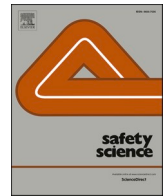




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A systematic approach to public health – Novel application of the human factors analysis and classification system to public health and COVID-19

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ABSTRACT

In this article, we argue for a novel adaptation of the Human Factors Analysis and Classification System (HFACS) to *proactive* incidence prevention in the public health and in particular, during and in 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 tertiary and secondary healthcare workers to primary public health officials, regulators, and policymakers).

1. Introduction

Principles of behavioural change (West et al., 2020) and science (Bonell et al., 2020), human factors, and ergonomics (Gurses et al., 2020; Sasangohar et al., 2020) have the potential to contribute significantly in controlling the spread of COVID-19 and minimising the health and socioeconomic effects of the novel coronavirus and beyond that to support health interventions/initiatives more generally (Voyer, 2015) with, for example, promising results in studies targeting tobacco consumption, physical activity, and eating behaviours (Blaga et al., 2018). 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, failures, and conditions that result in 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 and identify the causal pathways through which failures propagate to incidents. Given that humans are involved in every stage of an engineered solution including design, assembly, transportation, installation, use, maintenance, and dismantling/decommissioning (Glock et al., 2017), it also makes good practical sense to explore the impact of human factors on public health at all levels (i.e.,

primary, secondary, and tertiary). A proactive prevention toolkit is particularly important in complex environments which are more likely to be affected by risks, uncertainty, and adverse events.

Shappell and Wiegmann's (2000) original HFACS framework has been adapted to the public health domain and aptly named HFACS-PH. HFACS-PH has been developed with due consideration of the specific structure, governance, culture, and dynamics of the public health system (see Fig. 1). Supported by evidence from the literature, we introduce seven additional error/failure/condition categories: 'Acts of Sabotage' at Level 1; 'Social Environment' at Level 2; 'Management of Change' at Level 4; and all of Level 5 which includes 'International Regulatory Framework', 'National Regulatory Framework', 'Socio-political Context', and 'Ecological Influences'. We then present the same HFACS-PH model with an overlay of the statistically significant causal pathways (in orange) that were identified in the literature review (see Fig. 2). This serves to provide an example of a visual tool or checklist to be used to design, implement, monitor, and assess public health initiatives and policy. Checklists have proven successful in other high-risk, high-reliability domains and increasingly being applied, in primary healthcare (Hales and Pronovost, 2006) in particular, the surgery operating room (Borchard et al., 2012; de Vries et al., 2009; Weiser et al., 2010) and even to guide the design and deployment of clinical decision support systems (Van de Velde et al., 2018). We contend that HFACS-PH can provide its form and structure to achieve similar outcomes in the wider

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context of public health.

In the following sections, we will first explore the concept of public health and also the public health system itself. We then turn focus onto human errors and in particular, those specific to the public health domain. Next, we introduce the original the use of HFACS-PH as a *pro-active* incident management tool, exploring the potential implications of regulatory changes implemented during and in response to COVID-19 on public health in the United States (US), United Kingdom (UK), and Australia. Finally, we summarise our findings and suggest future directions for HFACS-PH research and practice.

2. Public health

Public health is a somewhat vague term used to describe both the health of the public (i.e., the public’s health) and the network of actors and institutions involved in the design, implementation, monitoring, and analysis of public health interventions and initiatives (i.e., the public health system). This obviously can cause great confusion so in this article, unless explicitly stated, when we refer to public health, we are referring to the latter.

Public health aims to improve the health of the population at large and as such, focuses on community outcomes, interventions, and behaviour change, often through prevention rather than direct treatment of disease and illness. As Schneider (2020) suggests, it can be

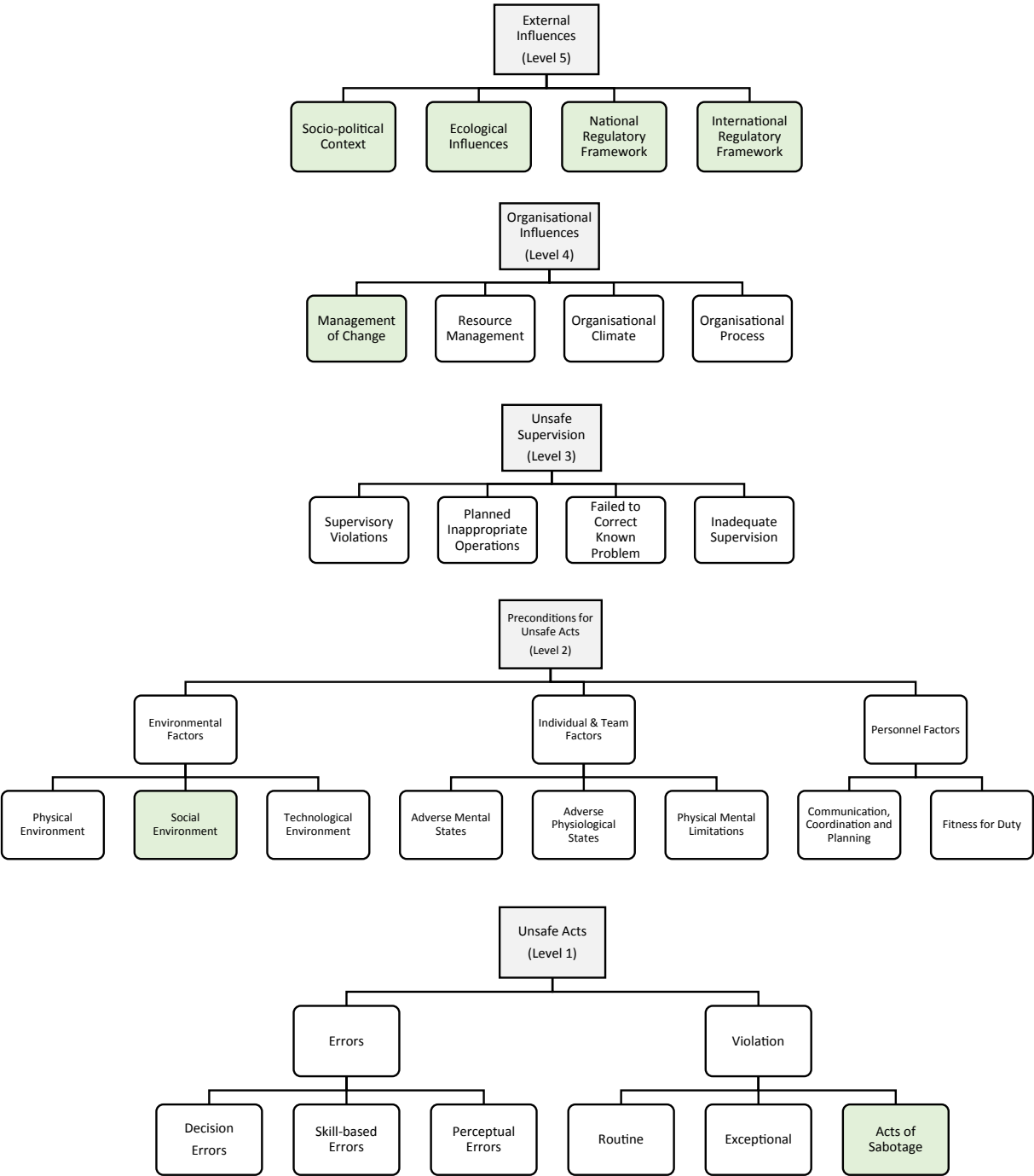


Fig. 1. Public Health Adaptation to the HFACS Framework (HFACS-PH) – additions to the baseline HFACS framework are shown in green.

