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CONTRIBUIÇÕES PARA GESTÃO DA COMPLEXIDADE ORGANIZACIONAL EM UNIDADES DE TERAPIA INTENSIVA

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Tese submetida ao Programa de Pós Graduação em Engenharia de Produção da Universidade Federal do Rio Grande do Sul como requisito parcial à obtenção do título de Doutor em Engenharia de Produção, modalidade Acadêmica, na área de concentração em Sistemas de Produção.

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Contribuições para gestão da complexidade organizacional em unidades de terapia intensiva

Esta tese foi julgada adequada para a obtenção do título de Doutor em Engenharia e aprovada em sua forma final pelo Orientador e pela Banca Examinadora designada pelo Programa de Pós-Graduação em Engenharia de Produção da Universidade Federal do Rio Grande do Sul.

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RESUMO

É notória a importância de estudos sobre gestão em serviços de saúde, dada a complexidade destes sistemas e a crescente demanda por serviços mais eficientes e de melhor qualidade. O tema central da tese está voltado a gestão de sistemas sócio-técnicos complexos (SSTC), em especial a abordagem de um conjunto de diretrizes de gestão de SSTC em Unidades de Terapia Intensiva (UTI). Assim, a questão de pesquisa norteadora da tese é "como as diretrizes de gestão de SSTC podem ser compreendidas em Unidade de Terapia Intensiva Adulta, tanto em situações normais quanto em situações de crise"? Para tanto, o objetivo principal da tese identificar e classificar práticas para lidar com a complexidade em UTI Adulta, em situações normais e de crise. Os objetivos específicos desdobram-se em: (i) identificar o quanto os projetos de melhoria de processos nas UTI Adulta, relatados na literatura, estão alinhados às diretrizes de gestão em SSTC; (ii) propor uma abordagem para investigação de eventos com resultados desejados em SSTC, a qual inclua a análise do papel das diretrizes de gestão de SSTC; (iii) identificar e classificar as práticas de resiliência organizacional em UTIs adultas brasileiras durante a pandemia de COVID-19, bem como lições aprendidas sob a perspectiva das diretrizes de gestão de complexidade. Como conclusão dos resultados da tese, as diretrizes foram consideradas totalmente aplicáveis e intuitivas, ao invés de adotadas explicitamente pelas intervenções. As abordagens realizadas na literatura apontaram a diretriz "projetar folgas" como sendo a mais utilizada nas ações provenientes da resiliência. Em decorrência destes artefatos ao realizar um estudo de caso mais aprofundado quanto a utilização das diretrizes em UTI's utilizando-se do FRAM, os recursos da diretriz projetos de folga foi um meio de responder às variabilidades provindas do ambiente em pesquisa, seja de modo oportunista enquanto o evento se desenvolve (por exemplo, emprestar cânulas da unidade cirúrgica) ou com base em recursos integrados com antecedência, mesmo que isso não seja amplamente conhecido por todos os funcionários (por exemplo, o uso de equipamentos VMI em VNI). Nestes moldes, utilizando as cinco diretrizes de complexidade como uma estrutura analítica, esta tese contribuiu também, estudos que abordam como é a resiliência nas UTIs durante a pandemia. Embora 70 resiliências práticas ou condições foram identificadas, várias delas claramente não se aplicam a todas as complexidades do dia (por exemplo, adição de vários novos leitos a curto prazo). Deste modo, os resultados apontaram para diferentes manifestações das diretrizes conforme os

cenários analisados, bem como para o papel central da diretriz sobre gestão de recursos folga (*slack resources*) em todos os cenários.

Palavras-chave: Complexidade. Sistemas sócio-técnicos complexos. Gestão. Saúde. Unidade de Terapia Intensiva.

ABSTRACT

The importance of studies on management in health services is notorious, given the complexity of these systems and the growing demand for more efficient and better quality services. The central theme of the thesis is focused on the management of complex socio-technical systems (SSTC), in particular the approach of a set of SSTC management guidelines in Intensive Care Units (ICU). Thus, the research question guiding the thesis is "how can SSTC management guidelines be understood in the Adult Intensive Care Unit, both in normal situations and in crisis situations"? Therefore, the main objective of the thesis is to identify and classify practices to deal with complexity in Adult ICUs, in normal and crisis situations. The specific objectives are: (i) to identify to what extent the projects for process improvement in Adult ICUs, reported in the literature, are aligned with the management guidelines in SSTC; (ii) propose an approach to investigating events with desired outcomes in SSTC, which includes an analysis of the role of SSTC management guidelines; (iii) identify and classify organizational resilience practices in Brazilian adult ICUs during the COVID-19 pandemic, as well as lessons learned from the perspective of complexity management guidelines. As a conclusion of the thesis results, the guidelines were considered fully applicable and intuitive, rather than explicitly adopted by the interventions. The approaches taken in the literature pointed to the guideline "designing slacks" as being the most used in actions arising from resilience. As a result of these artifacts, when conducting a more in-depth case study on the use of guidelines in ICUs using the FRAM, the resources of the slack projects guideline was a means of responding to the variability arising from the research environment, whether opportunistic or opportunistic while the event unfolds (eg borrowing cannulas from the surgical unit) or based on built-in features in advance, even if this is not widely known to all staff (eg the use of VMI equipment in NIV). Along these lines, using the five complexity guidelines as an analytical framework, this thesis also contributed to studies that address the resilience of ICUs during the pandemic. Although 70 practical resiliences

or conditions were identified, several of them clearly do not apply to all of the day's complexities (eg, adding several new beds in the short term). Thus, the results pointed to different manifestations of the guidelines according to the analyzed scenarios, as well as the central role of the guideline on slack resources management in all scenarios.

Keywords: Complexity. Complex socio-technical systems. Management. Health. Intensive Care Unit.

SUMÁRIO

1. INTRODUÇÃO

1.1 Contexto

A complexidade dos sistemas sócio-técnicos complexos contemporâneos tem sido percebida como crescente, por diversos pesquisadores (Kannampallil et al., 2011; Andersson e Gadolin, 2020; Margherita, Elia e Klein, 2021). De acordo com Rasmussen (1997), fatores como os seguintes contribuem para essa percepção: (a) evoluções tecnológicas, principalmente em termos de novas tecnologias da informação e comunicações; (b) aumento do porte das organizações, o que implica em um maior número de elementos em interação; (c) elevado nível de interdependência entre os sistemas; (d) aumento da competição entre as organizações, o que leva a menores folgas e processos mais rigidamente acoplados, facilitando a propagação da variabilidade. Além disso, muitos sistemas sócio-técnicos complexos (SSTC) possuem tecnologias perigosas, com potencial de causar danos com grandes consequências. São exemplos, os sistemas de assistência à saúde, geração e distribuição de energia, aviação, petroquímicas (Kulnik et al., 2008; Williams, 2013).

Uma característica fundamental dos SSTC é a variabilidade (antecipada ou não) que pode produzir interações não-lineares, ou seja, as consequências da variabilidade podem ser desproporcionais às causas (Soliman e Saurin, 2017). Além disso, características dos SSTC citadas por outros autores, tais como Dekker (2011) e Buchanan et al., (2018), são as seguintes: grande número de elementos em interações dinâmicas, grande diversidade desses elementos e a resiliência do sistema. Esta tese explora a complexidade em sistemas de assistência à saúde, os quais têm sido apontados como altamente complexos, por diversos autores (Braithwaite, 2018; Churruca et al., 2019). No setor de saúde, a complexidade se manifesta em diversas escalas, desde as atividades operacionais de atendimento ao paciente na beira do leito (micro), gestão de serviços de saúde como hospitais (meso) até as redes regionais e nacionais de assistência (macro) (Berg et al., 2018).

Embora SSTC não possam ser completamente controlados, os mesmos podem ser intencionalmente influenciados (Kernick, 2018). Nesse sentido, é importante que os métodos de gestão utilizados sejam compatíveis com a natureza dos SSTC (Righi e Saurin, 2015). Por sua vez, tendo em vista essa análise de compatibilidade, é necessário identificar diretrizes de gestão de complexidade que sirvam de referência. Nesta tese, são adotadas as seis diretrizes de gestão de complexidade propostas por Saurin et al. (2013): (1) suporte à visibilidade de processos e resultados; (2) provimento de folgas; (3) incentivar a diversidade de perspectivas ao tomar decisões; (4) monitorar e compreender a lacuna entre o trabalho como imaginado e o trabalho como realizado; (5) monitorar as consequências não intencionais de melhorias e mudanças; (6) criar condições que apoiem o desempenho resiliente.

Essas diretrizes foram elaboradas por Saurin et al. (2013) com base em uma revisão de literatura que abrangeu três fontes principais: (a) disciplinas que utilizam princípios de complexidade para projetar sistemas sócio-técnicos, como engenharia de resiliência e engenharia de sistemas cognitivos (Hollnagel e Woods 2005; Sheard e Mostashari 2009; Hollnagel et al. 2011); (b) relatos de experiências práticas de uso de princípios de complexidade para apoiar a melhoria de processos em diversos setores (Kernick 2004; Stroebel et al. 2005, Bertelsen e Koskela 2005; Sweeney 2006,); e (c) discussões teóricas sobre o uso da complexidade para melhorias no desenho organizacional, como o papel da liderança (Snowden e Boone 2007). Esse amplo escopo de fontes fornece validade de conteúdo considerável para as diretrizes.

As mesmas diretrizes foram testadas empiricamente, como ferramenta de avaliação, em um serviço de emergência hospitalar (Righi e Saurin, 2015) e em um processo de preparação e administração de medicamentos em uma unidade hospitalar (Saurin et al., 2019), dentre outros estudos. Essas aplicações apontaram a utilidade prática das diretrizes para a identificação de oportunidades de melhoria em SSTC.

As diretrizes citadas estão alinhadas com o paradigma da Engenharia de Resiliência (ER). De acordo com Nemeth e Herrera (2015), a ER tem ênfase em descrever, avaliar e influenciar a resiliência de SSTC por meio de ações projetuais. Quando aplicada à área da saúde, a ER é conhecida como *resilient healthcare* (Flanders

et al., 2020) definida como "(...) a habilidade de um sistema de saúde ajustar o seu funcionamento antes, durante, ou após mudanças e perturbações, de modo a sustentar o desempenho desejado tanto sob condições esperadas quanto inesperadas" citada por (Hollnagel, 2011, p. xxxvi). Segundo Hollnagel (2019) e Hegde et al., (2015) em contraponto com as visões tradicionais de segurança do paciente, que tem ênfase na redução do número de eventos indesejados, a ER tem ênfase na compreensão de como o sucesso ocorre.

Esta tese explora a complexidade e a resiliência, sob um ponto de vista organizacional, em Unidades de Terapias Intensivas (UTI) adultas. Esses ambientes são caracterizados por pacientes em estado crítico, que exigem cuidados por equipes multidisciplinares e apoio de tecnologias sofisticadas, bem como tomada de decisão sob incerteza (Fackler et al., 2009; Nemeth et al., 2016; Reader et al., 2018). Dessa forma, as UTIs são sistemas nos quais a eficácia dos cuidados e segurança do paciente emerge das interações sócio-técnicas (Fairbanks et al., 2014).

1.2 Problema de pesquisa

A perspectiva da complexidade tem sido usada para avaliar o desempenho de serviços de saúde por vários autores. Thompson et al. (2016) realizaram uma *scoping review* desse tipo de estudo, concluindo que a maior parte deles tem natureza exploratória, usa estudos de caso com métodos qualitativos, ocorre em serviços de saúde que envolvem pacientes que exigem cuidados de longo-prazo (*long-term care*) e tem ênfase nos relacionamentos entre os profissionais da saúde. Os atributos de SSTC mais usados envolvem interações/relacionamentos, diversidade e auto-organização (Thompson et al., 2016). Esses autores sugerem que pesquisas futuras tenham ênfase em operacionalizar a perspectiva da complexidade nos serviços de saúde.

Churruca et al. (2019) realizaram uma revisão bibliométrica do uso da perspectiva da complexidade na saúde. As conclusões dessa revisão apontaram para uma predominância de estudos em países desenvolvidos, bem como para uma recente mudança de ênfase de trabalhos conceituais para a aplicação de estratégias de melhorias baseadas na visão da complexidade, além de investigações mais aprofundadas sobre a natureza dos SSTC na saúde.

A presente tese aborda lacunas identificadas nas revisões citadas, tratando de abordagens da complexidade no contexto brasileiro, em serviços de UTI por meio de métodos mistos. Inicialmente, a tese explora a possibilidade de que a perspectiva da complexidade já seja implicitamente adotada em iniciativas de melhorias de processos nas UTIs. Tais iniciativas dizem respeito a intervenções formais, intencionalmente projetadas para melhorar o desempenho das UTIs, normalmente em termos de segurança dos pacientes e eficiência operacional. Entretanto, os estudos que relatam tais intervenções (por exemplo, Judd et al., 2014; Braithwaite; Wears e Hollnagel, 2015; Ogrinc et al. 2015; Hollnagel, 2017) não costumam explorar a compatibilidade entre a natureza da intervenção e a natureza complexa dos sistema-alvo. Deste modo, a análise explícita dessas intervenções, sob a perspectiva das diretrizes de gestão de SSTC, pode contribuir para a identificação de pontos fortes e fracos até então inexplorados.

