# Concepts and Models of Safety, Resilience, and Reliability

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| Abstract | Approaches to safety have often considered the “human” factor in an organisation or operation as a major contributor to unwanted outcomes. The view of “human” as a problem leads to responses that involve trying to exert more control over people. While these may make intuitive sense for some, research suggests that such a view may not be valid as there are an enormous number of other factors (many of which are beyond control of the human at the sharp end) that are behind the creation of success and the occasional failures. This chapter begins with a review of normal accident theory, before using complexity science to fill out the problematic nature of the notion of “human error”. It then discusses one of the prominent problems associated with complexity, safety drift. Lastly, this chapter looks at various proposed solutions (e.g. resilience engineering) by which a healthcare system can manage complexity and perhaps reduce the potential harm to patients. | |

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# 3 Concepts and Models of Safety, Resilience, and Reliability

Jonathan Gao and Sidney Dekker

*"This place would be a lot safer if I could just get rid of the nurses who make mistakes"*

*—Nurse Manager*



## Introduction

Approaches to safety have often considered the "human" factor in an organisation or operation as a major contributor to unwanted outcomes. Most responses to this "problem" involve trying to exert more control over people [1]. This can happen through the generation of policies, guidelines, and prescriptions, and of course the enforcement of procedures. While these may make intuitive sense for some, research suggests that such a view may not be valid as an extensive focus on failures creates the erroneous impression of humans as a liability, and ignores the many other instances of humans contributing to success and resilience [2]. Not only are people crucial in the creation of safety in the messy details of everyday work, there are also an enormous number of other factors (many of which are beyond control of the human at the sharp end) that are behind the creation of success and the occasional failures.

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## Normal Accident Theory

With the rapid advancement of technology, many organisations today are complex systems, and these systems interact with an equally (if not more) complex environment [3, 4]. Complexity has been argued to render these organisations accident prone in two ways. First, minor failures between multiple components within a system can interact in incomprehensible or difficult-to-follow ways to produce a larger failure. Second, the complexity of these systems makes it difficult for any one individual to fully comprehend every single process involved in keeping the system functional [4, 5]. Therefore, when an accident occurs, operators within the system may find it difficult to remedy the situation. Most retrospective responses to such issues rely on adding more components or layers of defences, such as an extra alarm or another backup power generator. However, this only adds to the system's complexity and might lead to even more unintended interactions and consequences. Given that failures involving complex component interactions are unusual and often unforeseen, they are not considered when we attempt to determine the probability of an accident occurring. Therefore, it is likely that the actual probability is much higher than we think.

Of course, not all organisations or surgical operations may encounter accidents since they are loosely coupled [3]. In such systems, the continued functioning of a component is rarely dependent on the functioning of other components [3, 6]. For instance, the performance of a medical faculty in a university is rarely dependent on the performance of the business faculty. This is not the case for tightly coupled systems such as the operating room, where the function of the surgeon depends greatly on the function of another component such as the anaesthesiologist, and thus an issue with one of them is likely to lead to an issue with the other. In turn, other personnel (e.g. nursing and the recovery room staff) who rely on them will experience disruption to their work as well. These disruptions and issues may interact with one another in an unforeseeable manner, causing an accident. In sum, organisations that operate using systems that are both complex and tightly coupled will likely experience an accident and numerous near misses at some point in time [3, 7]. These accidents are an expected by-product of a complex and tightly coupled system, and therefore seen as "normal". Hence the term normal accident theory.

## Complexity Science

Some might disagree with the above notion, and will continue to argue that accidents are a result of human error [8, 9]. This section discusses complexity and explains why blaming accidents on human error alone may be a simplistic approach that misses the bigger picture. To do that, we will look at the underlying assumptions of this viewpoint, and argue for why these assumptions may not be realistic, especially in a medical or surgical setting.