useful to think of such prevention efforts on three levels: primary (i.e., preventing exposure to illness/disease risk factors outright), secondary (i.e., minimizing the severity and damage of illness/disease), and tertiary (i.e., minimizing disability by providing medical care and rehabilitation). This functional distinction provides a useful and multi-level conceptual framework to approach the many ‘wicked’ problems that plague public health from more than one angle. For example, in the current COVID-19 pandemic the interventions for primary prevention of pandemic spread include social distancing guidelines, public event cancellations, and enforced city- or country-wide lockdowns to name a few (see, e.g., [Hsiang et al., 2020](#) for a more thorough account of COVID-19 pandemic policies). Secondary prevention includes mandated or

recommended testing and contact tracing programmes and minimum isolation/quarantine periods for infected individuals to minimize the interaction between the infected and susceptible in the community. Tertiary prevention involves the treatment and rehabilitation of patients with more serious cases of COVID-19 requiring hospital treatment and may also include emergency treatment by paramedics in some cases.

More often than not it is expected that government (local, state or national) will fulfil the primary role in delivering and directing public health through three core functions: assessment, policy development, and assurance ([Schneider, 2020](#)). These three core functions serve as the basis for a more concrete set of activities: ‘The Ten Essential Public Health Services’ ([IOM, 2002](#)). While the concerted efforts of private and

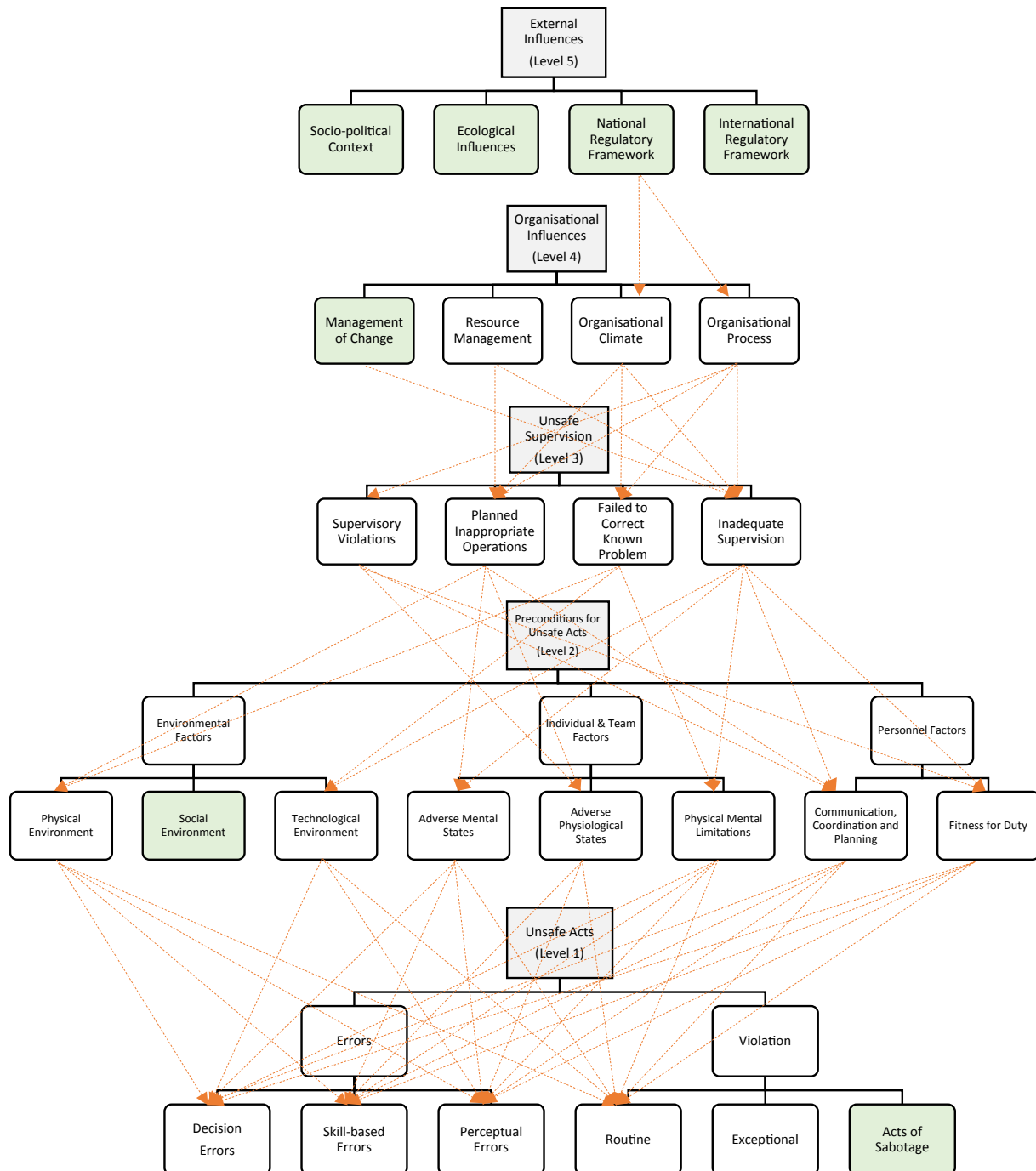


Fig. 2. Public Health Adaptation to HFACS Framework (HFACS-PH) with causal chains (statistically significant paths of association) in orange – depicts the possible paths of error propagation (from higher levels to lower levels) through the HFACS-PH Framework.

voluntary organizations and individuals should not be ignored, the state has always played a major role in public health and in particular, for positive and proactive promotion of 'good' health (Beaglehole and Bonita, 2004). However, as per US Institute of Medicine's conceptualization of a public health system, public health is made up of "a complex network of individuals and organizations that have the potential to play critical roles in creating the conditions for health" (IOM, 2002, p. 28). Public health interventions themselves are also complex systems, engaging networks of actors from various sectors (e.g., education, transportation, urban planning, police) and spheres (public, private, and community) with knowledge, resources, procedures, and technologies across varied spatio-temporal scales (Hawe, 2015). Such actors can include both organizations and agencies which are formally charged with driving public health policy and delivery (e.g., WHO, government), and non-governmental agencies and interest groups engaged in various lobbying and campaigning efforts (Hunter et al., 2010). Here, a visual framework comes in handy and we point the interested reader towards Dahlgren and Whitehead's (1991) 'rainbow diagram' (including socio-economic, cultural and environmental conditions at the 'top' level, living and working conditions at the next level down, social and community networks a level below this, individual lifestyle factors at the next level down and personal characteristics (e.g., age, sex, hereditary factors) at the 'base' level) and Barton and Grant's (2006) revised 'rainbow diagram' (including global ecosystem as the outer layer encompassing all levels including (respectively from 'top' to 'base' level) natural environment, built environment, living and working activities, local economy, community, lifestyle, and personal characteristics).