Na sequência, o uso da perspectiva da complexidade é investigado no âmbito de eventos com resultados desejados em UTIs, com início e fim bem definidos (por exemplo, uma instabilidade na condição de um paciente que desencadeou várias ações de controle até a sua estabilização). Tais eventos diferem das intervenções de melhorias de processo acima mencionadas, visto que nesse caso não houve uma intervenção pré-planejada e controlada, mas essencialmente uma resposta baseada em grande parte na auto-organização dos profissionais. Desse modo, o uso das diretrizes de gestão de SSTC tende a ser ainda mais implícito e a operacionalização das mesmas pode assumir formas diferentes. Além disso, o tipo de investigação proposta, com eventos positivos, permite avaliar a contribuição das diretrizes de gestão de SSTC para um tipo de investigação inovadora na área da saúde, visto que nesse setor as investigações são normalmente reativas, baseadas em eventos adversos (Verbano et al., 2017).

Um terceiro cenário de uso das diretrizes de gestão de SSTC ainda é explorado na tese, qual seja a pandemia de COVID-19. Nesse caso, as UTIs têm sido expostas a uma situação de estresse por um longo período, desafiando a manutenção de melhorias de processo implantadas no passado, estando sujeitas a uma provável maior incidência de eventos adversos em função da sobrecarga de trabalho e ao mesmo tempo exigindo contínua auto-organização e criatividade para atender aos pacientes.

Assim, a tese explora as diretrizes de gestão de SSTC em três cenários complementares nas UTIs: (i) iniciativas de melhorias de processos; (ii) eventos com desfecho desejado; (iii) emergência de saúde pública caracterizada pela pandemia de COVID-19. Esses cenários representam, em linhas gerais, um extremo (i) no qual é possível planejar com antecedência e cuidado a implantação das diretrizes e outro (iii) no qual as pressões de carga de trabalho e escassez de recursos dificultam tal planejamento e sua operacionalização. Os eventos com desfecho desejado (ii) podem ser caracterizados como situações intermediárias entre esses extremos. A investigação conjunta desses três cenários, que não ocorreu em estudos anteriores de complexidade na saúde e em estudos sobre o uso das diretrizes de gestão da complexidade de SSTCs, possibilita a identificação de padrões (ou variações) e constitui outra característica original deste trabalho.

1.3 Questões e objetivos da pesquisa

1.3.1 Questões de pesquisa

De acordo com os conteúdos apresentados nos tópicos anteriores, a principal pergunta a ser investigada nesta tese é enunciada da seguinte forma: como as diretrizes de gestão de SSTC podem ser compreendidas em Unidade de Terapia Intensiva Adulta, tanto em situações normais quanto em situações de crise?

1.3.2 Objetivo geral

Identificar e classificar práticas para lidar com a complexidade em UTI Adulta, em situações normais e de crise.

1.3.3 Objetivos específicos

-Identificar o quanto os projetos de melhoria de processos nas Unidades de Terapia Intensiva adulta, relatados na literatura, estão alinhados às diretrizes de gestão de complexidade em SSTC.

- Propor uma abordagem para investigação de eventos com resultados desejados em SSTC, a qual inclua a análise do papel das diretrizes de gestão de SSTC.

- Identificar e classificar as práticas de resiliência organizacional em UTIs adultas brasileiras durante a pandemia de COVID-19, bem como lições aprendidas sob a perspectiva das diretrizes de gestão de complexidade.

1.5 Delineamento da tese

A pesquisa desenvolvida nesta tese tem como base uma abordagem mista, elaborada por meio de uma revisão sistemática, estudo de caso e *survey*. Dessa forma, foram utilizadas metodologias que produzem dados quantitativos e qualitativos, a fim de triangulação de dados e métodos (Harrison et al., 2020).

Abordagens quantitativas consistem em mensurar variáveis e características dos fatos (Cervo e Bervian, 2002; Miguel, 2012). Abordagens qualitativas têm ênfase na interpretação subjetiva dos indivíduos e no delineamento do contexto da pesquisa (Miguel, 2012). Ambas abordagens são úteis para estudos exploratórios, os quais são caracterizados pela investigação de fenômenos recentes e novos, tais como a pandemia de COVID-19, abordada em um dos objetivos específicos.

Quadro 1.1. Etapas do delineamento da tese

Etapa 1	Etapa 2	Etapa 3
Questão de pesquisa: Em que extensão as diretrizes de gestão de SSTC são consideradas, mesmo que implicitamente, em intervenções voltadas a melhorias de processos em UTI adultas?	**Questão de pesquisa:** Como o FRAM pode ser adaptado para explicitar o papel da resiliência na análise dos resultados desejados?	**Questões de pesquisa**: Como é a resiliência nas UTIs durante a pandemia? Quais são as lições práticas e teóricas aprendidas para lidar com a complexidade?
Objetivo*:* Identificar o quanto os projetos de melhoria relatados na literatura estão alinhados às diretrizes de gestão em SSTC nas Unidades de Terapia Intensiva Adulta.	**Objetivo:** Propor uma abordagem para investigação de eventos com resultados desejados em SSTC, a qual inclua a análise do papel das diretrizes de gestão de SSTC.	**Objetivo:** Este artigo apresenta um estudo exploratório de como as UTIs no Brasil têm enfrentado a complexidade sem precedentes decorrente da pandemia. Cinco diretrizes para lidar com a complexidade foram adotadas como uma estrutura de coleta e análise de dados
Método de pesquisa: Revisão sistemática.	**Método de pesquisa**: Estudo de caso.	**Método de pesquisa:** Métodos mistos.

Fonte: Autor.

1.6 Estrutura da tese

A tese está estruturada em cinco capítulos, quais sejam: 1. Introdução; 2. Artigo 1; 3. Artigo 2; 4. Artigo 3 e 5. Considerações finais. Abordando os artigos, o primeiro artigo, intitulado "*Improvement interventions in intensive care units: how they cope with complexity and implications for resilience",* é composto por uma Revisão Sistemática de Literatura (RSL) que tem como principal objetivo identificar as lacunas teóricas e práticas cientificamente no eixo de Sistemas Sócios Técnicos Complexos com base na qualidade e melhorias dos processos e avaliações das diretrizes para gestão em SSTC. Para construção deste artigo, foi utilizado o método *Preferred Reporting Items for Systematic Reviews and Meta-Analysis* -PRISMA.

No artigo dois, intitulado *"Making resilience explicit in FRAM: shedding light on desired outcomes*", o objetivo é propor uma nova abordagem para a investigação de eventos com resultados desejados em SSTC, com base no FRAM. É apresentada uma aplicação da proposta para dois eventos que tiveram impacto na segurança do paciente em uma Unidade de Terapia Intensiva (UTI) adulta.

No terceiro artigo, intitulado "*When resilience is not enough: an exploratory study of Brazilian ICUs during the COVID-19 pandemic*", foi adotada uma abordagem de método misto, incluindo dados qualitativos e quantitativos. Esta estratégia de pesquisa permite a triangulação de dados e fontes de dados e é recomendada para a investigação de fenômenos complexos (Harrison et al., 2020). Utilizou-se também o questionário proposto (apêndice A3) no qual foi baseado no artigo elaborado por Righi e Saurin (2015), utilizado em departamentos de emergências.

1.7 Delimitações da pesquisa

As principais delimitações da tese envolvem: (i) o foco em unidades de terapia intensiva adulta; (ii) a ênfase na descrição e avaliação das práticas de resiliência existentes nas UTIs, ao invés da implementação e avaliação de novas práticas; (iii) a ênfase nos níveis micro e meso dos serviços de saúde relacionados às UTIs, embora algumas influências do nível macro também tenham sido abordadas no artigo 3; (iv) o contexto da

pandemia de COVID-19 para análise da resiliência em UTIs em situações de crise, ao invés de crises de outra natureza.

2. ARTIGO 1: *Coping with complexity in intensive care units: a systematic literature review of improvement interventions*

Wagner Pietrobelli Bueno, Tarcisio Abreu Saurin, Priscila Wachs, Ricardo de Souza Kuchenbecker, Jeffrey Braithwaite

Abstract

Intensive care units (ICUs) are complex socio-technical systems. Logically and practically, improvement interventions in these environments should be consistent with their characteristics. This study presents a systematic literature review of 91 studies of interventions in adult ICUs, aiming at assessing the extent to which they account for five guidelines for coping with complexity: (i) supporting visibility of processes and outcomes; (ii) design slack; (iii) encouraging diversity of perspectives when making decisions; (iv) monitoring and understanding the gap between work-as-imagined and work-as-done; and (v) monitoring unintended consequences of improvements and changes. Both qualitative and quantitative assessments of adherence to the guidelines were conducted. In the former, examples of applying the guidelines were grouped under 40 descriptors, offering insights into practical ways of coping with complexity in ICUs. For the latter, guidelines (ii) and (iii) were adopted to a similar extent, greater than the other three guidelines. Results indicate that resilience is theoretically connected to the guidelines and therefore it may have been intuitively adopted by the interventions to some extent. An agenda for future research is proposed.

Keywords: intensive care units, complexity, improvement, resilience, work-as-imagined, work-as-done.

2.1 Introduction

Intensive care units (ICUs) play a key role in healthcare systems, by providing expensive, sophisticated and dedicated resources to the management of patients with life-threatening conditions (James et al, 2018). ICUs also involve clinical decision-making under conditions of significant uncertainty, efficiency pressures, and patients with challenging mixes of needs and multiple morbidities (Reader et al., 2018; Nemeth et al., 2016; Fackler et al., 2009). While these complexity characteristics pose difficulties for improvement interventions[1] in ICUs, they also suggest that these interventions may have high relevance from an economic and human standpoint. According to Ogrinc et al. (2015), an intervention can be defined as "systematic effort intended to raise the quality, safety, and value of health care services, usually done at the system level".

In another strand of scholarship, complexity science has been promoted as a lens for the design and assessment of interventions in healthcare systems in general (e.g. Reed et al., 2018; Leykum et al., 2007; Matlow et al., 2006). The underlying assumption is that ICUs and healthcare as a whole are highly complex socio-technical systems (CSSs) (Braithwaite et al., 2018), and therefore interventions which map to or are consistent with the characteristics of CSSs tend to produce better outcomes. In these and other studies, the term "complexity science" is adopted as a perspective for the understanding of systems, rather than as a unified theory (Morel and Ramanujam 1999).

In the present study, an analysis is made of the extent to which improvement interventions in ICUs adhere to five guidelines for coping with complexity: supporting visibility of processes and outcomes; design slack; encouraging diversity of perspectives when making decisions; monitoring and understanding the gap between work-as-imagined and work-as-done; and monitoring unintended consequences of improvements and changes. These guidelines were devised by Saurin et al. (2013), based on a literature review of fourteen seminal studies and/or studies from classic authors from resilience engineering (e.g. Hollnagel et al., 2011), cognitive systems engineering (e.g. Hollnagel and Woods, 2005), reports of using complexity insights to improvement in healthcare

[1] For simplicity, the terms *intervention* and *improvement intervention* are used as synonyms in this paper

(e.g. Stroebel et al., 2005), and discussions on the use of complexity to enhance organizational design (e.g. Snowden and Boone, 2007). This broad scope of sources provides considerable content validity for the guidelines. These guidelines have been used as an assessment tool in an emergency department (Righi and Saurin, 2015) and in a process of preparation and administration of drugs (Saurin et al., 2019). In these studies, a number of improvement opportunities in the work system design were identified based on the guidelines, indicating their usefulness. Another reason for using these guidelines in the present study is their circumscribed number, which can facilitate the analysis of a large number of interventions. There are other levels of granularity for presenting similar guidelines for coping with complexity, such as the twenty complexity oriented enablers and insights suggested by Braithwaite (2018) but these were too large for the present study.

The five guidelines are theoretically connected to resilience (Saurin et al., 2013), which is the "ability of the healthcare system to adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required performance under both expected and unexpected conditions" (Hollnagel et al., 2013, p. xxv). In healthcare, resilience is traditionally approached from a psychological perspective, emphasizing how individuals cope with stress and disease (e.g. Tugade and Fredrickson, 2004). However, a systems-orientated view of resilience, in line with the resilience engineering approach of the concept, has been a topic of growing interest in healthcare (Braithwaite et al., 2015). This interest fits with the resilience engineering emphasis which describes the adaptive nature of healthcare. This is not typically acknowledged in traditional research and intervention approaches in this sector (Braithwaite, 2018).

Against this background and context, two research questions (RQs) are addressed by this study: (RQ1) how to map the guidelines for coping with complexity onto reported interventions in ICUs and evaluate the extent to which they have been accounted for? (RQ2) what are the implications of the adoption of the guidelines for resilient healthcare? In order to answer these questions, a systematic literature review of improvement interventions in adult ICUs was conducted. The derived data were analysed in light of the five guidelines and the implications for resilient healthcare. Considering that resilience

engineering is not yet widely known in healthcare, this study offers insights into whether and how it has been implicitly adopted in ICUs.

2.2 Coping with complexity

Although CSSs might be designed and managed, their irreducibly high variability sets a limit for the effectiveness of formal and centralized control mechanisms (Perrow, 1984). This variability is not necessarily detrimental, and it can be the source of both desired and undesired outcomes (Hollnagel, 2017). Table 2.1 presents the main aspects of each guideline and their association with the attributes of CSSs, which may be seen as the rationale for using the guidelines. Thus, the guidelines are more important in the face of complexity, and it follows that context matters in their implementation (Clegg, 2000).