The perception of accidents as the simple product of human error usually contains at least four underlying assumptions. First, it assumes that the system involved solely operates in a linear manner [10]. In other words, A only causes B, B only causes C, and so on. Second, it assumes that since the system operates in a linear manner, it therefore follows that with sufficient knowledge, an operator within the system can or should be able to predict the outcome of their actions. Therefore, when an adverse event occurs, such as a wrong-sided surgery, the surgeon is often blamed for not having anticipated the outcome. Third, it assumes that the linear manner in which the system operates means that it is possible for one to reverse the linear process to discover the cause of an accident. In other words, since C is only caused by B and B is only caused by A, this means that A is the source (or root cause) of the problem. Fourth, it assumes that it is possible for investigators to collect all the information necessary to form a true story of what exactly happened to give rise to the adverse event.

However, these assumptions may not be realistic, especially in the domain of healthcare and especially in highly complex surgical microsystems [11]. There are many examples which indicate that not all systems operate purely in a linear manner. For instance, the performance of a nurse in a hospital is potentially influenced by a plethora of factors like the nurse's case load, whether there is a staff shortage, the type of observation charts used, the noise level and lighting within the wards, and whether the nurse is interrupted [12–16]. Likewise, the performance of a surgeon can be affected by factors such as disruptions, fatigue, and stress levels [17–19].

Since the healthcare system operates in a complex manner, it stands to reason that the second assumption of outcomes being predictable is likely to be false. A complex system like healthcare is likely to experience a huge amount of interactions, some of which are non-linear, among all of its components [20–22]. These interactions can take a range of forms, such as the interactions between staffs across multiple disciplines or small physiological changes within a patient interacting to cause major disruptions in the patient's health. Systems of such complexity mean that it is impossible for any one individual to fully comprehend all the tasks necessary to keep it functional [4, 5]. Given the complexity and interactivity involved, outcome prediction is near impossible.

Following from the above, the third assumption is likely to be false as well. Since the healthcare system is immensely complex and highly interactive, finding out the factors contributing to an accident is not as easy as simply reconstructing a linear process [20–22]. Moreover, not all accidents have a cause, as discovered during the investigation into the accidental shooting of two US Black Hawk helicopters by two US fighter jets. This shooting is thought to have happened due to the many local units each developing their own procedures and routines to manage local demands. The development of local procedures and routines is a normal occurrence, as the original plans do not always suit the local situation. However, the differences in procedures and routines among the various units made it difficult for these units to act smoothly and successfully in a tightly coupled situation, leading to the shooting [23, 24]. Lastly, this assumption also depends on the accident investigator being given full access and the ability to gather all the necessary information to reconstruct an accurate picture of the accident. As will be argued below, it is highly unlikely for that to happen.

The fourth assumption regarding an investigator being able to gather all the necessary information to reconstruct an accurate picture of the adverse event is likely to be an invalid assumption, for the following reasons. First, systems that are highly complex and interactive tend to continuously evolve, thereby retarding any attempts at retrospective analysis especially for an outsider unfamiliar with the nuance changes in complex systems [25]. Second, a huge amount of information might be lost or difficult to obtain in the course of accident investigations since one's behaviour can be influenced by a multitude of factors, such as unwritten routines or subtle oral or behaviour influences by other supervisors or staff members [26].

Third, research has shown that memory is unreliable and highly context dependent [27–30]. The way in which a question is phrased has the capacity to alter answers and memories. Furthermore, people are also susceptible to incorporating misinformation from various sources into their memory of an accident, and this altered memory can remain even if people are made aware of the misinformation. Thus, this might hinder or at least affect attempts at information gathering and increase the chance of hindsight bias [31].

Lastly, the process of reconstructing a representation of an accident is at risk of succumbing to the hindsight bias [31]. Given that the outcome of an accident is already known, it is easy for accident investigators to determine which behaviour or decision led to the accident and wonder why the people involved failed to notice the same things. In doing so, the challenges that these people faced are trivialised and the bigger picture, that such accidents are mostly the product of complex and interactive systems, is missed (Table 3.1).

