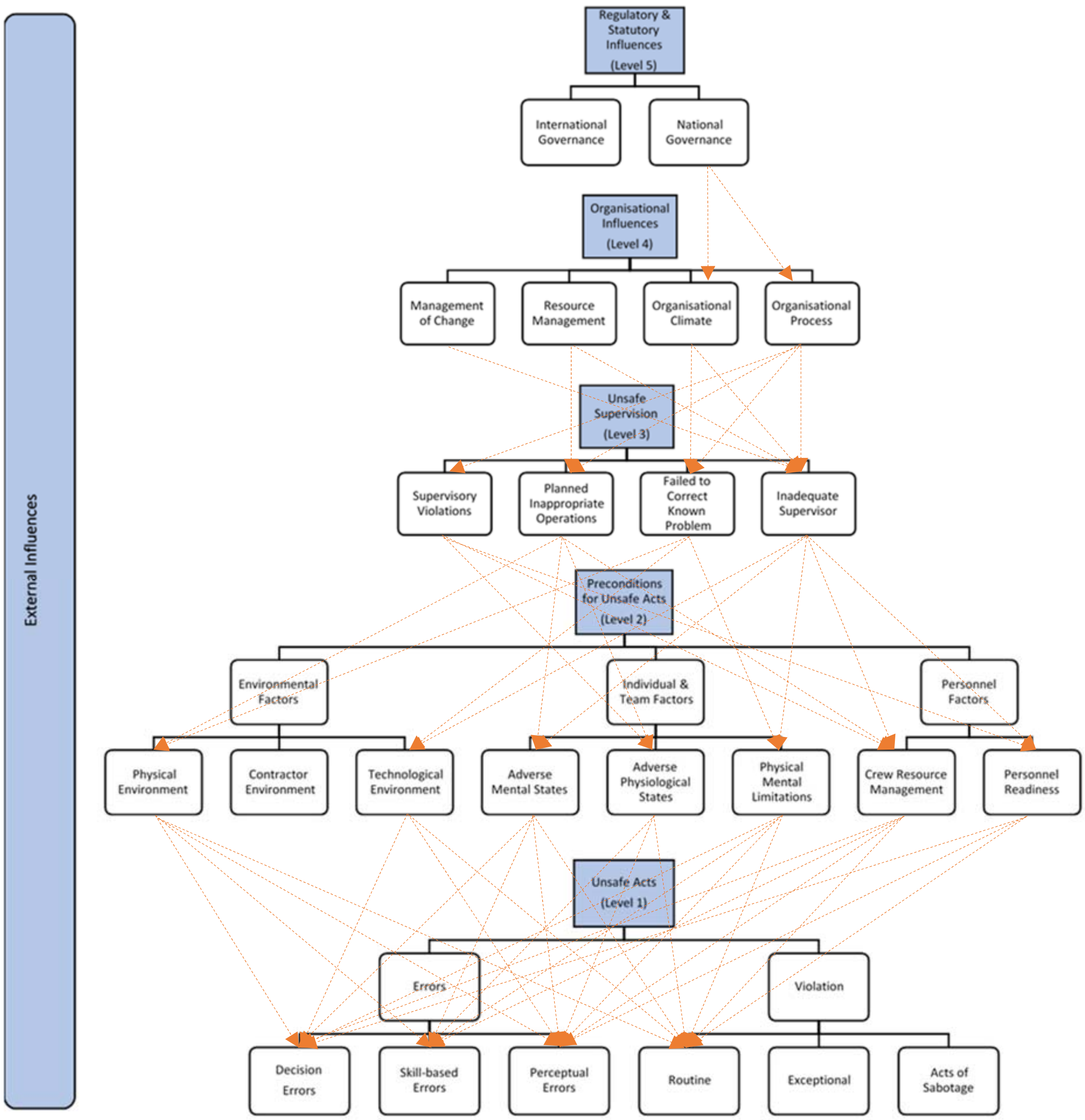

Figure 1: Public Health Adaptation to HFACS Framework (HFACS-PH) with causal chains (statistically significant paths of association) in orange – depicts the possible paths of error propagation (from higher levels to lower levels) through the HFACS-PH Framework.