Table 2.1. Guidelines for coping with complexity (adapted from Saurin et al., 2013)

Guidelines	**Main aspects of the guidelines**	**Complexity attributes* addressed by the guidelines**
Supporting visibility of processes and outcomes	Systems should be intuitive and visibility should be given to both formal and informal work practices (Clegg, 2000). Informal practices may encompass either useful innovations or latent hazards. Visibility should allow for real-time performance monitoring and the free sharing of information (Galsworth, 2017).	This guideline may be useful for coping with any complexity attribute, making these more salient and distinctive from each other.
Design slack	Slack is a mechanism for reducing interdependencies and slowing down or eliminating the propagation of variability (Safayeni and Purdy, 1991). This may be obtained through spare resources (e.g. human, technical) which can be called on in times of need (Nohria and Gulati, 1996).	This guideline aims at making processes loosely-coupled, and thus absorbing or dampening the propagation of *variability*. Since variability is normal in complex systems, slack also tends to be useful in everyday work. As a drawback, slack may increase the *number and diversity of elements* in the system.
Encouraging diversity of perspectives when making decisions	Diversity of perspectives may help to tackle uncertainty. Agents involved in decision-making should hold complementary skills. Some requirements for the implementation of this guideline are: high levels of trust, reduction of power differentials and identification of apt decision-makers (Page, 2010).	*Diversity* is a key attribute of complexity, and it may offer complementary perspectives of system functioning
Monitoring and understanding the gap between work-as-	Monitoring and understanding the gap between work-as-imagined and wok-as-done may shed light on variability sources that otherwise may be taken for granted. Reasons for the gap should be investigated, as well as its implications (Hollnagel, 2017).	Due to the *dynamic interactions between a large number of diverse elements*, and the resulting unexpected *variability*, work-as-imagined is different from work-as-done in CSSs.

imagined and work-as-done		
Monitoring unintended consequences of improvements and changes	Improvements and changes interact between themselves and with the environment, and this poses opportunities for unintended consequences (Perrow, 1984). These consequences may be benefits, problems, failures, or costs associated with the intervention (Ogrinc et al., 2015).	CSSs have *tightly coupled* processes *interconnected as a network*. Also, these systems are always *evolving* and *interactions* are *highly dynamic*. Thus, any changes may propagate in unexpected ways and *non-linearly* – i.e. consequences may be disproportionate to the causes.

Source: Authors.

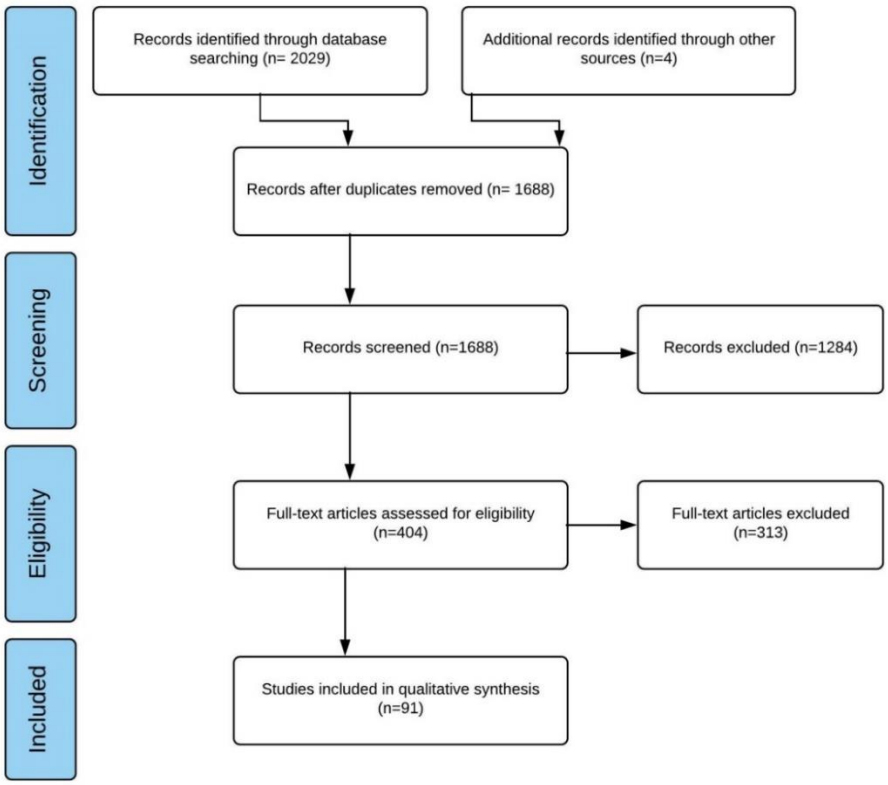
* The terms in Italics correspond to the attributes of complexity directly addressed by the guidelines.

2.3 Method

2.3.1 Selection of papers

For the literature review, we followed the steps recommended by Moher et al. (2009) (Figure 2.1), involving: (a) identification of the papers; (b) screening; (c) eligibility; and (d) inclusion.

Figure 2.1. Steps for selecting the papers



Source: Authors.

In the identification step, seven databases, which were available from the authors' institution, were included: Web of Science; Science Direct; Scopus; Emerald; Pub Med; Sage Journals; and Wiley. In each database, areas queried were business, management and accounting, decision sciences, engineering, medicine and dentistry, nursing and health professions, and social sciences. The databases were queried in June 2018 and, for each database, the results were downloaded in single batches and on the same day. The search criteria encompassed the terms *'Intensive Care Unit' OR 'Critical Care Unit' AND 'Safety' OR 'Quality' OR 'Process Improvement' OR Lean Production OR Six Sigma*, in the title, abstract and/or keywords. Lean production and six sigma were included as keywords given that these approaches have been increasingly adopted for improvement in healthcare (DelliFraine et al., 2010).

Resilience engineering was not used as a keyword since so far it has not been usually applied in the form of interventions, but usually as an analytical and descriptive approach (Righi et al., 2015). In turn, *resilience* was not a keyword since this term is traditionally used in healthcare in the sense of individual psychological resilience, as mentioned in the Introduction.

The period of publications was not specified. A total of 2029 records were identified and available through database searching and four were manually added (O´Brien et al., 2018; Verbano et al., 2017; Rosa et al., 2017; Clay-Williams et al., 2015). These four papers were identified from other research studies on similar topics carried out by one of the authors. After excluding 345 duplicates, 1688 records were identified at the end of the identification step. In the screening step, six exclusion criteria were applied: (i) non-scientific texts (e.g. magazine paper, 56 records); (ii) papers written in other languages than English (34 records); (iii) conference proceedings (37 records); (iv) literature reviews (181 records); (v) neonatal or paediatric ICUs (328 records); and (vi) interventions that were not focused on ICUs, even though this term appeared on the paper (648 records). Based on these criteria, 1284 articles were excluded and 404 remained for the next step.

For the eligibility step, the full contents of the 404 articles were analysed in light of one exclusion criterion, namely papers that reported the development and test of new drugs and equipment directly used in patient care. Since these interventions were essentially technical, and the guidelines had a managerial and system design emphasis, their applicability was assumed to be low in these situations. As a result of applying these criteria, 313 articles were excluded and 91 remained for the next step of the review. These 91 articles were included in a database, which contained the identification data (database, journal's name, title, year of publication), and information related to the data analysis categories discussed in Section 2.3.1.

2.3 Data analysis

2.3.1 Overall characterization of the interventions

In order to obtain an overall characterization of the interventions, seven data analysis categories were defined. The required information for this characterization was often clearly present in the abstract, or in the paper's sections that described the intervention and the research design, or both. These categories are:

(a) Bibliometric information: journal, year of publication, and country where the empirical study was carried out;

(b) ICU profile: number of beds, main specialty area (e.g. trauma, cardiac), and whether the ICU was part of a teaching hospital;

(c) ICU process emphasized by the intervention: whether the intervention addressed processes of direct patient care (e.g. administration of drugs) or support processes (e.g. ward rounds);

(d) Intervention practices adopted: this category is concerned with the nature of the practical measures implemented to operationalize the intervention (e.g. training);

(e) Research design: this focuses on the main decisions regarding how the intervention was conducted and evaluated;

(f) Performance dimensions emphasized: these were divided into three main types, namely the efficiency of ICU operations (e.g. reduction of lead-times, capacity gains, and cost savings), patient safety and well-being, and family members' satisfaction and well-being. Although these three performance dimensions types are likely to be correlated (e.g. lower length of stay may be beneficial both to safety and efficiency), data coding was based on the performance dimensions emphasized by the authors of the reviewed papers, in order to minimize bias. In general, the interventions' reports were clear in this regard;

(g) Results: the quantitative and qualitative impacts of the interventions were reviewed mostly as a support for the interpretation of the other data analysis categories, rather than as a key category by itself. While relevant, a meta-analysis (Viechtbauer, 2010) that could indicate the effect of using the guidelines on outcomes was beyond the scope of this study.

2.3.2 Qualitative assessment of the guidelines

The core portion of data analysis was the assessment of the guidelines presented in Section 2. It is worth noting that the guidelines were not, with some exceptions, explicitly adopted and reported in the interventions; the analytical framework was therefore imposed on the interventions as a heuristic device. Initially, for each paper, excerpts of text related to the guidelines were identified and coded into practical instantiations of the guideline. Then, similar instantiations were grouped under a same descriptor, using the same terms adopted by the studies to the possible extent – e.g. one of the descriptors for the guideline *Design Slack* was the "use of intervention bundles", which was a term that frequently appeared in the studies. These procedures were carried out primarily by the three first authors (WPB, TAS, PW), each of whom initially analysed a third of the overall selected papers.

The first three authors are human factors and industrial engineering researchers, with previous field research experience on improvement interventions in healthcare, including ICUs. Each of these researchers independently developed their own Tables with instantiations of the guidelines. Then, each researcher randomly selected five papers

analysed by their peers. For example, WPB selected five papers initially analysed by TAS and five by PW, carried out her own independent codification and then compared it with the original codification made by her peer. Next, there was a discussion and a consensus was achieved. In addition to this, this same procedure was followed by the fourth author (RK) – an experienced physician and risk manager of a large teaching hospital, who also randomly selected five papers from each of the first three authors. After the discussion with peers, each of these three authors also reviewed the codifications made for her other papers, and not only for those cross-checked. This analysis procedure created investigator triangulation and contributed to the maturing of the codification criteria and consistency between the analysts, in addition to obtaining insight from both healthcare and human factors experts. As a result of this approach, over 45 papers were fully analysed and cross-checked by at least two researchers.

2.2.3 Quantitative assessment of the guidelines

A quantitative assessment was carried out through the assignment of scores to the instantiations of applying the guidelines. The score could range from zero – guideline was not accounted for, to four – guideline was strongly implemented – including non-integers. The scores were initially assigned by each of the first three authors, and then subjected to the same cross-check procedures described in Section 2.2.3. The rationale for defining the scores was as follows:

(a) Supporting visibility of processes and outcomes: high scoring interventions involved the use of visual devices freely accessible to all agents, and that offered insight into abnormalities and the status of operations as close as possible to real-time;

(b) Design slack: high scoring interventions involved the use of slack as a result of design, rather than being opportunistic. Slack that was too much reliant on the expertise of professionals (which is difficult to observe and measure), or that created additional process steps and barriers, thus increasing interactive complexity, had lower scores;

(c) Encouraging diversity of perspectives when making decisions: high scoring interventions were designed based on inputs from different agents, *and* the intervention itself created opportunities for decision-making based on multiple perspectives;

(d) Monitoring and understanding the gap between work-as-imagined and work-as-done: high scoring interventions: were designed based on a deep study of work-as-done, which relied on a mix of quantitative and qualitative data; and were concerned with identifying the variability of everyday work and learning from what goes right, and not only from what goes wrong (Hollnagel, 2017);

(e) Monitoring unintended consequences of improvements and changes: a high scoring intervention had: a broad range of outcome measures, not being limited to the primary expected outcome; an assessment of the intervention over several months or years, thus allowing time for the emergence and acknowledgement of unintended consequences; and an explicit definition of the system boundaries, beyond which there should be no effects arising from the intervention, in principle.

In addition, there were two general assumptions underlying the assignment of scores:

(a) When two or more instantiations of applying the same guideline occurred on the same intervention, the highest scoring instantiation was adopted as a basis. For instance, if there were two different instantiations of designing slack in a certain intervention, the score assigned for the intervention corresponded to the score of the highest scoring instantiation;

(b) Sometimes the same instantiation had an impact on more than one guideline. This occurred mostly for the interventions that supported visibility of processes and outcomes, which also impacted on slack – e.g. visual aids were interpreted as redundancies to the human memory. In these cases, the implications of the intervention were assessed and codified separately based on its relevance for each guideline.

Based on these procedures and assumptions, a ranking of the interventions was developed considering their overall mean scores for the guidelines. Non-parametric Friedman´s test (at the 0.05 significance level) was conducted to check for statistically significant differences between the guidelines overall means.

2.4 Characterization of the studies and interventions

The 91 selected papers were published in 63 different journals, which suggests that there is a broad audience interested in the topic of improvement interventions in ICUs. The three most frequent journals, each having five papers, were the *Journal of Intensive Care Medicine*, the *Journal of Critical Care*, and the *American Journal of Medical Quality*. In turn, the reported interventions were carried out in 20 countries, with a higher frequency of the United States (51%), Australia, UK, and Canada (each accounting for 8.8% of the total). Only 11% of the interventions happened in developing countries (e.g. Brazil, China, Iran, and Turkey). 65% of the studies were published from 2013-2018.