In summary, attributing adverse events to human error hinges on the four assumptions being valid. However, these assumptions are unrealistic in complex and interactive systems like healthcare. Rather than looking at accidents using a linear approach, we should perhaps follow in the footsteps of high-reliability organisations (see section "Principles of High Reliability") and adopt a systems approach instead, which is well suited for complex settings such as in surgical setting. Essentially, this approach takes the view that an individual failure is a symptom of a larger problem within the system, which enables organisa-

**Table 3.1** Summary of the four assumptions of attributing accidents to human error and reasons that these assumptions are invalid

| Assumption | Reason(s) for assumption being invalid |
|---|---|
| System operates in a linear manner | Performance of healthcare practitioner is influenced by a plethora of factors |
| Operator within the system can predict outcome of actions | Complexity and interactivity of healthcare system or surgical microsystem make outcome prediction near impossible |
| Possible to reverse the linear process to discover the cause of an accident | Complexity and interactivity of the system make it difficult to reconstruct what happened |
| | Not all accidents have a cause |
| | Depends on investigator(s) having full access to all necessary information |
| Possible to collect all the information necessary to form a true story | Systems that are complex and interactive tend to evolve over time |
| | Information can be lost or difficult to obtain |
| | Memory can be unreliable and context dependent |
| | Risk of hindsight bias |

tions to learn from their mistakes and improve the system [32–34].

It should be noted that such an approach does not mean that humans are entirely blameless, as there are scenarios in which pursuing individual responsibility might be necessary [35]. However, most errors are arguably committed by proficient and well-meaning operators who possess a finite capacity (as do all humans) and who face numerous challenges when carrying out their duties [31, 36]. Thus, the focus here should not be on punishing them, but to examine the means of improving the system in order to alleviate some of their difficulties and attenuate future adverse events [32, 36].

## Safety Drift and Procedural Violations

### Safety Drift

Healthcare systems are vastly complex and set in an environment that is equally (if not more) complex [3, 4]. Besides consisting of a multitude of individual components (e.g. doctors and nurses, technological artefacts, regulatory pressures), systems of such complexity also possess subsystems (e.g. anaesthesiology team, general surgery team) that are working to achieve their own goals [25, 31]. These goals are not always compatible, however, resulting in conflicts that need managing. Those involved would have to make decisions based on the situation and some of these decisions might require the sacrificing/trade-off of safety to achieve a particular production goal or to live up to other duties [37, 38]. Typically, this trade-off does not yield any immediate negative consequences [39]. Therefore, those involved would be misled into assuming that the trade-off is acceptable and it becomes part of the normal process. When another conflict emerges and another trade-off is made with no adverse results, this second trade-off might be once again be assumed to be acceptable and becomes part of the normal process. This process (known as normalisation of deviance) will repeat itself, slowly nudging the system towards greater risks until an adverse event takes place.

Despite the risks involved, those within the system are unlikely to be aware of this drift to failure as signs are typically only noticed by those outside of the system (e.g. accident investigators) after an accident has occurred [24]. To those within the system, seemingly poor decisions in hindsight are actually rational, given the contemporaneous circumstances [31]. While seemingly a bad phenomenon, the drift away from safety is not necessarily a negative indicator of an organisation's performance [24]. Rather, it is simply a by-product of a complex system adapting to the challenges from both within itself and the environment. The challenge is to ensure that the clinicians involved understand the role and importance of these trade-offs (i.e. clinical sensemaking) [40].



### Features of Drift

So what are the elements that contribute to a system drifting towards failure? At present, it is theorised that at least five factors are involved, namely (a) scarcity and competition, (b) decrementalism, (c) sensitivity to initial conditions, (d) unruly technology, and (e) contribution of protective structure [24].

Scarcity and competition refer to an organisation experiencing a lack of resources, and facing intense competition [24]. Rasmussen suggested that a typical organisation has to work within three boundaries, the first being economic, the second being safety, and the third being workload [41]. Working beyond the economic boundary means that the organisation would not be able to maintain itself financially, while crossing the safety boundary means that the organisation's operation is highly dangerous (e.g. patient's well-being may be endangered). Lastly, exceeding the workload boundary means that the people and/or the technologies within the organisation are no longer capable of carrying out their work. As mentioned earlier, organisations generally drift away from the safety boundary to satisfy production pressure since the loss of safety is rarely felt while the reaching (or not reaching) of production pressure is tangible [37].