In HFACS-PH, Level 1 corresponds to errors made by frontline medical professionals such as doctors and nurses. Errors can be due to poor decision-making (e.g. misdiagnosis), skill-based errors (e.g. inadequate handwashing), perceptual errors (e.g. accidently entering quarantine zones), or violations of standard protocols (e.g. routine policy workarounds). Level 2 corresponds to contextual factors which directly increase the likelihood of unsafe acts. These can be environmental (e.g. unsanitary/overcrowded hospital environments), individual/team (e.g. stressed, fatigued or ill staff) or personnel factors (e.g. poor communication/coordination). Levels 3 and 4 correspond to higher-level health officials and hospital management which may inadequately train, advise and supervise frontline workers. Errors may also include blatant ethical violations (e.g. due to fears of hospital/department closures), poor resource management (e.g. PPE shortages) and inadequate operational planning (e.g. shift planning/pairing). Level 5 corresponds to regulatory/statutory influences. Level 5 errors could include lack of government funding, ill-defined emergency response guidelines, slow vaccine research and approval pathways and lack of support for frontline healthcare providers (including provisions for childcare, travel/accommodation, professional insurance, and prioritised testing).

3 Practical Applications of HFACS-PH

In the words of Wiegmann and Shappell (2003), "if the accident is going to be reduced beyond current levels, investigators and analysts alike must examine the accident sequence in its entirety...", further supporting the identification of causal pathways of incident causation. At the current time, quantitative paths of association in the health domain have only been identified for adverse drug events in hospitals (Min-Chih 2019) however, the causal pathways identified in other industries could be used to supplement the aforementioned findings and provide additional support for the predictive capability of the HFACS-PH framework. This could support its use in proactive incident management in a public health systems' response to the COVID-19 pandemic. Further research investigation and statistical analysis on healthcare-related incident/near-miss/event reporting datasets could confirm the *ex-ante* applicability of the abovementioned causal pathways to the public health domain. The proactive use of the HFACS-PH framework could be used to explore potential issues that may emerge in the reallocation of hospital resources, with changes to regulatory requirements (see examples in Section 3.1), when undertaking workplace re-designs and facility upgrades or when implementing process/procedural changes. The following section provides three examples of the proactive application of HFACS-PH in the context of regulatory changes.

3.1 Changes to Regulatory Requirements

In many countries health services prepared for the expected surge in demand resulting from COVID-19 by rapidly enlisting temporary healthcare workers to provide adequate care and alleviate stresses on existing health systems. In the US, for example, the US Senate approved a bill waiving telehealth restrictions (Donlan, 2020). In Australia, the Australian Health Practitioner Regulation Agency has relaxed usual return-to-practice requirements (registration fees, English proficiency, etc.) (Australian Health Practitioner Regulation Agency 2020). In the UK, routine quality inspections of registered health and social care providers have been temporarily suspended (Care Quality Commission, 2020). These level 5 regulatory and statutory decisions have the potential to ignite casual chains of error propagation through the US, UK, and Australian health systems. For example, see Table 1 where the errors highlighted in orange are statistically likely to be influenced by regulatory changes either directly, or through causal error chains as identified in the literature cited in Section 2.2.5. Table 1 is used below to explore the potential flow-on effects of the US, UK, and Australian examples of regulatory changes.

Table 1: Statistically significant causal relationships – Evidence from the reviewed literature.

Statutory / Regulatory Influences (Level 5)	**Organisational Influences (Level 4)**	**Evidence**
Regulatory Influence	Organisational Climate	(Theophilus et al., 2017)
Regulatory Influence	Organisational Process	(Inglis et al., 2010)
Organisational Influences (Level 4)	**Unsafe Supervision (Level 3)**	**Evidence**
Management of Change	Inadequate Supervision	(Theophilus et al., 2017)
Resource Management	Planned Inappropriate Operations	(Li et al., 2008; Min-Chih, 2019)
Resource Management	Inadequate Supervision	(Lenné et al., 2012; Li et al., 2008; Liu et al., 2013)
Organisational Climate	Failed to Correct Known Problem	(Min-Chih, 2019)
Organisational Climate	Inadequate Supervision	(Lenné et al., 2012)