Regarding the ICUs focused on by the interventions, they were characterized by: (i) different sizes, ranging from 8 to 88 beds (on average, 26 beds); (ii) belonging to both teaching (54%) and non-teaching hospitals (46%); and (iii) involving several specialties, such as trauma, cardiac, and neuro. The ICU characterization data provided by most studies was limited to these three characteristics (beds, teaching, and specialty).

As for the research design (Table 2.2), there was a much higher incidence of uncontrolled before-after single centre studies. This is consistent with previous systematic reviews of quality improvement in healthcare, which reported up to 75% of simple before-after designs (Shortell et al., 1998).

Table 2.2. Research design of the reviewed studies

Research design	N (%)
Uncontrolled before-after single centre	64 (70.3%)
Only evaluation after the intervention (either controlled or uncontrolled) – single centre	10 (11%)
Uncontrolled before-after multi centre	9 (9.9%)
Controlled before-after single centre	5 (5.5%)
Randomized controlled trial – single centre	1 (1.1%)
Only evaluation after the intervention (either controlled or uncontrolled) – multicentre	1 (1.1%)
Randomized controlled trial – multicentre	1 (1.1%)
Total	91 (100%)

Source: Authors.

In turn, patient safety and well-being were the most frequent concern of the interventions (e.g. Cahill et al., 2014) (n=83), in comparison with efficiency (e.g. Brown et al., 2013) (n=20), and the well-being and satisfaction of the families of patients (e.g.

Wysham et al., 2014) (n=8). Some interventions were explicitly concerned with more than one of these performance dimensions. None of the interventions focused on the safety and well-being of healthcare professionals, and just a few (e.g. Judd et al., 2014) provided evidence of their financial impacts – these studies were coded as emphasizing efficiency.

Other characterization data of the interventions are presented in the Appendixes 1 and 2. The first presents the twenty-nine ICU processes addressed by the interventions. There was a slightly greater incidence (54% of the total) of interventions focused on support processes (e.g. rounds) rather than on direct patient care. The second lists the twenty-seven categories of interventions practices adopted in the interventions. The use of standardization and checklists was the most frequent solution (28.2%), which suggests that there are many relatively linear sub-systems in ICUs, which do not necessarily rely too much on resilience.

Based on the characterization data presented in this Section, it is possible to say that the improvement interventions in ICUs: have been mostly carried out in developed countries; are usually designed as uncontrolled before-after single centre experiments; focus on patient safety and well-being; address a wide variety of processes directly related to patient care and support processes; and involve a wide variety of intervention practices, although very often relying on standardization and checklists.

2.4.1 Assessment of the guidelines for coping with complexity

2.4.1.1 Supporting visibility of processes and outcomes

Table 2.3 presents the results for the guideline *supporting visibility of processes and outcomes* (mean = 1.5; median = 1.5).

Table 2.3. Instantiations of the guideline related to the visibility of processes and outcomes

Instantiations	Freq.	Score
Physical memory aids and visual reminders. E.g. yellow sticker on the paper medication record next to the prescription; laminated cards with the assessment scale placed near the beds; visual reminders to support feedback and compliance with evidence-based practice; informative posters for patients relatives	22	2
Computerized tools for the monitoring of the status of exams, care plan, bed availability, lab results - they may include alerts, green/red/yellow status. E.g. electronic notification alert of bed assignment, electronic alert of pending prescription review, alerts in the computerised order-entry system, emphasising that ordering routine chest X-ray is not recommended	16	2
Whiteboards (in public spaces) for recording care planning and monitoring, usually as a support for group meetings. E.g. patient-specific rehabilitation plans and goals transcribed onto wall charts	9	4
Wide visual communication of the changes and results of the improvement initiative	7	2
Removal of unnecessary items from the workplace and organization of the remaining items (this can be interpreted as a partial and unstructured 5S implementation)	4	2
Total*	58	-
Guideline was not used in the intervention**	33	0

Source: Authors.

** The total number of instantiations can differ from the number of interventions (91) because: some interventions had more than one instantiation of the guideline; and the guideline was not used in some interventions.

* The frequency of *guideline not used* refers to the number of interventions, rather than the number of instantiations of the guideline. Observations * and ** also apply to Tables 4, 5, 6, and 7.

According to Table 2.3, around one third (n= 33, 36%) of the interventions did not use this guideline. In fact, even when the guideline was adopted, it was not usually a core aspect of most interventions. The two most frequent instantiations were physical memory aids and visual reminders, and computerized tools for monitoring the status of operations. Whiteboards, while less common, received the highest score (4) because of two strengths (Galsworth, 2017): they have a public interface, freely accessible to anyone

– this is an advantage in comparison with traditional computer-based tools; and they can support interactive group discussions that happen at the front-line and are based on the displayed information.

Verbano et al. (2017) present a sound example of applying this guideline (score 4), by describing the use of whiteboards to support daily briefings of an ICU, including a comparison between actual and planned actions for patient care. One of the indicators evaluated on a daily basis was the number of days where there was at least one ICU bed available. This illustrates how visual management can support the monitoring of slack. As for an example of using IT (score 2), Chen et al. (2018) describe the use of notifications through mobile phones and alerts in electronic health information systems, in order to warn infectious disease physicians that they need to review antimicrobial prescriptions prepared by clinicians.

Opportunities for further research and innovation concerning the guideline are related to: (i) the identification of the main needs for real-time visibility in ICUs; (ii) the development of means to support visibility of performance adjustments that occur in everyday work (Hollnagel, 2017), in complement to visibility of abnormalities; (iii) the development of means to support visibility of the status of slack resources, given the need for their prompt availability in critical situations; (iv) the implementation of visual systems (Galsworth, 2017), comprised of several interconnected visual devices that play complementary roles; (v) the use of a broader range of operationalization strategies (e.g. by using other human senses in addition to vision and hearing), which could be inspired by initiatives from other sectors and from other healthcare sub-systems; and (vi) the investigation of the contribution of the built environment design (e.g. layout of wards, furniture, illumination) as a source of process transparency.

2.4.1.2 Design slack

Table 2.4 presents the results for the guideline *design slack* (mean = 2.4; median = 2.5). The instantiations are associated with the slack deployment strategies, which may be operationalized through different resources. For instance, standby redundancy is a

strategy that may be instantiated through resources such as spare beds or family members who stay in the ICU for extended periods.

Table 2.4. Instantiations of the guideline Design Slack

Instantiations	Freq.	Score
Visual management interventions that played a role as redundancies to the human memory and/or that gave visibility to the status of slack resources	31	2
Active redundancy (Clarke, 2005): the redundant practice is fully loaded and operational, being involved in the task at hand. E.g. telemedicine, and intervention bundles since partly overlapping practices for patient care are applied at the same time	18	4
Conceptual slack or cognitive diversity (Schulman, 1993): divergence in analytical perspectives	14	2
Informal redundant procedures. E.g. encourage the use of checklists and the report of incidents	14	1
Capacity and/or financial slack, as a result of efficiency gains. E.g. cost savings with unnecessary medications; excess of ICU beds that were used by patients who did not need that type of support – money saved with this removal allowed for new beds elsewhere	11	4
Margin of Manoeuver, type 2 (Stephens et al., 2011): autonomous strategies to create margin via local reorganization or expand a unit´s ability to regulate its margin E.g. early detection of the need for palliative care; early detection of not completed care protocols; early detection and treatment of sepsis, early detection of the need for mobilising patients	8	3
Standby redundancy (Clarke, 2005): the redundant resource is neither loaded nor operational. E.g. spare bed in the ICU; spare parts in the trolley with equipment and supplies for central venous catheter	5	4
Control slack (Schulman, 1993): individual degrees of freedom, with some range of individual action unconstrained by formal structures. E.g. provision of alternative means for carrying out the same task, such as computer and paper-based report of incidents	5	2
Opportunistic standby redundancy. E.g. extended visits of family members in the ICU	4	2
Redundant procedures (Ong and Coiera, 2010). E.g. infectious disease physician reviews prescriptions by prescribing physician; notification by mobile phone if prescription not reviewed within 48 hours; audits of care and planning processes; external assessments of round quality	3	3

Duplication of functions (Clarke, 2005): two different units perform the same function. E.g. several professionals playing a role as incident reporters	3	3
Margin of Manoeuver, type 1 (Stephens et al., 2011): maintaining local margins by restricting other units´ actions or borrowing other units´ margin. E.g. radiology nurse goes to the ICU to support the early preparation of the patient for the exams. However, she is away from her position.	1	1
Total	117	-
Guideline was not used in the intervention	10	0

Source: Authors.

Twelve different deployment strategies, and a large number of instantiations (117) were identified. These findings reflect both the relevance of slack for coping with complexity and the slack definition (see Table 2.1) as any mechanism for slowing down or eliminating the propagation of variability. For instance, the early detection of the need for care, which exemplifies the margin of manoeuvre type 2 in Table 2.4, implies in the early identification of variability in the patient condition, which can be damped early, preventing propagation leading to further complications. Slack mechanisms may also involve spare resources, of any sort, which can be called on in times of need. These are not necessarily extra or idle resources, as they can be strictly necessary resources that may be relocated (e.g. the margin of manoeuvre type 1, on the bottom of Table 4) and used in different ways as needed (Saurin and Werle, 2017). It is also worth noting the distinctive nature of capacity and/or financial slack as a result of efficiency gains. In these situations, slack was created as a result of the intervention, rather than being an integral part of the intervention itself.

The most frequent strategy was the use of visual devices as redundancies to the human memory and/or to give visibility to the status of slack resources. These devices were interpreted as an additional agent in the system, in line with the notion of joint cognitive systems formed by an inseparable ensemble between human and technologies (Hollnagel and Woods, 2005).

The second most frequent strategy was active redundancy, such as the use of intervention bundles for implementing evidence-based practice, relying on complementary care measures. The study by Leblebicioglu et al. (2015) involved a multicentre introduction of five practices for improving hand hygiene in ICUs. As a drawback of these interventions, the extent to which each individual practice contributes to the outcomes is unknown.

Conceptual slack was the third most frequent, such as in the case of multidisciplinary rounds that create more opportunities for obtaining inputs from nurses (Ten Have et al., 2013). Similarly, nursing rounds involving specialty nurses from other areas than the ICU had an impact on slack, as recognized by this quotation from one participating nurses (Jennings and Mitchell, 2017): "*it's great to have these nurse rounds, because I feel the patient has some* ***extra care*** *from all over the hospital*".

There were also interventions with mixed impacts on slack. An example refers to the use margin of manoeuvre type 1 reported by Wells and Murphy (2014) – score 2. In this intervention, a nurse from the radiology department performed the patient assessment for magnetic resonance imaging in the ICU setting instead of in the radiology department. On the one hand, this contributed to an early preparation of the patient for the exam and provided conceptual slack since the assessment occurred jointly with the ICU staff. On the other hand, the nurse was absent from the radiology department, which was understaffed (Wells and Murphy, 2014).

Research and innovation opportunities associated with *design slack* refer to topics under-explored by the reviewed papers, such as: (i) the understanding of the complementary roles played by the slack resources, which may shed light on why the intervention worked or not; (ii) the explicit identification of the main variability sources that slack is intended to cope with – this may be a check for assessing whether the amount and location of slack are adequate; (iii) the assessment of the system-wide mixed implications of slack, including whether and how it can either increase or decrease waste and complexity.

2.4.1.3 Encouraging diversity of perspectives when making decisions

Table 2.5 presents the results for the guideline *encourage diversity of perspectives when making decisions.* This guideline had the highest mean (2.6) and median (3).

Table 2.5. Instantiations of the guideline related to the diversity of perspectives

Instantiations	Freq.	Score
The intervention design was based on multiple perspectives and the intervention itself created opportunities for this. E.g. multidisciplinary palliative care service; PDCA with strong workers involvement; multidisciplinary rounds	27	4
The intervention itself created opportunities for applying the guideline, although the intervention design stage did not follow the guideline. E.g. two or more professionals give inputs on the need for prescribing antibiotics	18	3
The intervention design was based on multiple perspectives (e.g. items included in the round checklist were defined after group discussion, multidisciplinary sepsis committee decided priority areas), but the intervention itself did not have an emphasis on this guideline	11	3
The intervention created more opportunities for obtaining inputs from patients and/or family members – e.g. family members attending the multidisciplinary rounds, family present in the ICU for a longer period	7	3
The intervention facilitated communication between the same professional category. E.g. doctor-to-doctor handovers	5	1
Patients could decide whether or not they would like to participate in the intervention. E.g. use of eye masks and ear plugs	3	1
As a result of the intervention, the need for applying this guideline was reduced. E.g. the intervention reduced the number of hand-offs, which in turn reduced the need for exchange of information and joint decision-making	3	1
Incident reporting systems where anyone could be a reporter and the reports were widely discussed – E.g. by a multidisciplinary committee, at the daily rounds, nursing workshops	2	4
Computerized decision support systems – to some extent, these systems incorporate expert knowledge	1	1
Total	77	-
Guideline was not used in the intervention	14	0

Source: Authors.

A high number of instantiations (30%, n = 27) were consistent with the most desirable situation related to this guideline (score 4), namely that the intervention design was based on multiple perspectives, and that the intervention itself created mechanisms for applying the guideline on a daily basis. An intervention to reduce unplanned extubation reported by Chao et al (2017) illustrates this point. A multidisciplinary team of intensivists, senior residents, nurses, and respiratory therapists devised a bundled intervention organized around eight key areas, which included improvement of communication skills and team resource management (Chao et al., 2017). Another high scoring intervention was reported by Parker et al. (2010). This intervention supported collaborative work between the tracheostomy experts who worked at the ICU and the professionals who would care these patients after they were transferred to the wards.