It is not difficult to relate human health to the environment, and equally, to social-ecological systems (also called human-environment systems) (Zinsstag et al., 2011) which consider the extricable linkages between humans, their socioeconomic systems, and their embedded environment. These systems relate outcomes (which can also be outcomes shared by public health) to systemic interactions between a resource system (e.g., a lake), its resource units (e.g., fish), the users of that system, and its governance system at a particular time and place and are embedded within larger (and smaller) socioeconomic, cultural, political, and ecological settings which give context to such complex and unpredictable interactions, outcomes, and historical (and evolving) conditions (Ostrom, 2007). Starting with the concept of 'One Medicine' – the acknowledgement of the similarity between veterinary and human medicine science and practice and the complex intertwined nature of human and animal health (Schwabe, 1964) – there is increasing recognition of and call for research on the complex and profound relationship between human health, animal health, and the health of the broader environment in which they are all embedded (Destoumieux-Garzon et al., 2018; Zinsstag et al., 2012). 'One Health' (going one step further than 'One Medicine' with the inclusion of environment) has been widely applied within public health, employed extensively in infectious disease surveillance, mapping, and control (Zinsstag et al., 2012), used to prevent and control antimicrobial resistance (Guardabassi et al., 2020; Rousham et al., 2018) and tick-borne diseases (Dantas-Torres et al., 2012), establish transformative approaches to food safety and security (Garcia et al., 2020), and in addressing chronic non-communicable diseases such as obesity (Bartges et al., 2017; Bomberg et al., 2017). Zinsstag et al. (2011) go one step further with their 'health in social-ecological systems' approach which considers not social and ecological determinants of human and animal (domesticated and wild) health, but also the social and ecological consequences of health interventions. Such systemic and comprehensive approaches to public health may even provide a more effective and equitable approach to public health interventions, particularly in low-resource settings (Cleaveland et al., 2017).

The World Health Organisation (2019) suggests that the increasing complexity of tertiary healthcare networks, policy, and practice makes 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 to 76.5% of adverse events resulting in admissions to an Intensive Care Unit (ICU) are preventable. Mistakes are also made at the policy and implementation levels for public health efforts. This can include failures to identify the root-cause of problems, ill-defined or inappropriate policy design and planning, and vague and/or subjective monitoring and reporting measures, to name a few. Relying heavily on retrospective accounts as sources of data and solutions are problematic due to, for example retrospective biases (Fischhoff, 2007). As March (1999) stresses, "[s]torylines and personal interests are intertwined to produce a fable that fits expectations and, as much as possible, confirms a story teller's conceptions of self-worth and the worth of others" (p. 345).

Clearly, taking an incident prevention approach (as opposed to a more reactive treatment) in public health would be of major benefit to population health and societal outcomes. This is particularly true in the current COVID-19 pandemic, where non-pharmaceutical interventions (NPIs) have been implemented by governments and organizations across the globe to prevent and limit the spread and contagion of COVID-19 (Bonell et al., 2020; Hale et al., 2021), hence increasing the need and demand for human and behavioural insights to inform pandemic policy and practice (Bonell et al., 2020; Gurses et al., 2020; Sasangohar et al., 2020; West et al., 2020). At the tertiary level, hospital systems have experienced a significant surge in demand, combined with staff absences of up to 20% due to illness or self-isolation requirements (Willan et al., 2020) placing further stresses on already overloaded tertiary healthcare networks. It is in these pressing times that humans are more likely to make mistakes and hence, an understanding of the antecedents and processes of human error in judgement, decision-making, and practice is a must. Snowden (2019) who has explored historically shows that major epidemics in history have often caught authority unprepared leading to confusion, chaos, and improvisation. This therefore requires finding ways of identifying and implementing tools that allow for a better societal preparedness and safety.

3. Human error

Reason (2000) introduces the human error problem through two lenses: 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 individuals and penalties dealt accordingly. In contrast, the systems approach views unsafe acts as arising from systemic weaknesses in organisations and institutions. In the systems approach, safety barriers or countermeasures are implemented at various levels of an organization or institution (management, supervisory, environment and front-line) with the aim of preventing exposure to the hazardous conditions and failures through which human 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 public health and tertiary 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 (Kopach-Konrad et al., 2007; Lipsitz, 2012; Martin, 2017; Miles, 2009; Sturmberg et al., 2012) embedded in specific contexts (social, economic, cultural, geographical, ecological). Similar systems approaches have subsequently been used to provide recommendations to reduce errors, failures, and maladaptive conditions in tertiary health surgery operating rooms (Dankelman and Grimbergen, 2005): standardization of procedures, processes, and toolkits; optimizing the information collection and dissemination process by using checklists and reminders; optimization of equipment and technology and standardization with lifecycle planning; reduction of sociotechnical system complexity; and comprehensive but cost-effective training and education programmes.

4. 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 such a framework: a formalised and hierarchical taxonomy of human errors and latent conditions. HFACS was developed based on Reason's (1990) Swiss-Cheese model, leveraging the four hierarchical levels of human active and latent failures: 'Unsafe Acts', 'Preconditions for Unsafe Acts', 'Unsafe Supervision', and 'Organizational Influences', from the lowest to highest levels, respectively. 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 was proposed by Rasmussen (1997).

As the Nuffield Council on Bioethics (2007) working group have suggested, "the many factors affecting health create problems for public health professionals and policy makers, as it is often difficult to identify a single causal factor for a specific population health problem" (p. 5). HFACS (once adapted) could lend its form and structure to such public health problems by providing a comprehensive framework of causal errors, failures, and conditions through which to design, modify, implement, and assess public health interventions and initiatives at multiple levels. After all, it is more efficient to intervene on multiple behaviours (which contribute to an individual's overall health profile) at the same time rather than in isolation, and this may even increase the likelihood of sustainable and lasting health outcomes (Prochaska et al., 2008). Inevitably, interventions targeted at single risk behaviours will always be limited in their impact (Hayes et al., 1999), hence by adapting HFACS to public health, multi-level interventions (those offering more sustainable, wide-spread, and lasting outcomes) can be identified and acted on. Like police fatal shootings (McFarlane and Amin, 2021), the legitimacy of public health outcomes and investigations of failures of public health could potentially be improved by adopting a systematic and structured framework like HFACS to provide transparency, accountability and also ease-of-use/application, supporting measurable performance and assessment on 'The Ten Essential Public Health Services' (IOM, 2002). Further, with HFACS we can reveal the latent problems in systems which cannot be adequately and routinely

addressed through the more traditional techniques such as root cause analysis (RCA) (Wang, 2020), which often fall short of identifying causal factors outside of the immediate (temporal and spatial) vicinity of the incident in question.