Organisational Process	Supervisory Violations	(Li et al., 2008)
Organisational Process	Planned Inappropriate Operations	(Li et al., 2008)
Organisational Process	Failed to Correct Known Problem	(Li et al., 2008)
Organisational Process	Inadequate Supervision	(Inglis et al., 2010; Li et al., 2008)
Unsafe Supervision (Level 3)	**Preconditions for Unsafe Acts (Level 2)**	**Evidence**
Supervisory Violations	Adverse Physiological State	(Inglis et al., 2010; Lenné et al., 2012)
Supervisory Violations	Crew Resource Management	(Liu et al., 2013; Ye et al., 2018)
Supervisory Violations	Personnel Readiness	(Li et al., 2008; Liu et al., 2013)
Planned Inappropriate Operations	Adverse Physiological State	(Berry, 2010; Min-Chih, 2019)
Planned Inappropriate Operations	Adverse Mental State	(Min-Chih, 2019)
Planned Inappropriate Operations	Physical Environment	(Li et al., 2008; Theophilus et al., 2017)
Planned Inappropriate Operations	Crew Resource Management	(Lenné et al., 2012)
Failed to Correct Known Problem	Physical Environment	(Berry, 2010; Sun et al., 2011; Theophilus et al., 2017)
Failed to Correct Known Problem	Technological Environment	(Berry, 2010; Min-Chih, 2019)
Failed to Correct Known Problem	Physical / Mental Limitations	(Berry, 2010)
Inadequate Supervision	Physical / Mental Limitations	(Inglis et al., 2010; Min-Chih, 2019)
Inadequate Supervision	Personnel Readiness	(Sun et al., 2011)
Inadequate Supervision	Crew Resource Management	(Inglis et al., 2010; Lenné et al., 2012; Li et al., 2008; Liu et al., 2013; Theophilus et al., 2017)
Inadequate Supervision	Adverse Mental States	(Inglis et al., 2010; Lenné et al., 2012; Liu et al., 2013)
Inadequate Supervision	Technological Environment	(Inglis et al., 2010; Theophilus et al., 2017)
Preconditions for Unsafe Acts (Level 2)	**Unsafe Acts (Level 1)**	**Evidence**
Physical Environment	Skill-Based Errors	(Inglis et al., 2010; Theophilus et al., 2017)
Physical Environment	Decision Errors	(Inglis et al., 2010)
Physical Environment	Perceptual Errors	(Inglis et al., 2010; Li et al., 2008; Ye et al., 2018)
Physical Environment	Violations	(Lenné et al., 2012)
Technological Environment	Perceptual Errors	(Theophilus et al., 2017)

Technological Environment	Decision Errors	(Lenné et al., 2012; Min-Chih, 2019)
Technological Environment	Violations	(Lenné et al., 2012)
Adverse Mental States	Skill-Based Errors	(Inglis et al., 2010; Li et al., 2008; Min-Chih, 2019)
Adverse Mental States	Decision Errors	(Berry, 2010; Inglis et al., 2010; Lenné et al., 2012; Min-Chih, 2019)
Adverse Mental States	Perceptual Errors	(Berry, 2010; Inglis et al., 2010; Lenné et al., 2012; Liu et al., 2013; Min-Chih, 2019; Theophilus et al., 2017)
Adverse Mental States	Violations	(Berry, 2010; Inglis et al., 2010; Lenné et al., 2012; Theophilus et al., 2017)
Adverse Physiological States	Skill-Based Errors	(Berry, 2010; Lenné et al., 2012)
Adverse Physiological States	Perceptual Errors	(Inglis et al., 2010; Min-Chih, 2019)
Adverse Physiological States	Violations	(Inglis et al., 2010)
Physical / Mental Limitations	Skill-Based Errors	(Li et al., 2008; Min-Chih, 2019; Ye et al., 2018)
Physical / Mental Limitations	Decision Errors	(Inglis et al., 2010; Liu et al., 2013)
Physical / Mental Limitations	Perceptual Errors	(Inglis et al., 2010)
Physical / Mental Limitations	Violations	(Inglis et al., 2010; Min-Chih, 2019)
Crew Resource Management	Skill-Based Errors	(Li et al., 2008; Min-Chih, 2019; Ye et al., 2018)
Crew Resource Management	Decision Errors	(Berry, 2010; Inglis et al., 2010; Li et al., 2008; Liu et al., 2013; Ye et al., 2018)
Crew Resource Management	Perceptual Errors	(Berry, 2010)
Crew Resource Management	Violations	(Berry, 2010; Lenné et al., 2012; Li et al., 2008; Liu et al., 2013; Sun et al., 2011)
Personnel Readiness	Decision Errors	(Sun et al., 2011)
Personnel Readiness	Perceptual Errors	(Sun et al., 2011; Theophilus et al., 2017)
Personnel Readiness	Violations	(Sun et al., 2011; Theophilus et al., 2017)