Research and innovation opportunities related to this guideline may involve: (i) the development of new means for obtaining inputs from patients and their families; (ii) an exploration of the costs of collaboration, which may introduce undesired side-effects – e.g. decision-making processes may become more time-consuming, and professionals highly demanded to collaborate with others may be subjected to frequent interruptions in their workflow; and (iii) the modelling of the collaborative decision-making process by ICU professionals, which is little known according to James et al. (2018).

2.4.1.4 Understanding and monitoring the gap between work-as-imagined and work-as-done

Table 2.6 presents the results for the guideline *understand and monitor the gap between work-as-imagined and work-as-done* (mean = 1.6; median = 2.0).

Table 2.6. Instantiations of the guideline related to the understanding and monitoring of work-as-done

Instantiations	Freq.	Score
Feedback systems (electronic or not, such as daily meetings to check planned actions and discuss issues from the previous day; PDCA cycles) that pointed out, as close to real-time as possible, deviations of work-as-done from work-as-imagined.	16	3
The pre-intervention phase focused on understanding the current process (e.g. using value stream mapping, flowcharts, business process mapping tools, FRAM, wide range of baseline data), using the findings as an input for refining the intervention design * score was 3 when the data collected included interviews with staff and observation of work-as-done	15	2
The evaluation stage compared the level of compliance with care protocols before and after the intervention. However, the reasons for the gap between work-as-done and work-as-imagined were not discussed.	15	2
The intervention mostly consisted of checklists that allowed for comparison between work-as-done and work-as-imagined. However, the analysis was limited to the items of the checklist and reasons for the gap were not discussed	6	3
Incident reporting systems. However, there was a focus on reporting only errors and failures, rather than everyday variability sources	5	2
The pre-intervention phase involved an audit of several cycles of the process. However, this was not used to improve the intervention design, which had been defined beforehand.	4	0.5
Improved monitoring tools, practices and knowledge offered insight into work-as-done. E.g. extended family visits in the ICU	4	1
The intervention made it necessary that professionals from other areas of the hospital went to the ICU, thus seeing with their own eyes how it worked. E.g. specialty nurses from other areas went to the ICU to attend inter specialty nursing rounds	3	2
Total	68	-
Guideline was not used in the intervention	27	0

Source: Authors.

About a third of the interventions (30%, n = 27) did not use this guideline, and none of the instantiations had a score 4. The main reason is that, except for Clay-Williams et al. (2015)[2], they were not concerned with identifying the variability of everyday work and learning from what goes right, which are two central principles for coping with complexity in the resilience engineering perspective (Hollnagel, 2017). This gap might be due to: (i) the fact that resilience engineering is not yet widespread in practice; (ii) the design of the vast majority of the studies, which emphasised the identification of *what* worked in detriment of understanding *why* and *how* it worked, and how it could be applied under different circumstances; and (iii) a reduced emphasis placed by researchers and journal editors in general on qualitative research in healthcare (Daniels et al., 2016).

Regardless of these drawbacks, some studies received a score 3. For instance, Chaves et al. (2014) defined minimum standards for the documentation of antimicrobial prescribing practices (e.g. documentation of the patient's antibiotic allergy status). These standards were agreed between the intervention design team as being non-negotiable and easily auditable core business standards of care. The first 12 weeks of the project were entirely dedicated to the observation of existing prescribing practices, through audits and surveys (Chaves et al., 2014). This study exemplifies the second most frequent way of applying this guideline, listed in the third row of Table 2.6 (i.e. the pre-intervention phase focused on understanding the current process).

The most salient research and innovation opportunities related to this guideline refer to: (i) interventions that combine in a balanced way the use of quantitative and qualitative data; and (ii) interventions that are preceded by a thorough understanding of work-as-done and what goes right, and that create opportunities for the continuous monitoring of performance adjustments.

[2] This study scored 3 because the implementation of the revised clinical guidelines was not reported, and also because the analysis of what goes right was not clear.

2.4.2 Monitoring unintended consequences of improvements and changes

Table 2.7 presents the results for the guideline *monitor unintended consequences of improvements and changes* (mean = 1.4; median = 1.0).

Table 2.7. Instantiations of the guideline related to the monitoring of unintended consequences

Instantiations	Freq.	Score
Potential or real unintended consequences (positive or negative) and barriers were mentioned, but not followed-up and explored. E.g. changes in behaviour because of being videotaped during the rounds; opportunistic teaching using whiteboards	26	1
A broad range of outcome metrics was gathered, and not all of these were directly linked to the main purpose of the intervention. E.g. infections and adverse events arising from the extended ICU visits; economic and clinical outcomes; nursing workload due to the new practices. As a drawback, the set of measures was defined before starting the intervention. Thus, unexpected consequences may have been missed.	12	3
After the intervention, evaluation data were collected over several months or years. Although there was no explicit concern with unintended consequences, this long-term follow-up offered opportunities for their identification.	10	2
One or two additional outcome metrics were gathered (in addition to the primary metric), and these were defined upfront. E.g. alert fatigue as a possible side-effect of a new electronic visual management system	7	2
Rapid cycle testing of changes (2-4 weeks) allowed for the early detection of unintended consequences	6	3
The intervention included a monthly monitoring of a set of pre-defined barriers for the implementation process. While the barriers were anticipated, their timing and intensity were not.	4	2
Total	65	-
Guideline was not used in the intervention	33	0

Source: Authors.

A substantial number of interventions (36%, n = 33), did not use the guideline, and none of the interventions was assigned the highest possible score. Instantiations were not aligned with at least one of the criteria defined in Section 2.3.2. A few studies explicitly acknowledge that this guideline was neglected (e.g. O´Brien et al., 2018) and

many others (second row of Table 7, 26%, n = 26) briefly mentioned potential or real unintended consequences and barriers, which were not explored in depth.

In other cases, unforeseen uses of the original solution were detected due to the use of a broad range of outcome metrics. For example, Wessman et al. (2017) reported the use of bedside glass doors for posting patient care and control planning, enhancing communication between ICU professionals (score 3). During the intervention, faculty started to use that information for teaching and lecturing, facilitating real-time didactics for the critical care team. This intervention itself was a response to the unintended consequences of changes on duty hours, which implied in more handovers, and thus in greater likelihood of communication problems.

Rapid cycle testing of changes was also a valuable approach related to this guideline, since this started with a small group of patients and staff members, allowing for the early detection of unintended outcomes. For instance, the study by Hatler et al. (2006), which scored 3, applied the said approach for reducing ventilator-associated pneumonia and catheter-related bloodstream infection.

There were also studies that scored highly due to the long period of intervention assessment and broad range of outcome measures (score 3). For instance, McWilliams et al. (2015) developed a supportive rehabilitation team with a focus on promoting early and enhanced rehabilitation for patients at high risk for prolonged ICU and hospital stays. The main outcome measures, gathered in the 12 months after the intervention, were mobility level at ICU discharge, mean ICU, and post-ICU length of stay, ventilator days, and in-hospital mortality.

Overall, the low attention paid to this guideline is in conflict with recommendations for complex interventions in healthcare systems (e.g. Craig et al., 2008). Possible reasons for this may be: the already mentioned lack of qualitative insight into the interventions; the lack of knowledge of how to operationalize the guideline (in this respect, Table 6 may offer some guidance); and the reduced length of time of the intervention assessment, which may be too short for giving rise to unintended consequences. The low number of reviewed papers focused on IT innovations (see

Appendix 2) may also have played a role in our findings, since IT is a well-known source of unintended consequences in healthcare (Ash et al., 2004).

As for research and innovation opportunities, it is possible to mention: (i) the use of system modelling (e.g. the FRAM) and simulation tools that could support the anticipation of unintended consequences; (ii) the gathering of outcome measures from upstream and downstream processes, and not only from the process directly focused on by the intervention; (iii) an explicit analysis of the trade-offs involved in the intervention – e.g. efficiency-thoroughness trade-off (Hollnagel, 2009). This last suggestion may benefit from the gathering of process measures, which could shed light on the necessary resources for implementing the intervention.

2.5 Discussion

2.5.1 Implications for resilient healthcare

In principle, the guidelines we have discussed can contribute to the operationalization of the four potentials of resilient systems defined by Hollnagel (2017): (i) the potential to *respond*, which implies knowing what to do, or being able to respond to regular and irregular changes, disturbances, and opportunities; (ii) the potential to *monitor*, which implies knowing what to look for, or being able to monitor what could seriously affect the system performance in the near term, positively or negatively; (iii) the potential to *learn*, which implies knowing what has happened, or being able to learn from experience, in particular to acquire the right lessons from the right experience; and (iv) the potential to *anticipate*, which implies knowing what to expect, or being able to prepare for developments further into the future, such as disruptions, constraints or opportunities. The potentials are inter-related (Hollnagel, 2017) and therefore the contribution of any given guideline is expected to be multidimensional, although it may exhibit different levels of intensity. Based on the reviewed studies, this point is illustrated as follows:

(a) Supporting visibility of processes and outcomes: visibility facilitates the identification of variability (Galsworth, 2017), thus it can support monitoring, the identification of when a response is necessary, and how it should be deployed. For instance, the whiteboards used in some interventions not only presented the monitoring of performance indicators, but also the care plan (i.e. planned responses) for each patient

(Verbano et al., 2017). Electronic notifications of bed assignment (Silich et al., 2012) and pending prescription review (Chen et al., 2018) illustrate the contribution of visibility to the identification of when a response is required;

(b) Design slack: by making processes loosely coupled, slack provides time for learning and deployment of responses. For example, the interventions that allowed for the early detection of the need for changing care plans (e.g. Hurst et al., 2018) created a wider time window for the setup of the resources for responding, such as staff. Furthermore, responding to cope with variability is of the essence of some slack strategies, such as the availability of at least one spare bed at the ICU (Silich et al., 2012);

(c) Encouraging diversity of perspectives: monitoring and anticipation may be more effective when different agents pay attention to complementary aspects of system functioning – this is a core reason for the multidisciplinary ward rounds (Ten Have et al., 2013) and multidisciplinary palliative care teams (Hurst et al., 2018). Responding may benefit from agents´ complementary response skills – e.g. when two or more different professionals give inputs on the need for prescribing antimicrobials (Chen et al., 2018). Lastly, an open mind for appreciating diverse viewpoints may challenge existing assumptions and support learning;

(d) Understanding and monitoring the gap between work-as-imagined and work-as-done: implications for monitoring and learning are the most salient, and they can offer insight into responding, in terms of using learning to design robust systems. Interventions that encompassed feedback systems illustrate the said positive influences. For example, Verbano et al. (2017) developed daily meetings to compare planned and actual actions (monitor), discuss issues from the previous day (learn), and set goals and actions for the following week (establish a vision/anticipation for a new cycle of work-as-imagined). By contrast, other interventions did not take advantage of the possible role played by standardization as a basis for monitoring work-as-done and continuous improvement. Standardization seemed to be static and an end in itself;

(e) Monitoring unintended consequences of improvements and changes: although the implications for the monitoring potential are the most salient, learning from unintended consequences may support system re-design. The studies that involved rapid cycle testing of changes (e.g. Hatler et al., 2006) illustrate how monitoring, learning, and responding can be articulated in order to identify and cope with unintended consequences.

It follows from this discussion that while not being explicitly focused on resilience, the reviewed interventions are theoretically connected to resilience. This suggests that the design and implementation of interventions can be adjusted (e.g. by placing more emphasis on understanding work-as-done) to introduce resilience principles into decision-making and organizational processes. A systematic approach may also be useful to the balanced exploration of the four resilience potentials. Although this study did not assess this balance, we speculate that there was an emphasis on responding and monitoring, as suggested by the higher scores obtained by the guidelines *design slack* (it contributes to responding as discussed above) and *encouraging diversity of perspectives* (this was frequently used in the design and monitoring of responses). Learning can have been hindered by the lack of integration of most interventions, at least as reported in the studies, into broader management systems underpinned by the PDCA cycle. In turn, anticipation seems to be neglected due to the assumed endpoint of the interventions (either uptake by the organization or achievement of goals), which are not seen as continuously evolving into the long-term future.

2.5.2 Matching the intervention complexity to the system complexity

The extent to which the intentional use of the guidelines, and their possible influence on resilience, is necessary, depends on the complexity level of the system under intervention – e.g. system may refer to the ICU functioning and structure as a whole, or its sub-systems, such as functional and structural characteristics related to patient discharge. In principle, the greater the system complexity, the greater should be the complexity of the intervention (Ashby, 1991), which means that the guidelines should be adopted to a greater extent. As a drawback, there are no reliable methods for the assessment of this matching. Thus, it is no surprise that essentially the same intervention

(e.g. checklists), adopting the same underlying guidelines, has been applied for substantially different sub-systems in the ICUs.

Although the assessment of the matching between intervention and system complexity is beyond the scope of this study, the adopted scoring system may be useful for the assessment of the intervention complexity in future studies. The underlying assumption is that the greater the score the greater the intervention complexity.