HFACS (owing to its high operability and taxonomic nature) is easily applied in a variety of industries and activities and is more suitable for multiple incident case studies and in identifying incident trends. HFACS provides a systematic methodology for analysing incident data through HFACS nanocode (e.g., see HFACS-PH practitioner's user guide and nanocode scheme/framework in *Supplementary Information*), increasing the robustness of learning without depriving the richness of textual and semantic information, and allows for easy aggregation across incident cases to assist in the identification of patterns, themes, or trends that consistently cause problems and issues (Cohen et al., 2018). Ultimately, it generally acknowledged that any quantitative prediction of human factors must be based on qualitative analysis, and this should include considerations of the embedded context (Hollnagel, 2000).

HFACS in general has been shown to possess both inter- and intra-rater reliability (Cohen et al., 2015; Ergai et al., 2016) however, with more detailed breakdown of the HFACS framework (by using a nanocode scheme) comes higher incidence of disagreement between raters, *but* only for those which *may* be causally related and not for those which are deemed unlikely to be causally related or irrelevant to the situation outright (O'Connor, 2008; Olsen and Shorrock, 2010). However, there is evidence that a process of thorough review and refresh every once-in-a-while can lead to promising results for inter-rater reliability when using HFACS nanocoding schemes and structures (King, 2015), and some form of education/training for users is required regardless of which framework you employ. We point the interested reader towards Hulme et al. (2019) for a comprehensive systematic review of HFACS and other systems thinking accident analysis methods including AcciMap, STAMP and FRAM.

HFACS is proven across many industries and contexts, and it also appears to help reduce some of the subjectivity inherent in incident investigations and analyses by ensuring a consistent and transparent data collection and analysis processes (Hale et al., 2012; Reinach and Viale, 2006). For public health and public policy more generally, there is great societal value and expectation to develop and maintain transparent policy and measurable progress (Ball, 2009), particularly when issues of fairness and equity enter the equation (Finkelstein, 2000). This is also particularly important for effective pandemic planning (French, 2011) and during public health emergencies in general (O'Malley et al., 2009), further supporting the notion of utilising HFACS as a tool for greater transparency in public health policy and intervention as it can provide "understandable, usable, quality information to the public on inputs, outputs, and outcomes" (Ball, 2009, p. 300) in both visual, qualitative, and quantitative forms.

The HFACS framework has been applied in retrospective incident analysis across numerous high-risk, high-reliability industries including aviation (Li et al., 2008; Li and Harris, 2013; Wiegmann and Shappell, 2003; Zhou et al., 2018), maritime (Chauvin et al., 2013; Griggs, 2012; Yildirim et al., 2019), rail (Baysari et al., 2008; Madigan et al., 2016; Reinach and Viale, 2006), mining (Lenné et al., 2012; Patterson and Shappell, 2010), oil and gas (Shirali et al., 2018; Theophilus et al., 2017), process safety management (Theophilus et al., 2018), natural disaster management (Brooks 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 tertiary healthcare service delivery in hospitals (Diller et al., 2014), surgery operating rooms (Cohen et al., 2018; ElBardissi et al., 2007; Thiels et al., 2015), pre-hospital emergency medical services (Hughes et al., 2013), anaesthesiology incidents (Neuhaus et al., 2018), trauma care (Cohen 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 (Baldissoni et al., 2019), aviation (Hooper

and O'Hare, 2013; Inglis et al., 2010; Li et al., 2008; Liu et al., 2013), 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) and even classify HFACS nanocodes from text data (Madeira et al., 2021). In the tertiary 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).

In the following sections, we describe each of the four levels (and their sub-categories) of the original HFACS framework as presented by Shappell and Wiegmann (2000). We also introduce more recent modifications to the HFACS framework at each level and in particular, the introduction of a Level 5 (or not) of the HFACS framework.

4.1. 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 and/or loss of situational awareness). 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).

Modifications at this level of HFACS can include 'Acts of Sabotage' (i.e., deliberate acts to negatively affect the system, process, work, or production – see Theophilus et al. (2017) for example). The authors cited no other modifications at this level of HFACS.

4.2. 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., semi-permanent or permanent limitations on 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 communication, coordination, and planning (e.g., shift planning and team pairing), and fitness for duty (e.g., training, and physical readiness).

Modifications at this level of HFACS can include 'Contractor Environment' (i.e., use of contractor services and partnerships and issues relating to their on-boarding and adherence to client policies, standards, and procedures – see Theophilus et al. (2017) for example), 'Task Factors' (i.e., task type, equipment required, and task tempo – see for example), 'Hazards by Others' (i.e., a hazardous condition created by (unknown) parties other than the victims – see Wong et al., 2016 for example), and 'Social Environment' (i.e., social pressures and social

psychological phenomena which lead to underestimation of risks and contribute to poor decision making and use of ineffective heuristics – see Paletz et al., 2009 for example). This level of HFACS has also been linked to the SHEL (software, hardware, environment, and liveware) model for causal factors associated with the 'sharp-end' of the incident environment (Chen et al., 2013; Theophilus et al., 2017).

4.3. 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). In addition, the authors cited no modifications at this level of HFACS.

4.4. 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.

Modifications at this level of HFACS can include 'Management of Change' (i.e., management and planning of modifications to processes, technology, equipment, procedures, and facilities – see Theophilus et al., 2017 for example), 'Safety Management' (i.e., procedures, operational planning, information management/feedback, and management oversight specifically focused on safety outcomes for personnel, plant and process – see Hale et al. (2012) for example), 'Organizational Competence' (i.e., technical knowledge, experience, and ability of the organization as a whole – see also Hale et al., 2012) and 'Management Violations' (i.e., senior-level and executive management violations and short-cutting of existing organization procedures and processes, and externally-imposed regulations – see Reinach and Viale (2006) for example).

4.5. Higher levels (or Not)

Some adaptations of HFACS have included a Level 5, most often to incorporate some element of external influence such as government (national and international), nature, the public, and/or the media. Theophilus et al. (2017), for example, include a Level 5 ('Regulatory and Statutory Influences') for their Oil and Gas Industry (HFACS-OGI) adaptation and note in particular that factors and failures "are mainly concentrated on deficiency with respect to national and international standards" (p. 170) and compliance with approved codes of conduct. Others have included legislation gaps, administration oversight and design gaps (Chen et al., 2013); political, regulatory, market and social/societal influences (Hale et al., 2012); regulatory oversight, and economic, political, social and legal environment (Reinach and Viale, 2006); and regulatory factors (i.e., government regulations and policies, and regulator inspections and enforcement) and other (e.g., economic

pressures, environmental concerns, and legal pressure) (Patterson and Shappell, 2010).

5. A public health adaptation (HFACS-PH)

Fig. 1 illustrates the proposed HFACS-PH framework which includes five levels at which errors, failures, and conditions can eventuate. Each higher level influences the next downward level creating causal chains which can propagate through to incident causation. The additional categories to the original HFACS framework are highlighted in green. In Fig. 2, the causal relationships identified in the literature cited in Section 4 (see Table S1 in the Supplementary Information for a summary of the cited literature) have been overlayed onto the HFACS-PH framework (in orange) to provide a visual tool to enable the proactive management of potential causal pathways *before* incidents occur. Together, these tools could be used to design, implement, monitor, and assess public health initiatives and policy and we demonstrate its use as one in the following section in assessing the potential implications of regulatory changes introduced by the US, UK, and Australia during and in response to the global COVID-19 pandemic.