The level 5 regulatory influences are likely to effect the level 4 factors of organisational climate (Theophilus et al. 2017) and organisational process (Inglis et al., 2010). In the US, this is by fundamentally changing the typical day-to-day activities of healthcare providers through the increased use of telehealth (organisational process). In Australia, this is by the rapid on-board of contractors who are less familiar to formal and non-formal rules, systems, methods of practice and operating guidelines via the relaxation of return-to-work requirements (organisational climate). In the UK, this is by the suspension of routine quality inspections thus, altering the perceived importance or incentives of continued quality reporting and improvement initiatives (organisational climate).

The influences on organisational climate are likely to increase the incidence of level 3 errors including failures to correct known problems (Min-Chih, 2019) and inadequate supervision (Lenné et al., 2012). In the UK, known problems in an organisation may persist due to the relaxed requirements on quality improvement and reporting initiatives. In Australia, supervisory health officers may wrongfully assume new starters have a higher level of knowledge/capability and as such, provide limited supervision/oversight and potentially assign work roles which are inappropriate for their level of skill or experience. The influences on organisational process is likely to increase the incidence of level 3 errors including supervisory violations (Li et al., 2008), inappropriate planning of operations (Li et al., 2008), failure to correct known problems (Li et al., 2008) and inadequate supervision (Inglis et al., 2010; Li et al., 2008). In the US, the introduction of telehealth could lead to the deteriorating quality of healthcare by not providing sufficient supervision and oversight to junior/less-experienced health professionals.

Following on through the HFACS-PH framework, the abovementioned level 3 errors will increase the likelihood of all level 2 errors (preconditions for unsafe acts), except for contractor environment. In turn, the affected level 2 errors will increase the likelihood of all level 1 errors (unsafe acts), except for acts of sabotage. Thus, it can be seen that there are multiple potential paths for errors to propagate through the US, UK, and Australian public health systems in response to the regulatory changes outlined earlier.

By leveraging Table 1 in combination with the HFACS-PH framework, appropriate and targeted measures can be quickly identified and established to mitigate potential errors at each level. For example, in the US, public healthcare providers at the management (level 4) and supervisory (level 3) level could establish online training modules specific to telehealth and implement internal mentor networks to ensure junior/less-experienced medical professionals are provided with appropriate supervision and experiences to develop professionally. Management would also need to invest in and distribute the technological resources (software and hardware) required to successfully implement telehealth services. In the UK, resources could be made available for the establishment of temporary internal quality auditors at the management level (level 4) and be implemented at the supervisory level (level 3) of ward officers to ensure continued excellence in health, safety and quality management. This would ensure that incidents and near-misses continue to be reported and assessed for any potential improvements in processes, procedures, and work plans. In Australia, the development of additional online training modules specific to COVID-19 practices and guidelines could be implemented at the management level (level 4) and on-the-job shadowing provided at the supervisory level (level 3) to quickly assimilate new workers into their roles and work environment. The ratio of new to experienced staff and the work roles of which temporary workers can fulfil could be also limited (crew resource management – level 2).

4 Conclusions and Future Work

A novel adaptation of the Human Factors Analysis and Classification System (HFACS) in the context of public health systems (HFACS-PH) has been presented. This framework builds on previous adaptations of the HFACS framework to healthcare settings by inclusion of the fifth level ‘Regulatory and Statutory Influences’ as per the HFACS-OGI variant (Theophilus et al. 2017). We have argued that the framework could be used in a *proactive* manner in the public health response to COVID-19 and future pandemics. This could be achieved by leveraging the evidence of causal pathways (paths of association) identified through research investigations in other high-risk, high-reliability industries such as mining (Lenné et al. 2012), process (Baldissone et al. 2019), aviation (Liu, Chi, and Li 2013, Inglis et al. 2010, Li, Harris, and Yu 2008), oil and gas (Theophilus et al. 2017), and construction (Sun et al. 2011, Ye et al. 2018) as well as analysis of adverse drug events in hospitals (Min-Chih 2019).