The study by McWilliams et al. (2015) represents a credible example of complex intervention. This was one out of the two articles that had the highest average score (3.4) – the other was reported by Hatler et al. (2006). McWilliams et al. aimed at the early identification of mechanically ventilated patients in need of rehabilitation, saving 584 bed days within the ICU, and thus creating capacity slack. The intervention relied on multidisciplinary teams that devised and reviewed the individual patient rehabilitation plan on a weekly basis. In turn, an example of simple intervention is the study by Jones and Dawson (2012). This intervention (score 0.6) tested the use of ear plugs and eye masks to improve the quality and quantity of sleep. These authors acknowledged that their intervention was too simple to match the complexity of the physiological and environmental factors involved in patients' sleep.

2.6 Conclusions

2.6.1 Contributions of this study

Two research questions guided this study: (RQ1) how to map the guidelines for coping with complexity onto reported interventions in ICUs and evaluate the extent to which they have been accounted for? (RQ2) what are the implications of the adoption of the guidelines for resilient healthcare?

Regarding RQ1, the guidelines were found to be fully applicable and intuitively rather than explicitly adopted by the interventions. The large number of identified examples, grouped under 40 descriptors (from Tables 2.3 to 2.7), provides a source of ideas for designers and contributes to bridging the gap between complexity theory and practice. However, the uptake of complexity by most interventions was in general on the low side, as indicated by the obtained scores. Moreover, the guidelines were clearly not

adopted uniformly: those related to diversity of perspectives (mean = 2.6) and slack (mean = 2.4) had statistically higher scores in comparison with those related to work-as-done (mean = 1.6), visibility (mean = 1.5), and unintended consequences (mean = 1.4).

The guidelines related to work-as-done and unintended consequences were the most difficult to be identified from the papers, since they had a more abstract nature. These two guidelines can possibly be framed as meta-guidelines, in the sense that they permeate the other three guidelines, and are also perspectives for understanding systems and making design decisions. However, these guidelines also have their own concrete manifestations, as we have seen above.

Concerning RQ2, it was demonstrated how resilience can be theoretically connected to the guidelines and therefore also instinctively adopted by the interventions to some extent. This suggests that resilience inputs could be explicitly integrated in existing intervention frameworks without starting from scratch. Also, a formal analysis of the match between intervention and system complexity might be a step towards a greater uptake of resilience. As mentioned in Section 2.5.2, in principle, the greater the system complexity, the greater should be the intervention complexity, which means that the guidelines should be adopted to a larger extent.

2.6.2 Limitations

Some limitations of this study must be mentioned. First, the space limitations imposed by scientific journals may have masked the real extent to which the guidelines were followed by the interventions. It is also possible that important information related to the guidelines was missing from the papers simply because the study focus was elsewhere. Second, the effect of the level of adoption of the guidelines on the interventions´ outcomes was not assessed. Third, the interventions were not clustered according to their type (e.g. main health condition or efficiency problem addressed), which is a variable that may have an influence on the guidelines' adoption. Fourth, and as usual in literature reviews, the adopted inclusion and exclusion criteria gave consideration to some sources and not others.

2.6.3 Future studies

This study set a basis for an agenda for further research, involving:

(i) The design of tools for the joint application of the guidelines over the whole life-cycle of healthcare interventions, from design to assessment. This proposal also implies considering the intervention implications for resilience;

(ii) To test the level of adoption of the guidelines as a leading indicator of resilience in healthcare. This should be preceded by the development of a measurement system of the guidelines, which could adopt the proposal of this study as a starting point;

(iii) The investigation of the research opportunities specifically associated with each guideline, described from Sections 2.4.2.1 to 2.4.2.5 – e.g. to explore the collaboration costs;

(iv) The development of analytical approaches to assess and interpret the match between intervention and system complexity. This can be useful for decision-making regarding the extent to which the guidelines are necessary;

(v) The assessment of the level of adoption of the guidelines in large samples of healthcare systems, controlling for factors such as intervention type. This would point out whether there are differences in outcomes depending on the level of using the guidelines;

(vi) The improvement of the before-after designs, by using a standardized framework for describing context, and a mix of qualitative and qualitative evidence collected over multiple points in time. Nevertheless, the low incidence of randomized controlled trials (only two studies - Su et al., 2013; Speroff et al., 2011) suggests that this approach has been under explored;

(vii) To devise interventions that involve the removal of existing practices, rather than only the addition of new practices. Standardization and checklists, which were the most frequent practices detected in this review, can lead to an excessive bureaucratization of management (Dekker, 2014). Interventions that remove practices can be complex in

the sense of following the guidelines, while at the same time being simpler to implement, which can make them more suitable for randomized controlled studies;

(viii) The development of similar reviews, including: other healthcare systems, such as emergency departments; a meta-analysis for assessing the effect of using the guidelines on the outcomes; different inclusion and exclusion criteria, and additional guidelines, or the same adopted guidelines with different granularity.

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3. ARTIGO 2: *Making resilience explicit in FRAM: shedding light on desired outcomes*

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Abstract

Resilience plays a key role in desired outcomes of socio-technical systems. However, the Functional Resonance Analysis Method (FRAM), which has been the main modelling tool in light of resilience engineering, does not make explicit the role of resilience. This paper addresses this gap by proposing new procedures for the development of FRAM models of desired outcomes. They are: *(i)* the active search for functions that display resilient performance; *(ii)* the assessment of the frequency at which the function output is expected to occur at the same way as it occurred in the desired outcome – frequent unwanted variabilities that occur despite desired outcomes tend to be hidden; *(iii)* understanding of the reasons for desired outcomes based on the analysis of the logical associations between each function, the abilities of resilient systems and guidelines for coping with complexity; and *(iv)* the proposal of recommendations for sustaining the observed successful performance. Two case studies of events with desired outcomes in an Intensive Care Unit illustrate the applicability of the proposal. The proposal is expected to be useful for making systems more resilient to everyday work, in which vulnerabilities might be hidden by desired outcomes.

Keywords: resilience, FRAM, complexity, intensive care unit, safety II.

3.1 Introduction

Organizational learning related to safety still commonly stems mostly from unwanted outcomes (Martinetti et al., 2019). However, the limitations of this approach have been increasingly clear as a result of: *(i)* the persistence of high levels of adverse events (Dekker & Pitzer, 2016); *(ii)* the reluctance of workers to report errors, as they fear legal implications and do not trust in a just organizational culture (Dekker & Breakey, 2016); *(iii)* the costly nature of this approach, which implies experiencing a loss before learning; and *(iv)* the assumption that events with unwanted outcomes do not fundamentally differ from normal performance (Hollnagel, 2014). This last factor has been interpreted as an indication that variability is present in both accidents and normal performance (Hollnagel, 2014).

Acknowledging these limitations, resilience engineering (RE) gained attention from both researchers and practitioners. RE has developed "theories, methods, and tools to deliberately manage the adaptive ability of organizations in order to function effectively and safely" (Nemeth & Herrera, 2015). RE defines resilience as the ability of socio-technical systems to adjust their functioning prior to, during, or following changes and disturbances, so that it can sustain required performance under both expected and unexpected conditions (Hollnagel et al., 2013). RE assumes that people will fill out gaps in underspecified standardized operating procedures, and this performance adjustment is underlying both everyday normal performance (i.e., success) and failure (Hollnagel, 2012). In turn, success is much more frequent than failure, and therefore it offers more learning opportunities (Hollnagel, 2014). This focus on learning from success is a key characteristic of Safety-II. It contrasts to Safety-I, which is mostly concerned with learning from undesired outcomes (Hollnagel, 2014). However, the Safety-II perspective has been mostly limited to conceptual studies and has been criticized for the scant empirical evidence of its practical utility (Woodward, 2019). Furthermore, while there are several taxonomies and methods for investigating what goes wrong (e.g., the taxonomy of error types, by Reason, 1990), there is a paucity of equivalent approaches and a corresponding vocabulary for understanding what goes well (Hollnagel, 2014).

This work explores the use of the Functional Resonance Analysis Method (FRAM) for investigating successful performance. FRAM has been the main tool for the modelling of socio-technical systems in light of RE and has been used in a number of

domains, such as healthcare, aviation, and maritime (Salehi et al., 2021; Patriarca et al., 2020). Benefits of using FRAM involve a better understanding of the gap between work-as-imagined (WAI) and work-as-done (WAD) as well as insights into how variability propagates in complex systems (Patriarca et al., 2020).

FRAM models commonly shed light on resilience characteristics of systems (Patriarca et al., 2020). However, despite the contributions of earlier studies (see section 2.2) they have limitations such as: *(i)* their modelling of successful performance is usually concerned with everyday work (Patriarca et al., 2020), rather than events that have a clearly defined and desired endpoint, likewise accidents (i.e., when the injury or damage is the endpoint); *(ii)* they usually take an overly descriptive and *ad-hoc* approach for analyzing the role played by resilience (e.g., Arcuri et al., 2020; Saldanha et al., 2020), which makes it difficult the comparison between different case studies – thus, there is an opportunity for prescriptive studies; and *(iii)* the FRAM steps are more often than not applied according to the original proposal by Hollnagel (2012), which leaves the consideration of resilience insights implicit and too much dependent on the experience of the analyst (Patriarca et al., 2020) - e.g., inclusion of functions relevant to resilience, recognition of variabilities that exist despite desired outcomes, and concern with practical recommendations to sustain good performance.

Against this backdrop, the research question that guided this study is stated as follows: how can the FRAM be adapted to make it explicit the role of resilience in the analysis of desired outcomes? In order to answer this question, additions were proposed to the traditional FRAM steps, providing a prescriptive contribution. These changes were tested in the analysis of two events with desired outcomes in an adult clinical and surgical intensive care unit (ICU). Healthcare systems are usually highly complex, which makes them common targets to FRAM applications (Salehi et al., 2021; Gustafson et al., 2020; Patriarca et al., 2020).

3.2 Background

3.2.1 Resilient engineering and complexity

Resilience engineering (RE) takes a socio-technical perspective of resilience (Hollnagel et al., 2006) and is concerned with resilient performance at the system level (Bergstrom et al., 2015). This means that RE does not rely on the outstanding performance of individual parts (e.g., people, machinery) but rather on their interactions (Wachs et al., 2016). Although human actions and decisions are usually the most visible faces of resilience, in light of RE that performance is inseparable from the technological, organizational, and social context (Pecillo, 2016).

Patriarca et al. (2018) offer a comprehensive literature review of how the RE field has evolved over time. They concluded that RE moved from a safety-related perspective towards a resilience per se representation. That review also indicated that the focus of RE research has shifted from defining to modelling resilience. Another extensive review of RE was conducted by Righi et al. (2015). Those authors pointed out that RE studies were mostly descriptive and that there was a need for prescriptive research that could offer guidance for practitioners interested in translating theory into practice. Thus, the present study addresses gaps mentioned by earlier reviews as it provides a prescriptive contribution for modelling resilience.

The four abilities of resilient systems proposed by Hollnagel (2017) have been widely used for the modelling of resilience (e.g., Bertoni et al., 2021; Arcuri et al., 2020; Chuang et al., 2020). They are (Hollnagel, 2017): *(i)* the ability to respond, which implies knowing what to do, or being able to respond to regular and irregular changes, disturbances, and opportunities; *(ii)* the ability to monitor, which implies knowing what to look for, or being able to monitor what could seriously affect the system performance in the near term, positively or negatively; *(iii)* the ability to learn, which implies knowing what has happened, or being able to learn from experience, in particular to acquire the right lessons from the right experience; and *(iv)* the ability to anticipate, which implies knowing what to expect, or being able to prepare for developments further into the future, such as disruptions, constraints or opportunities.

Earlier research has also made clear that RE is strongly based on complexity thinking, which is unsurprising as resilience is a characteristic of complex systems (Woods, 2015). As such, resilience is an emergent phenomenon, which means that it is a property that arises from the dynamic interactions between the wide diversity of elements that make up complex systems (Wachs et al, 2016). Another implication of emergence is that resilience cannot be influenced directly but rather through proxies such as the aforementioned four abilities (Hollnagel, 2019). In the present study, in addition to those four abilities, four other proxies of resilience are adopted as a basis. They are the five guidelines for coping with complexity, and therefore influencing resilience, proposed by Saurin et al. (2013) – Table 1. These guidelines encompass practical actions that are logically connected to resilience such as the provision of slack resources and visual management in the workplace.

Several earlier studies have used these same guidelines for the purpose of resilience assessment, indicating their utility for the identification of improvement opportunities. In a systematic literature review of 91 quality and safety improvement interventions in ICUs, Bueno et al. (2019) found that the implicit use of those guidelines was ubiquitous. These guidelines were also used for the assessment of resilient healthcare in surgical units by Mahmoud et al. (2021), the preparation and administration of drugs in surgical wards by Saurin et al. (2019), and in emergency departments (Righi & Saurin, 2015). Saurin (2021) used the guidelines as a framework for the analysis of the implications of the COVID-19 pandemic for system-safety theories.

Table 1. Guidelines for coping with complexity (adapted from Saurin et al., 2013)

Guidelines	Dimensions of the guidelines
Provide slack	Slack is a mechanism for reducing interdependencies and slowing down or eliminating the propagation of variability (Safayeni & Purdy, 1991). Slack is usually operationalized through some human (e.g. cross-trained professionals), technical (e.g. spare pieces of equipment) or organizational resource (e.g. double-check of quality specifications). Slack can be either designed into the system or arise opportunistically as a result of self-organization (Saurin &Werle, 2017).
Give visibility to processes and outcomes	Systems should be intuitive (Clegg, 2000), to reduce imaginary complexity. Visibility should be given to informal work practices, which may encompass either useful innovations or latent hazards that overtime may be taken for granted as part of regular work. Visibility should allow for real-time performance monitoring and the free sharing of information (Galsworth, 2017).
Encourage diversity of perspectives when making decisions	Diversity of perspectives may help to tackle uncertainty. Agents involved in decision-making should hold complementary skills. Some requirements for the implementation of this guideline are high levels of trust, reduction of power differentials and identification of apt decision-makers (Page, 2010).