Decrementalism means that an organisation moves to the edges of the safety boundary over a series of small steps (instead of instantaneously), as it attempts to meet production pressure, as explained earlier [24]. This should not be confused with normalisation of deviance, which refers to trade-offs made in response to abnormal situations (e.g. high demands) being seen as the new norm.

Sensitivity to initial conditions (otherwise known as the butterfly effect) essentially argues that seemingly small factors in a system's starting conditions can lead to large failures, as these factors interact in novel ways to give birth to unintended consequences, pushing an organisation towards the edge of the safety boundary [24]. Unruly technology refers to the gap that exists between how designers of a technology think it will work, and how the technology actually works when exposed to the environment [24, 42]. For instance, the introduction of poorly designed health information technology in some hospitals has been argued to cause issues such as (a) making it difficult for physicians to gain a proper understanding of a patient's condition, and (b) producing reports that lack information value, due to the technology's insistence of using standard phrases [43].

The last factor is the contribution of protective structure, which suggests that the protective structure that was deliberately created to keep the operation safe can end up contributing to a drift towards failure [24]. One example is a safety or governance department that, through its generation of many different layers of defence and guidelines, actually contributes to complexity, thereby rendering real sources of risk less visible to the sharp end users.

## Possible Means to Reduce Potential for Drift

Despite the potential for drift to result in unwanted consequences, a definitive solution to reduce an organisation's potential for drift does not appear to exist. Nonetheless, this section will be devoted to the exploration of some of the ideas in the hopes that some would find it useful.

As suggested earlier, signs of drift are not always obvious to those within the organisation [24]. Therefore, one plausible approach of reducing an organisation's potential for drift is to study how decision makers make sense of the information environment (e.g. why they take in certain bits of information and ignore others) as well as how they make and rationalise their decisions [44]. However, this may not be a fruitful endeavour since an organisation's drift into failure is usually only known after an accident has occurred and any knowledge gleaned might be specific to that accident and have little applicability in other contexts.

Arguably, a decision maker must pay attention to multiple sources of information and invite doubt to make the best possible decisions [45]. But this may be an idealistic notion as decision makers may be bombarded with an enormous amount of information, which would require a long time to process, and immense cognitive resources [24]. Furthermore, tell-tale signs of drift may be weak or unbelievable, and hence go unnoticed [37].

Another potential approach would be to move the organisation away from the safety boundary, reducing the likelihood that it will be crossed and produce an accident [41]. Examples include reducing production pressure or investing in proven safety methods. However as with the above, expecting an organisation to reduce production pressure might be wishful thinking. Even if an organisation chooses to invest in proven safety methods, it is highly likely that production pressure will follow this increase as staffs would be expected to produce a greater output with the same resources (i.e. be more efficient) [37].

In sum, while there has been several suggestions on ways to diminish an organisation's potential for drift, these suggestions each come with their own caveat. Nevertheless, this does not mean that it is impossible to reduce an organisation's drift potential since there may be other solutions that have yet to be explored. For example, Rochlin and his colleagues have observed that the various subsystems on board a naval aircraft carrier were able to balance multiple constraints and pressures to consistently produce smooth performances [5]. Perhaps an in-depth study on how these subsystems co-operate and negotiate with one another might yield some useful information.

## Procedural Violations

As argued earlier, drift is not an indicator of an organisation's failing, but a sign of it adapting [24]. It can appear in many forms, such as procedural violation (also known as workarounds). Workarounds appear to be frowned upon as it deviates from rules and regulations, which some consider sacred [46]. Such a viewpoint may have its merits, for deviations from rules and regulations have resulted in unwanted results. For instance, it was argued that non-compliance with rules and regulations contributed to an incident where the wrong patient was given an invasive procedure.