Ultimately, to confirm the applicability of use of such casual pathways, additional research is required to explore associations between different levels of the HFACS-PH framework. This could be done by applying HFACS coding methods to existing data in incident / near-miss /event reporting systems for hospitals, medical clinics, and other healthcare providers. From this, statistical analyses could be undertaken to identify the strength and direction of any potential associative pathways. Identified causal chains could then be used to predict adverse events *before* they occur and hence, enable more proactive incident management in public healthcare settings. Ultimately, this will improve patient safety outcomes through mitigation of preventable errors in public healthcare provision.

References

Australian Health Practitioner Regulation Agency. (2020). "Australian Health Practitioner Regulation Agency - Pandemic response sub-register." accessed 2 April 2020 https://www.ahpra.gov.au/News/COVID-19/Pandemic-response-sub-register.aspx/.

Baldissone, Gabriele, Lorenzo Comberti, Serena Bosca, and Salvina Murè. (2019). "The analysis and management of unsafe acts and unsafe conditions. Data collection and analysis." *Safety Science* **119**, 240-251. doi: 10.1016/j.ssci.2018.10.006.

Baysari, Melissa T., Andrew S. McIntosh, and John R. Wilson. (2008). "Understanding the human factors contribution to railway accidents and incidents in Australia." *Accident Analysis and Prevention* **40** (5), 1750-1757. doi: 10.1016/j.aap.2008.06.013.

Berry, Katherine. 2010. A meta-analysis of Human Factors Analysis and Classification System causal factors: Establishing benchmarking standards and human error latent failure pathway associations in various domains. edited by Scott A. Shappell, Anand Gramopadhye, Brian Melloy, Paris Stringfellow and Doug Wiegmann: ProQuest Dissertations Publishing.

Bonsu, J., W. van Dyk, J-P. Franzidis, F. Petersen, and A. Isafiade. (2016). "A systems approach to mining safety: an application of the Swiss Cheese Model." *The Journal of the Southern African Institute of Mining and Metallurgy* **116** (1), 777-784. doi: 10.17159/2411-9717/2016/v116n8a10.

Castelfranchi, Christiano. (2000). "Through the Agents' Minds: Cognititve Meaditors of Social Action." *Mind & Society* **1** (1), 109-140.

Chauvin, Christine, Salim Lardjane, Gaël Morel, Jean-Pierre Clostermann, and Benoît Langard. (2013). "Human and organisational factors in maritime accidents: Analysis of collisions at sea using the HFACS." *Accident Analysis and Prevention* **59**, 26-37. doi: 10.1016/j.aap.2013.05.006.

Cohen, Tara N., Jennifer S. Cabrera, Tracy L. Litzinger, Kevin A. Captain, Michael A. Fabian, Steven G. Miles, Scott T. Reeves, Scott A. Shappell, and Albert J. Boquet. (2018). "Proactive Safety Management in Trauma Care: Applying the Human Factors Analysis and Classification System." *Journal for Healthcare Quality* **40** (2), 89-96. doi: 10.1097/JHQ.0000000000000094.

Cohen, Tara N., Sarah E. Francis, Douglas A. Wiegmann, Scott A. Shappell, and Bruce L. Gewertz. (2018). "Using HFACS-Healthcare to Identify Systemic Vulnerabilities During Surgery." *American Journal of Medical Quality* **33** (6), 614-622. doi: 10.1177/1062860618764316.

Collins, Susan J., Robin Newhouse, Jody Porter, and Akkeneel Talsma. (2014). "Effectiveness of the Surgical Safety Checklist in Correcting Errors: A Literature Review Applying Reason’s Swiss Cheese Model." *AORN Journal* **100** (1), 65-79. doi: 10.1016/j.aorn.2013.07.024.

de Vries, E.N., M.A. Ramrattan, S.M. Smorenburg, D.J. Gouma, and M.A. Boermeester. (2007). "The incidence and nature of in-hospital adverse events: a systematic review." *Quality and Safety in Health Care* **17** (3), 216-223. doi: 10.1136/qshc.2007.023622.