In HFACS-PH, Level 1 can correspond to errors and violations made by tertiary and/or secondary medical professionals (e.g., doctors, nurses, and other allied health) as well as the general public in adhering to public health directives and policy. Errors can be due to poor decision-making, skill-based, or perceptual errors/failures. Violations can be routine (e.g., routine non-compliance with social distancing rules), exceptional (e.g., forgetting to stay home, get tested, or self-isolate when displaying flu-like symptoms), or acts of sabotage (e.g., outright refusal and protest against strict social distancing and self-isolation mandates). Level 2 corresponds to contextual factors which most directly (temporally and spatially) increase the likelihood of unsafe acts for both tertiary/secondary medical professionals and the general public. These can be environmental (e.g., unsanitary and/or overcrowded environments, ill-equipped contact tracing systems and technology, and social norms/conventions), individual (e.g., stressed, fatigued, or ill staff), or personnel factors (e.g., poor communication/coordination, lack of preparedness and training). Level 3 corresponds to higher-level public health officials and state departments of public health which may inadequately train, advise and supervise the implementation of public health interventions and enforcement of regulations. Errors at Level 3 may also include blatant supervisory violations (e.g., underreporting of COVID-19 related statistics and adverse incidents), inadequate operational planning (e.g., poor shift planning/pairing, inappropriate plan to actual conditions, failure to provide correct information and data, and planned operational activities which do not meet regulatory/statutory compliance requirements), and failure to correct known problems (e.g., failure to identify and communicate the gaps and deficiencies of COVID-19 plans, and failure to implement corrective actions). Level 4 corresponds to upper management and executive decision-making errors and shortcomings by National Public Health departments and country-level organizations including poor resource management (e.g., PPE shortages, low funding, outdated/irrelevant technology systems), organizational climate (e.g., culture, organizational structure, and policies), process (i.e., everyday processes and procedures which govern the operation and monitoring of organizations), and management of change (e.g., processes, plans and procedures for technology, procedural, organizational and facility restructures, modifications and upgrades). Level 5 corresponds to external influences including the international and national regulatory frameworks (e.g., standards, licensing, and minimum skills/education requirements, and enforcement/monitoring of such), socio-political context (e.g., social activism, political tensions, war, income inequality), and ecological influences (e.g., local, regional, national, and/or global natural, economic, social, and environmental ecosystems) in which a public health system is embedded. For example, the Europe's COVID-19 vaccine roll-out delays suffered, for example, according to *The Economist* (2021) from the European Commission being

"inexperienced and slow, signing deals months after Britain. It got bogged down in haggling with drugs firms over liability and price – mere details in a pandemic" (p. 10).

For easy reference we provide a description and examples for each of the HFACS-PH levels and their errors/conditions/factors in Table 1. The HFACS-PH modifications/additions to the original HFACS framework are highlighted in orange and include 'Acts of Sabotage' at Level 1, 'Social Environment' at Level 2, 'Management of Change' at Level 4, and all of Level 5 which includes 'International Regulatory Framework', 'National Regulatory Framework', 'Socio-political Context', and 'Ecological Influences'.

As we have seen in recent times, populations can outrightly refute and protest public health interventions with the potential to enable unexpected and adverse outcomes to proceed. For example, during COVID-19 we have seen protests in various countries on claims of the restriction of freedom owing to the introduction strict pandemic policies (Reicher and Stott, 2020) including city- and country-wide lockdowns, mandatory quarantine and self-isolations, and curfews. Such protest and disagreement with policy and authority may be localised to certain socioeconomic area or extend across expansive regions and may or may not be directly related to COVID-19 (e.g., Black Lives Matter protests Gibson et al., 2020 and presidential campaigns). Regardless of context and sentiment, the evidence for intentional departures and refusals to comply with public health advice and policy provides support for the inclusion of 'Acts of Sabotage' at Level 1 of HFACS-PH.

Literature reporting on the relationship between social environment and health is on three lines of focus: (1) describing the role of community socioeconomic status on health risks, characteristics, behaviours, and literacy, (2) the influence of social structures on health including structural discrimination, and organizational diversity, and income inequality/distribution, and (3) measuring the quality (and perceived quality) of the environment including neighbour services, crime, problems such as vandalism, litter, pollution, and traffic (Yen and Syme, 1999). These social conditions and norms lead to biases and heuristics (sometimes maladaptive) in the decision-making process (e.g., following the group/leader, informational bias, recency bias) and can even alter one's perceived reality, constrain (or enhance) their actual (and perceived) number of feasible alternative options/courses of action (i.e., leveraging social capital to gain access to resources and material goods and services) and their ability to avoid harmful environments and maintain social support networks (McNeill et al., 2006). For example, Paletz et al. (2009) propose both direct and indirect social pressures related to heuristics and biases (e.g., sunk cost) in the decision-making/problem solving process, and when learning from others, in perception of the situation/environment, and in risk identification and assessment, respectively. Findings from an international study reported that respondents who report low support from their personal environment (i.e., family, friends, school, and workplace) were more than twice as likely to live sedentary lifestyles to those who receive high social support (Ståhl et al., 2001). Considering the implications of social environment on individual health behaviours, decision making, access and perception, we find appropriate the inclusion of 'Social Environment' at Level 2 of HFACS-PH.

Efficacy in the planning and execution of management of change in public health can greatly influence the degree to which a change is accepted, how quickly it is adopted, and the degree to which negative or adverse (often unexpected and unpredictable) outcomes occur in tandem (Bamford and Daniel, 2005). Effective management of change may also encourage a lifecycle or staged approach to public health interventions (e.g., for cigarette smoking cessation) and elements of social identification and marketing may also prove effective in typifying and classifying sub-populations by their change stage of change (Paula et al., 2011) and hence, improve the granularity of targeted public health interventions, monitoring, and analysis. Sørensen et al. (2011) highlight the importance of trust relations and repair in management of change, as with change often comes uncertainty, thereby provoking more intense

Table 1

Description of HFACS-PH and examples of errors/failures/conditions at each level.

Error / Condition / Factor		Description	Examples
Level 1 – Unsafe Acts			
Errors	Skill-based	Relating to errors occurring during the execution of routine activities or in the execution of a specific action.	Inadequate handwashing, unintended operation of equipment/PPE, and checklist and/or procedure not followed correctly.
	Decision	Relating to errors made due to knowledge, experience, and/or informational deficiencies.	Misdiagnosis, inadequate assessment of reality, ignored cautions or warnings.
	Perceptual	Relating to errors owing to the degradation and/or impediment of sensory inputs.	Accidentally entering quarantine zones, misoriented, misperceived communication and observational patterns.
Violations	Routine	Related to <i>routine</i> departures from organisational procedures, rules, and regulations.	Cutting corners in monitoring and enforcement of regulations and standards or procedures, routine mis- and/or under-reporting of incident statistics.
	Exceptional	Related to <i>one-time</i> departures from organisational procedures, rules, and regulations neither typical of the individual or condoned by management.	Mistakes, disruptive or threatening behaviour, consent not given nor implied, significant and unusual deviation from typical behaviour and practice.
	Acts of Sabotage	Related to the intentional acts to negatively affect the system, work, process, or production in question.	Deliberate removal of safety layers, process sabotage, vandalism, and acts of terrorism.
Level 2 – Preconditions for Unsafe Acts			
Environment	Physical	Relating to operational setting, workstation design and/or ambient environmental conditions	Unsanitary and /or overcrowded environment, built environment, ambient conditions, and immediate natural resources.
	Social	Relating to the social influences from group (e.g., family, neighbourhood, country, culture, workplace) interactions and settings which contribute to poor decision making.	Informational bias, impression management and self-consistency, scope and ethical creep, other social norms, biases, and heuristics.
	Technological	Relating to tools, methodology, and technology which enable the completion of workplace tasks (e.g., computers, software, checklists, equipment, PPE)	Lack of usability, poor design/construction, inadequate features, failures and defective parts, and vague/ill-defined policy, standards, procedures, or tools.