However, it might be a mistake to assume that all forms of procedural violations are bad. For example, one form of medical guidelines in the USA specified the use of levofloxacin for community-acquired pneumonia [47]. But others have suggested that a physician should not always follow these guidelines as levofloxacin is an expensive form of antibiotics that not all patients can afford, and not having antibiotics could lead to patients' conditions worsening [48]. To avoid this outcome, physicians need to deviate from the rules and regulations and prescribe a different and more affordable form of antibiotics. Furthermore, each patient has their own unique co-morbidities and medical history, making it near impossible to create a set of guidelines to address each case. Under such circumstances, physicians should be allowed to act as they see fit instead of being penalised for not complying with procedures. In other words, procedural violation may not always be a bad thing as it captures the local wisdom of the providers.

## Stretching the Limits of Adaptive Capacity

As argued above, healthcare organisations have to adapt to multiple constraints both within itself and the environment [24, 25, 31]. One way of doing so would be to stretch its adaptive capacity. Adaptive capacity refers to a system's ability to adjust its actions in response to high production pressure, such as a hospital temporarily using stretchers or chairs in the hallways when there are insufficient beds to accommodate a sudden spike in demand [49, 50]. When a system attempts to adapt itself to handle a particular type of disruption, it will inevitably become less adept at handling other types of disruptions [51]. When these other disruptions actually happen, the system's adaptive capacity will be tested and failure is a real possibility. Since failure is an unwelcome result, it is therefore important for a system to know where it stands in terms of its adaptive capacity, the type of problems that can arise in an adaptive system, and the means of stretching this finite resource if necessary [52]. For a system to figure out where it stands in terms of adaptive capacity, it should possess at least the following *three characteristics*: (a) capacity to reflect on how well it has adapted, (b) awareness to know what it is adapting to, and (c) changes within its environment [51].

There are three potential ways by which an adaptive system can break down [51]. The first is decompensation, which essentially refers to a system's adaptive capacity being unable to keep up with a disruption that has occurred. In the initial phases of decompensation, the system automatically attempts to compensate when a disruption takes place and is somewhat successful in doing so, hence masking the problem as it continues to fester. Eventually, the system's adaptive capacity would be drained, causing a sudden collapse and failure.

The second issue is one that has been discussed earlier, namely the possibility of various subsystems having conflicting goals with one another, leading to each subsystem taking actions that may benefit them individually but limits the system's adaptive capacity [51]. The final possibility is that the system may persist in using outdated practices even though the environment has changed and despite the introduction of new practices.

Given the importance of adaptive capacity in ensuring that a surgical system remains functional, it is therefore necessary to figure out the means of stretching this finite resource to avoid a system failure [52]. One plausible way might be to stay sensitive to indicators that the system is silently compensating for disruptions and to take remedial actions immediately when these indicators display abnormal signs [51]. However, this might not be an easy task since it requires one to be able to successfully differentiate between good adaptive behaviours (e.g. workarounds to increase efficiency) and bad adaptive behaviours (disruptive behaviours that indicate that the system is on the path to failure).

## Resilience

A second means of dealing with constraints and complexities would be to apply the principles of resilience engineering. Resilience is defined as the ability of a system to adapt its functioning prior to, during, or following any changes or disruptions to sustain regular operations under all conditions [53]. The key term in the definition is adapt, meaning that resilience is about the system's ability to adjust its functioning to meet challenges. A system that is able to sustain regular operations under all conditions is not necessarily resilient, since this can be easily achieved via inefficient means such as stockpiling an absurdly large amount of resources (e.g. having multiple empty wards in a hospital in case of an emergency). Hence, adaptation is important.

However, some form of excess resources may still be necessary for the system to draw upon in times of need, meaning that not all excess resources should be removed under the pretext of efficiency [52]. Therefore, one possible problem with resilience engineering would be the difficulty in determining whether a set of spare resources should be removed for efficiency or retained to achieve resilience. Whether a system can successfully manage this is likely to depend on how it implements and sustains the four pillars of resilience. For example, if a system is proficient in predicting future threats (one of the four essential pillars of resilience), it should be able to determine if the extra resources available would be useful in helping it achieve resilience by allowing it to better meet challenges, or if the extra resources are a hindrance as it prevents the system from operating efficiently.