Monitor and understand the gap between work-as-done (WAD) and work-as-imagined (WAI)	Standardized operating procedures cannot cover all situations. Complexity theory regards procedures as dynamic, local, and situated constructions, which need adaptation in the face of variability. This is in contrast with the traditional view of procedures as "devised by experts (management) to guard against the errors and mistakes of fallible human operators at the sharp end, who are more limited than the experts in their competence" (Hale & Borys 2013). Procedures may be of different types (e.g., objet-oriented, action-oriented) and, for all types, the gap between them and practice should be monitored.
Monitor unintended consequences of improvements and small changes	The impacts of small changes and improvements may be significant in complex systems due to non-linear interactions (Perrow, 1984). Improvements and small changes interact between themselves, and this poses opportunities for unintended consequences. Small changes and improvements may be either non-intentional or intentionally self-initiated by the organization (e.g., through kaizen) as well as originated from external sources (e.g., a client changes its order).

3.2.2 FRAM and resilience

FRAM was originally developed for the investigation of accidents (Hollnagel, 2004). This is still a frequent FRAM application, which indicates how resilience was lacking instead of how it was present– e.g., Pereira et al. (2014) in the blowout of Deepwater Horizon. According to a literature review carried out by Patriarca et al. (2020) the use of FRAM as a retrospective method, which mostly includes accident analysis, accounted for 22% of the studies.

Applications for prospective purposes, which emphasize the presence of resilience, have been more common since 2016 (Patriarca et al., 2020). A common approach has been the development of methods for the identification of functions that are a key for resilient performance (Falegnami et al.; 2020; Raben et al., 2018). Others, such as Bellini et al. (2020) have stressed the quantification of the level of resilience in a system at a certain time, based on the corresponding FRAM model. In turn, the study by Aguillera et al. (2016) exemplifies a typical FRAM application for the qualitatively modelling of performance variabilities (in oil spill response, in that case), as a basis for improving system resilience. In the same vein, Carvalho (2011) investigated characteristics of the air traffic management system resilience in Brazil, based on the FRAM modelling of a mid-air collision. That study analyzed five resilience characteristics proposed by Woods (2006), namely buffering capacity, flexibility, margin, tolerance, and cross-scale interactions. Lundberg and Woltjer (2013) argue that some of those characteristics (e.g., buffering) are established through several functions together.

Saldanha et al. (2020) describe a FRAM application for modelling artisanal fishing, in order to show how good safety performance usually occurs despite formal management systems. Although not making explicit reference to resilience, the FRAM

model developed in that study presents functions relevant to resilience e.g., sense-making functions (Saldanha et al., 2020). Arcuri et al. (2020) take another approach when using the FRAM for modeling resilience in a referral prioritization system in the public health sector. In this case, the FRAM model had only four functions, each named according to one of the four resilience abilities proposed by Hollnagel (2017). Although the outputs of these generic functions corresponded to resilient practices, the models did not make clear the actual functions that contributed to resilience. Despite the contributions of earlier FRAM studies, they have the limitations previously mentioned in the Introduction – e.g., too much reliance on the experience of the analyst for connecting the case study to resilience theory (Patriarca et al., 2020).

3.3 Method

3.3.1 Research strategy

This study is based on the premises of Design Science Research (DSR), which aims at developing or improving an artefact to solve a practical problem and at the same time generating a theoretical contribution of a prescriptive nature (Holmstrom et al., 2009). DSR usually produces one or more of the outputs as follows: methods, models, constructs, and instantiations (March & Smith, 1995). In this work, the practical problem refers to the lack of tested and tailored methods for the investigation of events with desired outcomes in complex systems such as healthcare services. Hence, we improved an existing method (i.e., FRAM), and the corresponding adapted application steps constitute the theoretical prescriptive contribution.

3.2 The proposed adapted FRAM

The original FRAM proposed by Hollnagel (2012) encompasses five steps: recognize the purpose of the FRAM analysis; identify and describe the functions; the identification of variability; the aggregation of variability; and consequences of the analysis. Several studies have described the rationale and procedures for the application of these steps, and thus they are not repeated here. For a detailed FRAM tutorial, the reader is referred to Hollnagel (2012) and Hollnagel et al., (2014). The proposed adaptations are presented next and schematically represented in Figure 1:

(i) **Definition of the purpose of the analysis**: our proposal focuses on events with desired outcomes. Hollnagel (2014) uses the term "what goes well" to refer to any situation in which there is presence of safety. Based on Penaloza et al. (2020), an operational definition of analyzing "what goes well" is set out, encompassing the analysis of events with desired outcomes, in which there is a defined and desirable endpoint such as a patient properly cared or a managerial problem (e.g. lack of supplies) solved. These events might be rare/frequent, long/short duration, simple/complex, past/present/future. Desired outcomes also include events with unsafe conditions or unsafe behaviors, provided there was no harm to people neither any material loss;

(ii) **Identification of functions:** as usual in FRAM modelling, functions must be identified based on the analysis of what occurs in reality (i.e., work-as-done) through techniques such as interviews, observations, and incident reports. To make sure that the model includes relevant functions to resilient performance, model developers might actively search for:

- Functions temporally and spatially distant from the event as the outputs of these functions may consist of relatively stable latent conditions that pose either constraints or opportunities that demand resilience – these functions tend to refer to performance shaping factors (Hollnagel, 2012). Also, they are likely to be organizational functions, which are those conducted by a group or groups of people, where the activities are explicitly organized (Hollnagel, 2012);

- Functions that represent the deployment of resilience skills, which are defined by Wachs et al. (2016) as "skills of any type necessary to adjust performance, in order to maintain safe and efficient operations during both expected and unexpected situations". Wachs et al. (2016) and Saurin et al. (2014) discuss the identification and categorization of resilience skills, noting that these arise from interactions between work constraints, unplanned learning that occurs through trial and error, gaps in standardized operating procedures, and organizational support for resilience. These are likely to be human functions, which are those carried out by humans, either as individuals or in small, informal groups (Hollnagel, 2012). These functions are typically activated just-on-time as they occur as the event unfolds in real-time.

Despite the role played by the aforementioned functions on resilience, it must be noted that any function by itself cannot be resilient since this is a system property that emerges from the variation and interaction of several functions. Thus, a more precise wording would be "function that displays resilient performance". This terminology problem is the same faced by Perrow (1984) in his taxonomy of interactions in complex systems. Perrow (1984, p. 78) makes clear that the term "complex interactions" is an oversimplification since interactions by themselves cannot be complex, only systems can. Likewise Perrow, we recognize that it is difficult to find precise terms that are also brief; we opted for brevity and used the term "resilient function";

(iii) **Description of functions according to their aspects:** the six aspects of functions should be considered, namely input (I), output (O), resource (R), precondition (P), time (T), and control (C). Although no changes are proposed in this stage of the original FRAM, the functions' aspects should be interpreted as enablers of resilient performance in light of our proposal. Thus, the functions "have" aspects in order to "do" resilience, which is aligned with Hollnagel's (2012) recommendation to write down aspects as nouns and functions as verbs;

(iv) **Analysis of the variability of the output of each function:** likewise the original FRAM, this analysis should account for variability both in terms of time (too early, on-time, too late, and not at all) and precision (precise, acceptable, and imprecise). Additionally, a third dimension for the assessment of output variability is proposed, namely the frequency at which the output is expected to occur at the same way as it occurred in the event with desired outcomes – e.g., if the output was too late, the analyst should wonder whether that was unusual or not. This assessment can also occur for outputs with either no variability or desired variability. The identification of frequent unwanted variabilities that occur despite desired outcomes is important as these tend to be hidden (e.g., by costly resilience mechanisms).

We suggest the assessment of the frequency of the unwanted variabilities based on a questionnaire answered by one or more people that played an active role (or could play a role, in case of prospective assessment) in the studied event. The variabilities should be presented to the respondent as a list, and they should be asked the following question: how frequent are these variabilities in everyday work? For that judgment, a continuous scale from zero to 10 is provided, with two endpoints – *rarely* and *frequently*.

In case of multiple respondents, average scores can be produced. Four ranges of frequency are suggested: very rare (zero to 2.5); unusual (2.6 – 5.0); frequent (5.1 – 7.5); and very frequent (7.6 – 10.0);

(v) **Analysis of the aggregated variability for a chosen scenario**: at this stage, the only change refers to the visual representation of the FRAM model, which should highlight the aspects associated with resilient performance – i.e., those aspects (I, P, R, T, C) provided by the outputs;

(vi) **Understanding of the reasons for desired outcomes**: this stage is new and involves the analysis of logical associations between each function and the four abilities of resilient systems as well as the five guidelines for coping with complexity (see section 2). Both types of associations can be defined through consensus building between the team members in charge of applying FRAM. The use of a five-point scale is proposed as a basis for the assessments at this stage: zero (the function is unrelated to the resilience ability /complexity guideline); 1 (weak relationship); 2 (moderate relationship); 3 (strong relationship); and 4 (very strong relationship).

Considering that the resilience abilities are highly dependent on each other (Hollnagel, 2017), we suggest that if there is any relationship between a function and an ability, all other abilities should score at least 1. As for the complexity guidelines, a score equal to zero would be acceptable given that the guidelines are assumed to be relatively more independent on each other, in comparison to the resilience abilities.

Based on that, it is possible to produce scores for the strength of the logical association between each function and each resilience ability as well as between each function and each complexity guideline. Aggregated scores can also be produced, such as an average score for each resilience ability and for each complexity guideline, considering its relationships with all functions. These scores are intended to highlight functions and theoretical principles (i.e., resilience abilities and complexity guidelines) that played a major role in the desired outcomes; and

(vii) Practical consequences: similarly, to the original FRAM, this step focuses on recommendations for improving the work system design. However, recommendations should address not only the avoidance of failures, but also the means for sustaining successful performance. The average score obtained by each theoretical principle can indicate focal points for improvements. For example, high-scoring principles offer an

abstract explanation for successful performance, which can be a source of ideas for coping with similar situations. Additionally, thinking in terms of theoretical principles might support the analysts in the recognition of patterns (e.g., role of slack resources for successful performance) that could otherwise be invisible.

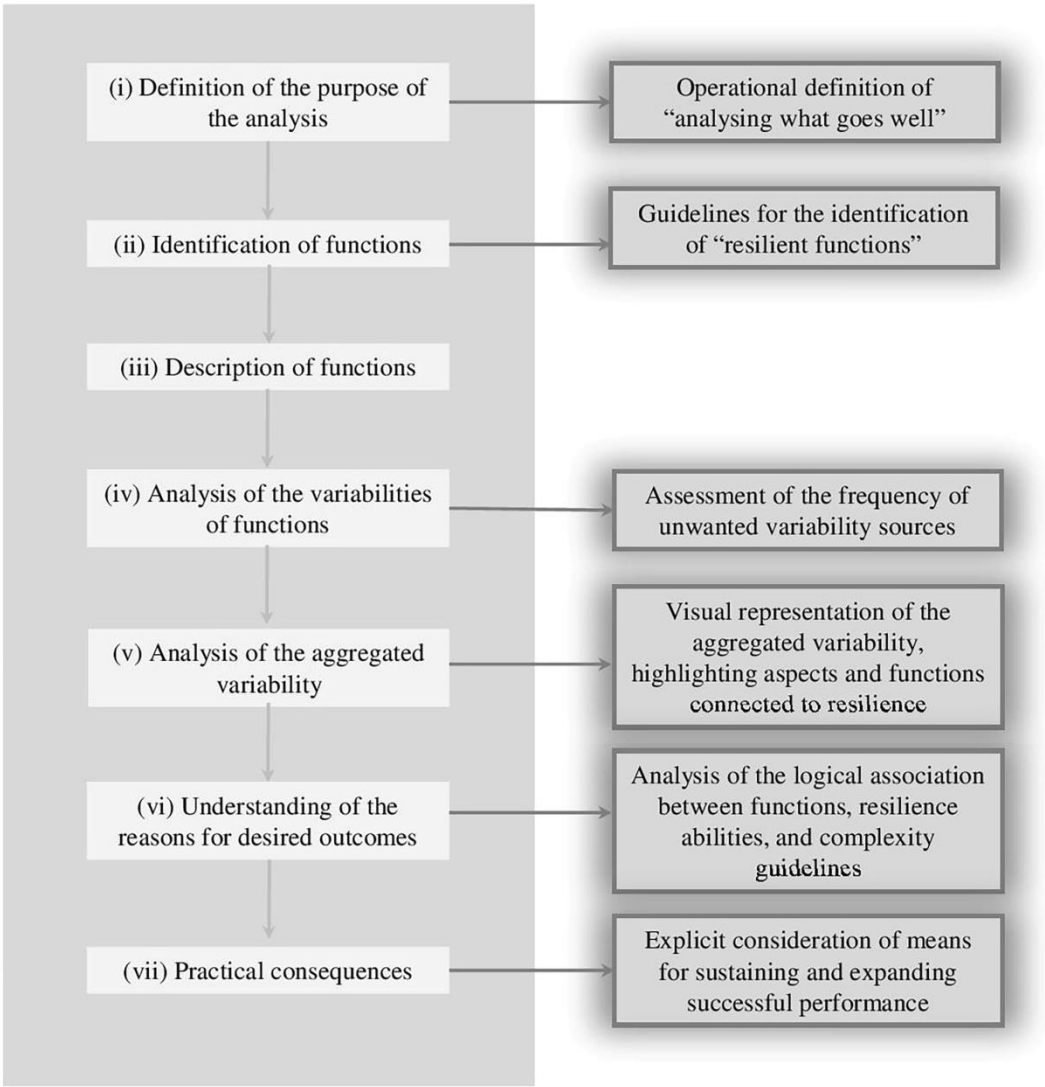


Figure 1. FRAM steps for the analysis of desired outcomes. Left: application steps. Right: changes in relation to the original FRAM.