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Table 1 (continued)

Individual	Mental States	Relating to cognitive processes which degrade human performance.	Mental fatigue, stress, distraction, or loss of situational awareness.
	Physiological States	Relating to acute impairments of physiological conditions.	Intoxication, acute illness and injury, or physical fatigue.
	Limitations	Relating to permanent mental or physiological conditions and limitations.	Physical strength, cognitive capacity, disability, chronic illness/disease.
Personnel	Communication, Coordination and Planning	Relating to communication, coordination, and planning issues in team environments.	Communication, coordination, information sharing shift planning, and team pairing.
	Fitness for Duty	Relating to off-duty activities required to perform optimally on the job/goal.	Training, proper sleep and nutrition, drug and alcohol usage, and mental, physical, and emotional readiness.
Level 3 – Unsafe Supervision			
Failed to Correct Known Problem		Relating to failure to correct known deficiencies in competencies, equipment, procedures, and areas for safety improvement.	Failure to identify existing equipment failures and operation errors, and failure to implement corrective actions.
Inadequate Supervision		Relating to a failure to provide adequate guidance, leadership, and education/training opportunities for the frontline (e.g., public health official, volunteer, or the general public) in public health interventions.	Negligence of duty, failure to provide guidance and training, failure to track and manage personnel qualifications and suitability of equipment.
Planned Inappropriate Operations		Relating to the planning, management, and assignment of work including setting operational direction and tempo, risk management, and compliance with necessary and relevant statutory and regulatory directives.	Inappropriate plan to actual conditions, failure to provide correct information and data, planned operation and maintenance activities not in accordance with regulatory and statutory requirements.
Supervisory Violations		Relating to a conscious and deliberate disregard for rules, regulations, and standard procedures. These can be routine, exceptional, or acts of sabotage.	Ethical violations, authorizing the use of unqualified personnel, and failure to enforce rules and regulations.
Level 4 – Organizational Influences			
Management of Change		Relating to the management of modifications (change) to processes, technology, equipment, procedures, and facility.	Technology and facility modifications and upgrades, changes to operating procedures, and organizational restructures.
Organizational Climate		Relates to the broad class of organisational variables which influence worker performance and satisfaction.	Culture, command structure, and policies.

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Table 1 (continued)

Organizational Process	Relates to the procedures and methods which govern the everyday and ongoing activities of the organization and enable management/executive oversight over operations.	Production quotas, incentive schemes, schedules, standards, procedures, work instructions, safety programs and managerial oversight.
Resource Management	Relates to the allocation and maintenance of organisational resources including personnel, finance, technology, and capital.	Human resources, monetary/budget resources, and equipment/facility resources.
Level 5 – External Influences		
International Regulatory Framework	Relates to international regulatory influences including the (in)sufficiency of regulations and (in)effectiveness of regulators (e.g., industry bodies, government regulators, auditors).	International standards, licensing, mandatory skills, training, and schooling, failures to carry out regulatory duties, as well as the clarity and consistency of regulatory standards.
National Regulatory Framework	Same as above except at the National level. The International and National Regulatory Frameworks are also inherently intertwined.	Same as above except at the National level.
Socio-political Context	Relates to social, economic, political, and environmental pressures on public health policymaking, interventions, monitoring, and reporting.	Social change, political influence, societal values, and policy prioritisation.
Ecological Influences	Relating to the embedded context including national, regional, and global economic, social, and built environments, and environment.	Local, regional, state, national, and global economic, social, and environmental / wildlife conditions, country development, natural and built environment, and geographical constraints.

Notes: * See Table S2 to S5 in Supplementary Information for the HFACS-PH nanocode scheme and coding framework. The HFACS-PH nanocode scheme and framework can be used in incident/near-miss reporting systems for new and existing reports, the established coding philosophy is expandable with significant built-in spare capacity.

scrutiny on the possible intentions of said change by those affected (positively and/or negatively). The possibility for adverse outcomes (potentially devastating in public health) when management of change procedures and policy are ill-defined, poorly communicated and executed, or non-existent provides support for the inclusion of ‘Management of Change’ at Level 4 of HFACS-PH.

We have seen that proponents of public health and environmental regulations often try to incite uncertainty in the underlying scientific evidence of regulators in order to prevent or delay their being regulated (Michaels and Monforton, 2005), even going so far as to engage industry-employed scientists to counter their arguments and findings. Some good examples of such practice can be found in the tobacco industry, polluters, and producers of hazardous products. This balance of compliance and enforceability is socio-political in nature and is also related to public health efforts in the control and containment of infectious diseases and in particular, mass immunization campaigns (Taylor, 2009). When facing emerging and re-emerging infectious diseases, public health policy and practice should consider the need to protect the public’s health, and also the wider social, economic, and environmental impacts of the proposed intervention (Degeling et al., 2015). These social, economic, and political interests can further complicate the public health policy decision-making process and

practice, influence individuals’ motives, and increase the uncertainty present in the decision-making environment. The strong evidence on the socio-political influences on public health provide support for the inclusion of ‘Socio-political Context’ at Level 5 of HFACS-PH. The entwined nature of public health, politics, regulation, and socio-political context at both the National and International (Sidel and Sidel, 1977) scale provides support for the inclusion of ‘International Regulatory Framework’ and ‘National Regulatory Framework’ at Level 5 of HFACS-PH.

Human systems (e.g., social, economic, sociotechnical) are naturally embedded in an ecological environment with many complex interactions, feedbacks, and interdependencies, and existing on multiple spatial (e.g., global, regional, national) and temporal (e.g., daily, weekly, monthly, annually) scales. Public health is no different. Numerous studies acknowledge the complex interdependence between humans and their surrounding environment and more generally, between humankind and the global environment (Zinsstag et al., 2011). Changing demographics also have the ability to significantly alter the patterns of fertility, mortality, disease, and illness in a society (Geard et al., 2015), with underdeveloped and less developed countries experiencing both much higher fertility and mortality rates when compared to their more developed counterparts. Depending on where you live, you

may also be at higher risk of certain communicable infectious diseases particularly if you live in areas at the intersection of wild and settled land (Murray et al., 2015). This is increasingly common in nations and regions experiencing rapid and ongoing urbanization but not those with greater biodiversity (Wood et al., 2017). The importance of ecological context in public health provides support for the inclusion of 'Ecological Influences' at Level 5 of HFACS-PH.