### Four Pillars of Resilience

Given the apparent benefits of resilience (i.e. able to handle disruptions), healthcare systems might consider adopting at least some of its principles. Currently, it is argued that a resilient system should possess four key abilities, namely (a) the ability to respond to disruptions, (b) the ability to monitor ongoing developments, (c) the ability to predict potential threats and opportunities, and (d) being able to learn from both failures and success [54].

For a system to be able to respond to disruptions, it should come up with a list of potentially disruptive events and develop a set of possible responses to these events, so that it may react appropriately in a timely manner when the disruption occurs [53]. For the list to be effective, the disruptive events that are being included should be rigorously examined on a frequent basis to ensure their relevance and timeliness.

In terms of developing a set of responses, the system needs to be able to verify its effectiveness as well as consider appropriate means of maintaining such responses [53]. As mentioned above, having an absurdly large amount of excess resources (e.g. dozens of empty beds) might be an effective response, but it is certainly not efficient and is costly to maintain in the long run.

For a system to have the capacity to monitor ongoing developments, a list of valid and reliable indicators needs to be developed and continuously monitored [53], in other words, an organisational dashboard of indicators that can consistently yield useful information. An example of a poor indicator would be the number of human errors committed, since it depends on unrealistic assumptions and misses the bigger picture, as argued earlier.

Additionally, these indicators are unlikely to always remain relevant, and thus should be constantly revised and updated [53]. A clear set of guidelines is necessary to guide this revision process as the typical approach is to simply revise the indicators after an accident has occurred. Such an approach is inadvisable because of two reasons, namely (a) it holds the unrealistic expectation that indicators should be able to predict all adverse events, which is unlikely to happen due to complexity, and (b) revisions based on this approach usually do not yield effective solutions due to a heavy focus on face validity. Aside from the above, the development of suitable monitoring indicators requires the consideration of other factors as well, such as the predictive value of the indicators, the means by which the indicators are measured, and whether the information provided by the indicators refer to temporary or permanent events.

To determine if a system is capable of predicting both potential threats and opportunities, the assumptions that it holds about the future should be examined [53]. If a system perceives the future to be a replication of the past, or that past events can be used to deduce future events, then the system is unlikely to possess the ability to predict potential threats or opportunities as the past may not always be a good indicator of the future [33, 53, 55]. If a system perceives future events to be a phenomenon caused by the complexity and interactions both within itself and the environment, then it might be able to successfully predict potential threats and opportunities.

Lastly, a resilient system might display the willingness to learn from both failures and successes, since both types of events arguably share the same underlying processes save for the recovery from failure [53]. Academics studying resilience have argued for the importance of studying success as it provides useful information for the occurrence of failures, the rationale being that there are no magical processes that only manifests themselves when an accident happens, but otherwise remain dormant [54, 56]. Instead, if an accident happens, it is likely that the underlying causes have been around for a while and are only made obvious by the accident. Furthermore, understanding how success happens and investing in it can not only reduce the possibility of things going wrong, but can potentially increase productivity as well. For a system to truly be resilient, all four components are thought to be essential. However, the importance of each component in a particular system generally depends on the system in question and is highly context dependent.

## Limitations of Resilience

Despite the positive sides to resilience engineering, it still possesses some limitations which could mitigate its effectiveness. Many of its recommendations are vague and thus hinder attempts at implementing them. For example, it recommends that a resilient system should develop both a list of plausible disruptive events and a set of responses to these disruptions [53]. However, it may not always be clear as to which events should be included on the list, and which events should be excluded.

Moreover, as a system seeks to improve its performance in dealing with a particular set of disruptive events, it will inevitably experience some form of setback in dealing with other types of events [51]. Therefore, when these other types of events do happen, failure becomes a real possibility.

## Principles of High Reliability

### Concept and Characteristics of High Reliability

Despite the problems mentioned above, some complex and tightly coupled organisations have been able to defy the odds and limit failures, yet consistently produce high performance [5]. Such organisations are said to possess high reliability.