Diller, Thomas, George Helmrich, Sharon Dunning, Stephanie Cox, April Buchanan, and Scott Shappell. (2014). "The Human Factors Analysis Classification System (HFACS) Applied to Health Care." *American Journal of Medical Quality* **29** (3), 181-190. doi: 10.1177/1062860613491623.

ElBardissi, Andrew W., Douglas A. Wiegmann, Joseph A. Dearani, Richard C. Daly, and Thoralf M. Sundt. (2007). "Application of the Human Factors Analysis and Classification System Methodology to the Cardiovascular Surgery Operating Room." *The Annals of Thoracic Surgery* **83** (4), 1412-1419. doi: 10.1016/j.athoracsur.2006.11.002.

Ergai, Awatef, Tara Cohen, Julia Sharp, Doug Wiegmann, Anand Gramopadhye, and Scott Shappell. (2016). "Assessment of the Human Factors Analysis and Classification System (HFACS): Intra-rater and inter-rater reliability." *Safety Science* **82** (1), 393-398. doi: 10.1016/j.ssci.2015.09.028.

Fukuoka, Koji, and Masao Furusho. (2016). "Relationship between latent conditions and the characteristics of holes in marine accidents based on the Swiss cheese model." *WMU Journal of Maritime Affairs* **15** (2), 269-292. doi: 10.1007/s13437-015-0099-8.

Gholam Abbas, Shirali, Pour Mojtaba Nakhaei, Jahani Fereshteh, Shakib Mehdi, and Mir Iman. (2018). "Identification and Evaluation of Human Errors Leading to Incidents in a Gas Refinery using Human Factors Analysis and Classification System." *Muhandisī-i bihdāsht-i ḥirfah/ī* **4** (4), 1-11. doi: 10.21859/johe.4.4.1.

Griggs, Forrest J. 2012. A Human Factors Analysis and Classification System (HFACS) Examination of Commercial Vessel Accidents. edited by Ca Naval Postgraduate School Monterey.

Gui, Ye, Tan Qin, Gong Xiaoli, Xiang Qingting, Wang Yuhe, and Liu Qinjun. (2018). "Improved HFACS on Human Factors of Construction Accidents: A China Perspective." *Advances in Civil Engineering* **2018**. doi: 10.1155/2018/4398345.

Harris, Don, and Wen-Chin Li. (2019). "Using Neural Networks to predict HFACS unsafe acts from the pre-conditions of unsafe acts." *Ergonomics: Ergonomics and Human Factors in Aviation* **62** (2), 181-191. doi: 10.1080/00140139.2017.1407441.

Hoffman, Ronald B., Cindy G. Segal, Julie A. Foster, and Laura C. Rhoads. (2013). "Adaptation of the Human Factors Analysis and Classification System to Patient Safety Studies." *2013 International Symposium on Human Factors and Ergonomics in Health Care: Advancing the Cause*.

Hughes, Ashley M., Shirley Sonesh, Stephanie Zajac, and Eduardo Salas. (2013). "Leveraging HFACS to Understand Medication Error in Emergency Medical Services (EMS): A Systemtic Review." *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* **57** (1), 1688-1692. doi: 10.1177/1541931213571375.

Inglis, M., M.J. Smithson, K. Cheng, D.R. Stanton, and S.T. Godley. 2010. Evaluation of the Human Factors Analysis and Classification System as a predictive model. Canberra, Australian Capital Territory: Australian Transport Safety Bureau.

Kopach-Konrad, Renata, Mark Lawley, Mike Criswell, Imran Hasan, Santanu Chakraborty, Joseph Pekny, and Bradley N. Doebbeling. (2007). "Applying Systems Engineering Principles in Improving Health Care Delivery." *Journal of General Internal Medicine* **22**, 431-437. doi: 10.1007/s11606-007-0292-3.

Lenné, Michael G., Paul M. Salmon, Charles C. Liu, and Margaret Trotter. (2012). "A systems approach to accident causation in mining: An application of the HFACS method." *Accident Analysis and Prevention* **48** (1), 111-117. doi: 10.1016/j.aap.2011.05.026.