6. Applying HFACS-PH during COVID-19

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 association in the (tertiary) 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 more immediate use of HFACS-PH as a proactive incident management tool during and in response to the COVID-19 pandemic. Further research investigation and statistical analysis on public health-related incident/near-miss/event reporting datasets (classified/coded using the HFACS-PH framework and nanocode – see Table S5 in [Supplementary Information](#)) could confirm the *ex-ante* applicability of the abovementioned causal pathways to public health and guide the development of novel causal pathways specific to incidents in public health.

In proactive incident management, one could leverage HFACS-PH to engage in counterfactual thinking and reasoning (Costello and McCarthy, 1999) to explore the various "what ifs" of policy design, improvement, and analysis and yet, still remain within the well-defined form and structure of HFACS-PH. This could be used to explore potential issues across the many facets of public health for example, for issues which may emerge in the reallocation of public health (primary, secondary, and tertiary) resources, in anticipation, response and adaptation to regulatory and statutory changes, when undertaking workplace/facility/built environment re-designs, upgrades, and urban planning, and when implementing process and/or procedural changes in public health service delivery. In the context of COVID-19, there is evidence that subtle differences in the regulatory frameworks (e.g., government effectiveness) and socio-political considerations (e.g., the degree of social, economic, and political globalization) can influence the speed and severity of implementing government NPIs such as international travel restrictions and border closures (Bickley et al., 2021), as well as domestic closure, containment, and disease surveillance policies, and information/education campaigns (Adolph et al., 2020; Cronert, 2020; Sebhatu et al., 2020). Further exploring the implications and "what ifs" of regulatory changes on the public health system and the public's health seems warranted.

The following section provides three examples of a proactive (qualitative) application of HFACS-PH in the context of regulatory changes in the US, UK, and AU public health systems. To support the rigour of our qualitative exploration, we investigate the impact of changes to regulatory requirements in the US, UK, and Australian public health systems by working our way down the HFACS-PH framework from Level 5 to Level 1 in a top-down manner. When undertaking retrospective HFACS-PH incident investigation, we do the reverse (i.e., start from the immediate cause, the 'Unsafe Act' at Level 1, and work our way upwards through the framework). See for example the 'HFACS-PH Quick Users Guide' in [Section 1 of Supplementary Information](#).

6.1. Changes to regulatory requirements

6.1.1. Level 5 (External Influences)

In many countries public health systems prepared for the expected surge in demand resulting from COVID-19 by rapidly enlisting

temporary healthcare workers and initiating non-insignificant changes to public health policy, procedures, practice, and funding, all with the aim of providing more adequate and efficient care and in doing so, alleviate surge and on-going stresses on public health systems. In the US, for example, the US Senate approved a bill waiving telehealth restrictions (Donlan, 2020). There is evidence that tele-health services can provide considerable improvements in access to health services, cost-effectiveness, enhanced educational opportunities, improved health outcomes, better quality of care and life, and enhanced social support (Jennett et al., 2003) and in particular, during pandemics such as COVID-19 (Gurwitsch et al., 2020; Whaibeh et al., 2020; Zhou et al., 2020). However, issues with upfront (and ongoing) costs, reimbursements, and technology are described as major barriers to adoption for health centres (Lin et al., 2018). In Australia, the Australian Health Practitioner Regulation Agency has relaxed usual return-to-practice requirements (registration fees, English proficiency, etc.) for tertiary healthcare workers (AHPRA, 2020) to entice an influx of spare and surge capacity labour. Similar to contract workers (Graham, 2010), this labour force sub-population may be more likely to become involved in unsafe acts and hence, care should be taken in the roles and responsibilities assigned to these individuals, and ensuring they are fit for practice and purpose (Payne and Green, 2005). Registered but non-practising health professionals (i.e., those that meet educational/training requirements but are not actively working in the field) are of keen interest to attract back to work however, they often experience high levels of anxiety, and lack self-confidence so clinical supervision and mentoring would likely be beneficial (McMurtrie et al., 2014). In the UK, routine quality inspections of registered health and social care providers have been temporarily suspended (CQC, 2020). Whilst this may reduce the overheads with auditing and compliance, organizations may also become more complacent with their quality management and monitoring duties over time which may spill over to informational deficiencies in other strategic domains (Donabedian, 1989), and leading to reduced performance on patient feedback and satisfaction (Griffiths and Leaver, 2018) which is also a useful proxy for quality performance.

These Level 5 regulatory and statutory decisions (classified as 'National Regulatory Framework') have the potential to enable and ignite casual chains of errors, failures, and conditions through the US, UK, and Australian public health systems. For example, see [Fig. 2 in Section 5](#) to visually trace the potential causal chains of changes to the national regulatory framework. See also [Table S1 in Supplementary Information](#) for a tabular representation of this information wherein the errors/failures/conditions 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 4](#). We can use either representation – tabular (see [Table S1 in Supplementary Information](#)) or visual (see [Fig. 2 in Section 5](#)) – to explore the potential flow-on effects of US, UK, and Australian national regulatory changes introduced during and in response to COVID-19 on their respective public health system.

6.2. Level 4 (Organizational Influences)

Evidence from the cited literature suggests that the level 5 national regulatory framework changes are likely to affect 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) and hence, introducing them to novel and unfamiliar situations. 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) and hence, require either greater supervision or restricted work roles and task responsibilities. 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) and altering the typical day-to-day activities of quality management, auditing, and improvement systems and personnel (organizational process).

6.3. Level 3 (Unsafe Supervision)

Evidence from the cited literature suggests that organisational climate influences are likely to increase the incidence of Level 3 failures/conditions 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 (failure to correct known problems). In Australia, supervisory health officers may wrongly 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 (inadequate supervision). The influences on organisational process are likely to increase the incidence of Level 3 failures/conditions 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 (Ingilis 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.

6.4. Levels 2 and 1 (preconditions for unsafe acts and unsafe acts)

Following on through the HFACS-PH framework, the above-mentioned Level 3 errors will increase the likelihood of all Level 2 failures/conditions (preconditions for unsafe acts), except for social environment (due to lack of inclusion in the HFACS frameworks of the cited literature). In turn, the affected Level 2 failures/conditions will increase the likelihood of all Level 1 errors and violations (unsafe acts), except for exceptional violations and 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.

6.5. Potential preventative measures

By leveraging Table 1 and Table 2 (see below) in combination with the HFACS-PH framework (Fig. 1, Fig. 2, and Table S1 in *Supplementary Information*), appropriate and targeted measures can be quickly identified and established to mitigate potential errors at each level. In particular, remedial actions should be focused on areas which share the strongest and greatest number of significant causal associations (i.e., those on common root of paths of association and with high odds ratios) (Li and Harris, 2006). 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 and the equitable access to such resources for both practitioners and the general public. 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

Table 2

Potential solutions at each level of HFACS-PH.