In an attempt to understand how these organisations managed such a feat, different groups of researchers have studied these organisations and identified different sets of characteristics which they believe might be the key. The lists that these researchers came up with share several similarities, but possess some differences as well. Therefore, this section will first discuss the common characteristics before looking at the differences observed.

## Common Characteristics of High Reliability

The first characteristic of high-reliability organisation is their proactive approach towards risk management. Rather than aiming to prevent failures, which would be an impossible enterprise, these organisations choose to make allowances within their systems for them [33, 34, 57]. Additionally, they obsess over failures and regard them as symptoms of a larger problem within the organisation. As such, personnel are encouraged to (a) report errors (and are rewarded for doing so), (b) learn from near misses, (c) avoid being overconfident, and (d) be aware of the potential for small failures to interact and produce an exponentially larger failure.

The second characteristic of high-reliability organisation is their appreciation of the complexity involved in the daily operations of the organisation, and knowing that they can never fully comprehend it [33, 34]. Therefore, they do not become overconfident but instead continue to remain hyper-vigilant for possible disruptions. Furthermore, they understand that the system's complexity means that it is impossible for a single individual to fully master every single task needed to keep the organisation operational [5]. Therefore, tasks are broken down into smaller tasks, with a specific group attending to each smaller task.

The third characteristic of high-reliability organisation is their deference to experts instead of authority [5, 34]. In this case, experts do not refer to those with the most experience, as experience may not always be the best indicator of expertise. Instead, expert here refers to the person who has the specific set of knowledge needed to respond appropriately to the situation at hand, regardless of the person's authority [58].

## Different Characteristics

As mentioned in the introduction to this section, some differences exist between the two lists of characteristics of a high-reliability organisation. By differences, we mean that one group of academics have proposed a particular characteristic (e.g. continuous learning) as a contributing factor to high reliability, while another group of academics have not.

The first characteristic is the habit of continuous learning. While on board an aircraft carrier, Rochlin and colleagues observed that personnel of high-reliability organisations are continuously learning, with new methods of work constantly being introduced, and conventional means always being scrutinised for flaws [5]. However, this does not mean that procedures are always changing. Rather, new methods are only accepted after its benefits are proven.

The second characteristic is constant communication among personnel, even when there is a lull in activities [33]. Such behaviours not only keep communication channels open and help everyone to stay updated, but they also permit trust to grow and experienced members of the team to spot signs that might indicate potential trouble.

The third and final characteristic is the display of sensitivity to the needs and requirements of those working at the front line [34]. As stated above, healthcare organisations today operate under incredibly complex and regulatory situations, meaning those at the front line of the organisation are required to adapt to changing circumstances on a frequent basis in order for the organisation to operate safely. Conversely, those who work at the back end are typically temporally and spatially removed from the front line and hence have a limited understanding of what is actually happening at the sharp end [4]. High-reliability organisations are aware of this and therefore attempt to be sensitive to the needs of the front line to close this gap.

## Limitations

While the works on high-reliability organisations have produced fascinating and useful information that all organisations can apply, they are not without flaws. A common criticism of studies on high-reliability organisations is that they have been focusing mainly on unique organisations like the Navy or air traffic control, and hence the applicability of principles gleaned from these organisations to other settings remains to be seen [59, 60]. Furthermore, these unique organisations often do not face production pressure unlike other organisations in domains like healthcare, where medical staff have to attend to a large number of patients in a small amount of time and where technology continues to curb their autonomy [61]. Hence, it may be unrealistic to expect organisations with these constraints to achieve high reliability [62].

Such concerns are certainly valid, and while a few studies have displayed some level of success in applying high-reliability principles in a healthcare setting, many questions remain unanswered and hence additional empirical research is necessary [63–65]. For example, Madsen and his colleagues found that although their implementation of high-reliability principles improved the performance of a paediatric intensive care unit, medical staff from other departments resisted the change. Furthermore, these improvements were abandoned when the implementers left the unit. Therefore, further research could examine the optimal means of introducing high-reliability principles with minimal resistance, as well as looking at ways of ensuring that these principles are sustained in the long run. This means addressing the barriers to culture and organisational change that can get in the way of moving towards higher reliability of care [66].