Li, Wen-Chin, and Don Harris. (2013). "Identifying Training Deficiencies in Military Pilots by Applying the Human Factors Analysis and Classification System." *International Journal of Occupational Safety and Ergonomics* **19** (1), 3-18. doi: 10.1080/10803548.2013.11076962.

Li, Wen-Chin, Don Harris, and Chung-San Yu. (2008). "Routes to failure: Analysis of 41 civil aviation accidents from the Republic of China using the human factors analysis and classification system." *Accident Analysis and Prevention* **40** (1), 426-434. doi: 10.1016/j.aap.2007.07.011.

Li, Y., and H. Thimbleby. (2014). "Hot cheese: a processed Swiss cheese model." *Journal of the Royal College of Physicians of Edinburgh* **44** (2), 116-121. doi: 10.4997/JRCPE.2014.205.

Lipsitz, Lewis A. (2012). "Understanding Health Care as a Complex System: The Foundation for Unintended Consequences." *Journal of the American Medical Association* **308** (3), 243-244.

Liu, Shao-Yu, Chia-Fen Chi, and Wen-Chin Li. 2013. "The Application of Human Factors Analysis and Classification System (HFACS) to Investigate Human Errors in Helicopter Accidents." Engineering Psychology and Cognitive Ergonomics. Applications and Services, Berlin, Heidelberg, 2013//.

Madigan, Ruth, David Golightly, and Richard Madders. (2016). "Application of Human Factors Analysis and Classification System (HFACS) to UK rail safety of the line incidents." *Accident Analysis and Prevention* **97**, 122-131. doi: 10.1016/j.aap.2016.08.023.

March, James G. (2003). "Understanding Organisational Adaptation." *Society and Economy* **25** (1), 1-10.

Martin, C.M. (2017). "Complex adaptive systems approaches in health care - A slow but real emergence?" *Journal of Evaluation in Clinical Practice* **24** (1), 266-268. doi: 10.1111/jep.12878.

Miles, Andrew. (2009). "Complexity in medicine and healthcare: people and systems, theory and practice." *Journal of Evaluation in Clinical Practice* **15** (1), 409-410. doi: 10.1111/j.1365-2753.2009.01204.x.

Min-Chih, Hsieh. (2019). "The investigation of human error analysis in adverse drug events in Taiwan—From the perspective of causality assessment." *Human Factors and Ergonomics in Manufacturing* **29** (4), 340-349. doi: 10.1002/hfm.20791.

Neuhaus, Chistopher, Matthias Huck, Gotz Hofmann, Michael St. Pierre, Markus A. Weigand, and Christoph Lichtenstern. (2018). "Applying the human factors analysis and classification system to critical incident reports in anaesthesiology." *Acta Anaestheiologica Scandinavica* **83** (4), 1412-1419. doi: 10.1111/aas.13213.

Patterson, Jessica M., and Scott A. Shappell. (2010). "Operator error and system deficiencies: Analysis of 508 mining incidents and accidents from Queensland, Australia using HFACS." *Accident Analysis and Prevention* **42** (4), 1379-1385. doi: 10.1016/j.aap.2010.02.018.

Perneger, Thomas V. (2005). "The Swiss cheese model of safety incidents: are there holes in the metaphor?" *BMC Health Services Research* **5** (1), 71-77. doi: 10.1186/1472-6963-5-71.

Rasmussen, Jens. (1997). "Risk management in a dynamic society: a modelling problem." *Safety Science* **27** (2-3), 183-213. doi: 10.1016/S0925-7535(97)00052-0.

Reason, James. (1995). "A systems approach to organisational error." *Ergonomics* **38** (8), 1708-1721. doi: 10.1080/00140139508925221.

Reason, James. (2000). "Human error: models and management." *British Medical Journal* **320** (7237), 768-770. doi: 10.1136/bmj.320.7237.768.

Reason, James T. (1990). *Human Error*. Cambridge: Cambridge University Press.

Reinach, Stephen, and Alex Viale. (2006). "Application of a human error framework to conduct train accident/incident investigations." *Accident; Analysis and Prevention* **38** (2), 396. doi: 10.1016/j.aap.2005.10.013.