Error/Condition/Factor		Examples of Interventions
Level 1 – Unsafe Acts		
Errors	Skill-based	Simulated practice; shadowing/mentor programmes; regular training, and ‘refresher’ educational courses; usability/operability technology reviews and workshops; automation.
	Decision	Nudges (e.g., opt-out, incentive changes); adding ‘friction’ (e.g., decision or hold points) to the decision-making process; pre-operative checklists and cognitive aids; decision and diagnosis support systems; and peer reviews.
	Perceptual	Eliminating or minimising distractions and interruptions (e.g., concentrated ‘focus’ periods); limiting exposure to hazardous environments; simplifying information display and loading (e.g., traffic light indicators).
Violations	Routine	Regular work breaks; easing cognitive loads; workflow re-design; increased procedural vigilance/surveillance.
	Exceptional	Incident investigation; risk management workshops; shared safety learnings; and adapting organisational policy and practice to suit findings.
	Acts of Sabotage	Human resources case study (e.g., extensive exit interview); increased security; and engineering and procuring inherently safe functions and safety systems.
Level 2 – Preconditions for Unsafe Acts		
Environment	Physical	Workplace/built environment re-design; routine health, safety and environment inspections; strategic relocation of organization and service delivery locations.
	Social	Appropriate shift pairing/planning; operational and organizational culture redefines; community-led/grass root approaches to risk identification and management; personal empowerment and challenging maladaptive norms.
	Technological	Design specify and procure systems (e.g., user portals, websites, machine interface, instruments/equipment) for usability, operability, and maintainability; standardise public health procedures and processes (e.g., checklists, tools, and templates); goal-oriented information display and reporting.
Individual	Mental States	Increased staffing; spread workload and responsibilities; increased supervision and guidance; appropriate planning of work to capabilities and experience.
	Physiological States	Reduce manual handling activities where possible and practical (e.g., equipment upgrades, automation); encourage regular short breaks, hydration, and good nutrition; monitor fatigue and exhaustion.
	Limitations	Work role review and/or re-design, workplace/facility layout review and/or re-design, more selective hiring, and targeted interventions with (sub) population characteristics.
Personnel	Communication, Coordination, and Planning	Pre-operative briefing and risk assessment (e.g., toolbox meetings); standard template meeting agendas (to ensure appropriate communication occurs); redundancy in staff

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Table 2 (continued)

Error/Condition/Factor	Examples of Interventions
Level 1 – Unsafe Acts	
Fitness for Duty	capability/responsibility; crew resource management training. Training and certification management (and audit); adequate breaks during and time to recover between shifts; drug/alcohol testing (where reasonably required); easier reporting protocols and integrated supervisory monitoring systems.
Level 3 – Unsafe Supervision Failed to Correct Known Problem	Formal risk assessment and management processes based on quality management standards (i.e., for registering and tracking preventative correction actions); supervisory key performance indicators and incentive structures aligned to action close-outs; safety and continual improvement culture.
Inadequate Supervision	Pre-operative briefing and safety shares; 'hands on' approach to training and development with appropriate oversight and monitoring; increased supervisory staffing and professional development pathways; standardization of procedures and processes; decision and/or hold gates.
Planned Inappropriate Operations	Specify future technology systems' compatibility with existing systems; standardise on procedures and processes; proactive regulatory and statutory compliance management; consistent application of risk identification techniques.
Supervisory Violations	Relative to the severity of the violation: incident investigation; risk management workshops; shared safety learnings; and adapting organisational policy and practice to suit findings.
Level 4 – Organizational Influences Management of Change	Front-end risk identification, assessment, and management workshops with stakeholders; lifecycle planning approach; staged project gating mechanisms (e.g., review, decision, and hold points).
Organizational Climate	Promote (and incentive) incident/near-miss reporting; safety culture (e.g., learn, share, and promote all things safety); quality and continual improvement culture; regular review and update of policy and strategy in line with changing environment and context.
Organizational Process	Integrate risk identification and management into all aspects of organizational activity; optimise workflows and undertake regular reviews of process optimisation and regulations/standards; measurable and transparent reporting systems; concerted management- and executive-level direction and leadership.
Resource Management	Lifecycle planning in projects, products, services, and initiatives; encouraging and enabling (via various productive technologies) operational data collection, analysis, and reporting; commitment to research and development of process, product, and people.
Level 5 – External Influences International Regulatory Framework	

Table 2 (continued)

Error/Condition/Factor	Examples of Interventions
Level 1 – Unsafe Acts	
National Regulatory Framework	Development of policies, standards, and guidelines; increased/decreased involvement in international organizations, cooperatives, and development efforts; international accreditation and regulation; listening/consulting various industry and academic actors and constituents as well as the general public.
Socio-political Context	Development of policies, standards, and guidelines; resource management and funding; research and development spending; accreditation pathways and regulation programmes; listening/consulting various industry and academic actors and constituents as well as the general public.
Ecological Influence	Listening/consulting various industry and academic actors and constituents as well as the general public; education campaigns; community outreach programmes and social corporate responsibility; sustainability focus, monitoring, and regulation.
	Same as above, with keen focus on the broader socioeconomic, natural, and ecological environment.

workers into their roles and work environment. The ratio of new to experienced staff and the work roles and responsibilities of which temporary workers can fulfil could be also necessarily limited to ensure adequate supervision, mentoring, and support (communication, coordination, and planning – Level 2). We provide Table 2 below as a quick for potential interventions at each level of HFACS-PH.

7. Conclusions and future work

A novel adaptation of the Human Factors Analysis and Classification System (HFACS) in the context of public health (HFACS-PH) has been presented. This framework builds on previous adaptations of the HFACS framework by inclusion of the fifth level 'External Influences' which includes 'International Regulatory Framework', 'National Regulatory Framework', 'Socio-political Context', and 'Ecological Influences', as evidenced by the literature. We also include 'Acts of Sabotage' at Level 1, 'Social Environment' at Level 2, and 'Management of Change' at Level 4 of HFACS-PH again, with supporting evidence from the literature.

We have argued that the framework could be used in a *proactive* manner in the public health response to COVID-19 and future pandemics and, in public health interventions and initiatives more generally. The immediate use of HFACS-PH in proactive incident prevention could be achieved by leveraging the evidence of causal pathways (paths of association) identified in other high-risk, high-reliability domains such as mining (Lenné et al., 2012), process (Baldissone et al., 2019), aviation (Inglis et al., 2010; Li et al., 2008; Liu et al., 2013), oil and gas (Theophilus et al., 2017), construction (Sun et al., 2011; Ye et al., 2018), and hospital drug interventions (Min-Chih, 2019). However, to confirm the applicability of use of such casual pathways, additional research is required to explore associations between different levels and sub-categories of the HFACS-PH framework. This could be done by applying the HFACS-PH coding scheme (see Table S5 in [Supplementary Information](#)) to existing and/or future data in incident/near-miss/event reporting systems for hospitals, medical clinics, and other actors in the public health system. From this, statistical analyses could be undertaken to identify the strength and direction of any potential associative pathways. New and identified causal chains could then be used to predict adverse events *before* they occur and hence, enable more proactive

incident management in public health. Ultimately, this can help to improve public health outcomes and uncertainty absorption in crisis situations such as pandemics through mitigation of preventable errors, failures, and conditions in policy development, implementation, monitoring, and assessment.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ssci.2021.105312>.

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