Besides facing different challenges (e.g. production pressure), high-reliability organisations and normal organisations may also differ in other ways, which could make the application of high-reliability principles difficult. One instance would be personnel selection. Given the stringent nature of the recruitment practices used by air traffic control and the Navy, it is plausible that the personnel within these organisations are not representative of the personnel that one might find in a typical organisation [67, 68].

Also, a study in Germany discovered that individuals low in agreeableness, neuroticism, and openness to experiences were more likely to choose military service over community service [69]. This might mean that individuals with particular personality traits are more likely to join the Navy, and these traits in turn make it easier for the Navy to achieve high reliability. This is purely conjuncture, given that the study was conducted in Germany, whereas the studies on high reliability in the Navy were carried out in the USA. Extensive empirical studies are needed to determine if there is any truth to the speculation.

## Surgical Microsystems

Aside from the teachings of high reliability, the idea of surgical microsystems has been touted as another possible contender for those seeking to manage the various constraints in the domain of healthcare while maintaining a high level of performance [65, 70]. According to Sanchez and Barach, the concept of microsystems originated from Quinn's works regarding intelligent enterprises [65, 71]. In the domain of healthcare, a microsystem refers to a small group of individuals delivering a service to a particular group of patients for a certain purpose. For example, a surgical ICU can be considered as a microsystem as it is made up of a group of people (e.g. healthcare practitioners and the patients' family) working together to care for the patient with the goal of helping the patient recuperate. It is proposed that the microsystems are the building blocks of a system and thus any attempts at improving the healthcare system to cope with the multitude of constraints should begin at this micro level [70].

### Characteristics of Surgical Microsystems

Sanchez and Barach suggest that a good surgical microsystem should possess the following principles, some of which are similar to the principles of high reliability [65]. First, there should be an acknowledgement of the fallibility of humans, and the acceptance of accident (or errors) as normal. Instead of pursuing individual responsibility when something goes wrong, it should focus on the complex systemic factors behind the incident.

Second, a good microsystem needs to possess chronic unease, a state where an individual (or in this case, a microsystem) is concerned that potential risks are not being properly managed [65, 72]. It has been suggested that such an unease is useful as it keeps people alert to possible dangers and reduces the potential for complacency. Third, it is essential that communication channels remain open and dissenting views are not swept aside. Additionally, workers should be provided with proven tools that can help reduce the potential for errors. One example might be the redesign and usage of clinical charts that were specially designed to be user friendly using applied human factor principles [73, 74].

Fourth, the reporting of errors and near misses should be encouraged, and the learning value of near misses needs to be appreciated [65]. Fifth, patients should not be excluded from communication channels and in face communication needs to be designed around the needs of the patient care with the focus on co-producing exceptional outcomes with the patients [7, 65, 75]. In other words, when a patient is erroneously exposed to danger, a good surgical microsystem should pay attention to the patient's side of the story in order to gain a better understanding and learn from this safety breach. Lastly, effective microsystems need to base their system on proven human factor principles to optimise performance, support staff engagement, and attenuate impact of errors and other constraints such as providing nurses with user-friendly clinical charts [65, 73, 76].

## Conclusions

Rapid technological advancement has led to organisations becoming complex systems and dealing with a complex environment, making accidents a normal part of operations [3, 4]. Arguments that these accidents are caused by human errors hinge on several unrealistic assumptions being valid, and do not address the complexity in today's surgical world [10]. Such complexity creates multiple challenges and constraints for both the system and its subsystems, which forces them to adapt in ways that could cause a drift towards failure [24, 25, 31, 37]. To manage these issues, systems can learn to stretch their adaptive capacity, attempt to become more resilient, apply the same principles as high-reliability organisations, and/or learn from clinical microsystem wisdom [5, 33, 34, 51–54, 65]. While each of these ideas come with their own limitations, they are nevertheless an excellent starting point for anyone seeking to improve performance and safety in the surgical care of patients across the perioperative continuum.



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