Shappell, Scott A., and Douglas A. Wiegmann. 2000. The Human Factors Analysis and Classification System - HFACS. Washington, DC 20591: U.S. Department of Transportation

Simon, Herbert A. (1990). "Invariants of Human Behaviours." *Annual Review of Psychology* **41** (1), 1-19.

Simon, Herbert A. (2001). "Complex Systems: The Interplay of Organisations and Markets in Contemporary Society." *Computational & Mathematical Organisation Theory* **7** (1), 79-85.

Stenvall, Jari, and Petri Virtanen. (2017). "Intelligent Public Organisations." *Public Organizational Review* **17** (1), 195-209. doi: 10.1007/s11115-015-0331-1.

Sturmberg, Joachim P., Di M. O'Halloran, and Carmel M. Martin. (2012). "Understanding health system reform – a complex adaptive systems perspective." *Journal of Evaluation in Clinical Practice* **18** (1), 202-208. doi: 10.1111/j.1365-2753.2011.01792.x.

Sun, Kai, Jian Zhou, Zhi Sun, and Kun Li. 2011. Correlation Analysis of Behavioral Factors of Construction Safety Based on the Chi-Square Test. Zurich: Trans Tech Publications Ltd.

Theophilus, Stephen C., Victor N. Esenowo, Andrew O. Arewa, Augustine O. Ifelebuegu, Ernest O. Nnadi, and Fredrick U. Mbanaso. (2017). "Human factors analysis and classification system for the oil and gas industry (HFACS-OGI)." *Reliability Engineering and System Safety* **167** (1), 168-176. doi: 10.1016/j.ress.2017.05.036.

Underwood, Peter, and Patrick Waterson. (2014). "Systems thinking, the Swiss Cheese Model and accident analysis: A comparative systemic analysis of the Grayrigg train derailment using the ATSB, AcciMap and STAMP models." *Accident Analysis and Prevention* **68** (1), 75-94. doi: 10.1016/j.aap.2013.07.027.

Vlayen, Annemie, Sandra Verelst, Geertruida E. Bekkering, Ward Schrooten, Johan Hellings, and Neree Claes. (2010). "Incidence and preventability of adverse events requiring intensive care admission: a systematic review." *Journal of Evaluation in Clinical Practice* **18** (1), 485-197. doi: 10.1111/j.1365-2753.2010.01612.x.

Wiegmann, Douglas A., and Scott A. Shappell. (2003). *A Human Error Approach to Aviation Accident Analysis: The Human Factors Analysis and Classification System*. New York, USA: Ashgate Publishing.

Willan, John, Andrew John King, Katie Jeffery, and Nicola Bienz. (2020). "Challenges for NHS hospitals during covid-19 epidemic." *British Medical Journal* **368** (1), 1-2. doi: 10.1136/bmj.m1117.

World Health Organisation. (2019). "Patient Safety." accessed 9 June 2020. https://www.who.int/news-room/fact-sheets/detail/patient-safety.

Xia, Nini, Patrick X. W. Zou, Xing Liu, Xueqing Wang, and Runhe Zhu. (2018). "A hybrid BN-HFACS model for predicting safety performance in construction projects." *Safety Science* **101**, 332-343. doi: 10.1016/j.ssci.2017.09.025.

Ye, Gui, Qin Tan, Xiaoli Gong, Qingting Xiang, Yuhe Wang, and Qinjun Liu. (2018). "Improved HFACS on Human Factors of Construction Accidents: A China Perspective." *Adances in Civil Engineering* **2018**, 1-15. doi: 10.1155/2018/4398345.

Yıldırım, Umut, Ersan Başar, and Özkan Uğurlu. (2019). "Assessment of collisions and grounding accidents with human factors analysis and classification system (HFACS) and statistical methods." *Safety Science* **119**, 412-425. doi: 10.1016/j.ssci.2017.09.022.

Zhou, Tuqiang, Junyi Zhang, and Dashzeveg Baasanuren. (2018). "A Hybrid HFACS-BN Model for Analysis of Mongolian Aviation Professionals' Awareness of Human Factors Related to Aviation Safety." *Sustainability* **10** (1), 4522-4542. doi: 10.3390/su10124522.