3.3.3 Application to the ICU case study

3.3.3.1 Overview of the ICU

The study setting was a 34-bed adult clinical and surgical ICU of an 831-bed Brazilian public university hospital. There were two main reasons for choosing this ICU: *(i)* the high complexity of ICUs in general, which involve sophisticated technologies and multidisciplinary care – resilient performance tends to be more important under complex conditions; and *(ii)* a recent history of research collaboration with the ICU staff (e.g., Ransolin et al., 2020), which facilitated access to the sources of data. Results from these previous studies provided descriptions of the ICU from a socio-technical viewpoint (Table 2).

Table 2. Main characteristics of the studied ICU (Ransolin et al., 2020).

Socio-technical sub-system	Main characteristics
Social	There are about 200 employees from 15 professional categories. Doctors (n= 40) have on average 23 years of experience in intensive care, nurses (n= 32) 18 years, and nurse technicians (n =115) 19 years.
Technical	The ICU has 34 beds and is located on the top floor of a 13-floor building. It has two adjacent pods: (i) an older area (21 beds) not originally built to host an ICU, where the bays have on average 9 m^2 and are divided by curtains – this area has a few sinks for hand hygiene and is intended to receive acute critical care patients with length of stay < 13 days; and (ii) a newer area (13 beds) originally intended to be an ICU, where bays have from 10 to 13 m^2 and are divided by glass walls. Patients admitted to this last pod are expected to stay for more than 13 days – i.e., chronic critical care. Several equipment is permanently around the bedside, such as respiratory support and infusion pumps. Other equipment is brought to the bay when necessary, such as for haemodialysis. Other ICU areas involve: a room for private communication between staff and patient family, waiting room for family, room for medical prescription, nursing station, pharmacy, cleaning room where medical devices are sterilized, and 7 elevators.
Work organization	Nursing professionals work in six partially overlapping shifts. Intensive care physicians work mainly at 12-hour shifts There is a daily interdisciplinary ICU clinical round when the whole team of healthcare workers meets on the bedside and reviews the status of every patient. The ICU clinical round takes about 20 minutes per patient and provides inputs for medical orders and exams.
External environment	Patients are admitted from: the emergency department on the ground floor; the surgical and clinical wards located in several floors, and from other hospitals. Several areas of the hospital interact with the ICU, involving flow of supplies and staff – e.g. warehouse, radiology, food supply, and central pharmacy. Season of the year impacts on the incidence rate of certain diseases, affecting the demand for the corresponding resources for care.

3.3.3.2 Data collection

Data collection consisted of non-participant observations, analysis of documents, interviews, and questionnaires. The research project was approved by the hospital's ethics committee and all interviewees signed an informed consent form.

There were around 45 hours of non-participant observations by researchers, on different times of the day and days of the week, covering several activities such as preparation and administration of drugs, checking of vital signs, care procedures, and multidisciplinary ICU clinical rounds. Records of these observations were maintained on a field diary, and they supported understanding of work-as-done.

In turn, documents contributed to the understanding of work-as-imagined (e.g., clinical pathways, standard operating procedures and daily care plans for each patient) as well as results of performance indicators (e.g., compliance rate with hand hygiene protocols), which provided insight into the variability of some functions (e.g., hand-washing).

Three types of interviews (Table 3) were conducted and all of them were audio recorded and fully transcribed by research assistants. Initially, 10 semi-structured interviews were carried out with healthcare ICU professionals randomly selected, aiming to obtain a general understanding of the ICU clinical work, as well as to identify contextual factors that could assist in the understanding of the events to be analyzed based on FRAM. These interviews were based on a five-question script encompassing: a description of the activities carried out by the interviewee; interactions with other professionals, including non-critical care and clerical workers; difficulties for carrying out their activities; variabilities in their activities; and suggestions for improvements.

Next, three interviews were carried out using the critical decision method (CDM) with professionals who stood out for their performance, according to the ICU chief-physician. These professionals were invited to describe a cognitively challenging event, with a positive outcome, in which they played a key role. After reporting the event, the other CDM stages were followed, namely (Crandall et al. 2006): elaboration of the timeline, deepening, and "what if" questions in order to explore alternative scenarios. From the five events discussed in the CDM interviews (some of them involved more than one event) four were related to direct patient care and another involved the management of supplies. In order to increase the external validity of our proposal, we selected two events:

one related to patient care and the one related to supplies. The interviewees that reported the selected events were approached on a follow-up occasion to answer the questionnaire proposed in the adapted FRAM (see section 3.2, step iv of the method). The fulfilment of the questionnaire was quick, taking no more than five minutes. After completing the questionnaire, the respondent was invited to justify their answers in an audio-recorded interview – this approach is known as questerview (Adamson et al., 2004).

Table 3. Information on the interviewed professionals. Note: *interviews selected for FRAM analysis

Interview	Type	Professional category	Experience time (years)	Duration of the interview (min)
1	Prepared script	Clerical worker	11	77
2	Prepared script	Nurse	34	70
3	Prepared script	Pharmacist	17	77
4	Prepared script	Physiotherapist	12	57
5	Prepared script	Speech therapist	4	43
6	Prepared script	Cleaners	16	70
7	Prepared script	Physician	29	51
8	Prepared script	Nutritionist	10	27
9	Prepared script	Radiologist	17	85
10	Prepared script	Nurse technician	10	75
11*	CDM	Physician-A	38	70
12*	CDM	Physiotherapist	16	67
13	CDM	Physician-B	10	44
14	Quester view	Physician-A	(same as 11)	60
15	Quester view	Physiotherapist	(same as 12)	60
Total				933

3.3.3.3 Data analysis

A thematic analysis was carried out based on the transcripts of the CDM interviews and notes from observations made by the investigators. The themes were defined upfront as they corresponded to the necessary information for developing a FRAM model, namely the identification of functions, their aspects, output variability, and recommendations for work system design. There were several rounds for data coding and analysis. Initially, each of the first two authors independently highlighted excerpts of text related to the chosen themes. Then, these excerpts were compared in a consensus building meeting. Data codification resulting from that meeting was further validated with the two professionals who reported the two studied events. Thus, these professionals had an active participation in the development of the FRAM models, in dedicated meetings for that purpose. There were two meetings with each professional, each lasting one hour.

As for the scores of the strength of the relationships between functions, resilience abilities, and complexity guidelines, these were assigned based on the guidance described in section 3.2 – e.g., using a five-point scale. A preliminary assignment of the scores was independently carried out by the two researchers directly involved in data collection (both PhD students), by another experienced researcher familiar with human factors research in healthcare settings (PhD), and yet by another senior researcher that supervised the whole study and had a deep familiarity with the complexity guidelines (PhD). Each of these researchers took about 45 minutes to assign the scores for each case study. Two 1-hour consensus building meetings were held to compare the assignments – one meeting for each case study. In case of disagreements, participants presented the rationale for their assignments. Final scores presented in this paper were obtained after several rounds of discussion and refinement. Despite these careful procedures, it is worth noting that the role of the scores in our proposal should not be overestimated. The scores should be interpreted as general indications to be jointly analysed with the qualitative evidence.

3.4 Results

3.4.1 Case A: care provided to a tracheostomized patient

3.4.1.1 Description of case A

Physician A (38 years of experience) reported this case, which involved the care of a patient that had suffered a traumatic accident and had been initially admitted to the ICU of another hospital, a trauma centre. Due to the patient's clinical condition and the need for certain resources, the patient, who already had a tracheostomy, was transferred to the ICU focused on this paper. After a few days in the new ICU, the attending physician noticed, based on the monitoring of vital signs, that the patient started to show signs of respiratory instability. Then, that physician requested help from other members of the care team (i.e., nurse technician, registered nurse, and physiotherapist), who promptly identified an obstruction in the tracheostomy cannula as the immediate cause of the respiratory instability. The obstruction was due to laceration of the tracheal tissue, resulting from the trauma suffered by the patient.

As the first countermeasure, the team attempted to reposition the tracheostomy cannula, positioning the patient's cervical spine in hyperextension. Although that manoeuvre was sufficient to promote better stability in relation to oxygen levels, the care

team assumed that its effectiveness would be short-lived. Thus, the hospital's thoracic surgical team was activated for a more effective intervention. However, the surgical team was not dedicated full-time to the ICU and, at that time, it was performing a procedure in the surgical unit, which is located on the 12thfloor of the hospital, while the ICU is on the 13th.

The thoracic chief-surgeon promptly sent a resident physician to the ICU for an emergency assessment of the patient and then reported to the surgical team indicating that the patient was stable. Based on this feedback, the surgical team made the decision to complete the ongoing surgical procedure before moving to the ICU. On arrival at the ICU, around two hours later, the surgical team decided to replace the patient's tracheostomy cannula. Therefore, it was necessary to check the availability of other types of tracheostomy cannulas in the ICU. However, the desired types of cannulas were not stored in the ICU, which led the team to seek for them in the surgical unit. Eventually, the available cannulas were found and tested.

Unfortunately, the performed tests with the available cannulas were not successful as the airway obstruction remained. Thus, the clinical team decided to keep the original cannula, further adjusting its positioning. The following interview excerpt illustrates what happened: "*they (surgical team) performed the procedure and were unable to get a better cannula insertion. They made several attempts with various types of cannulas and complementary devices…they ended up leaving the original cannula even though that implied the patient was not on a comfortable position*". Despite this condition, the tracheal tissue regenerated during the following days and the event had a positive outcome allowing the patient to receive adequate levels of oxygen. The whole event, since the initial diagnosis by the attending physician to the decision to maintain the cannula, lasted around six hours – from 7am to 1pm, approximately.

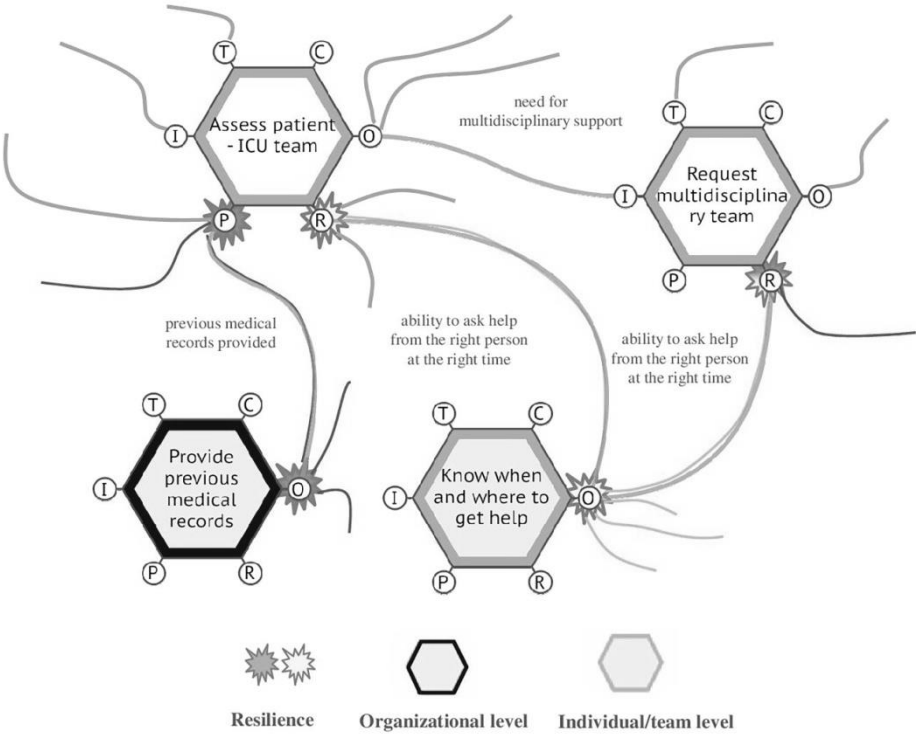
3.4.1.2 FRAM model: case A

Figure 2 shows an excerpt of the FRAM model correspondent to case A (see full model in appendix A), in which the functions' aspects that directly contribute to resilient performance are highlighted. The model includes 21 functions (see Table 4), of which many possibly would not be represented in a traditional FRAM model as there is not usually an explicit concern with making visible the source of resilience performance. An

example of resilient function, which resembles the previously mentioned concept of resilience skill, is to <know when and where to get help>.

It is worth noting that system boundaries are arbitrary and that functions are recursive, that is, additional functions could be included in order to go even further in the investigation of the sources of resilience. In Figure 2, a possible additional function of that type, whose output could be connected to <know when and where to get help> could be related to learning from trial and error.

Figure 2. Excerpt of the FRAM model – case A.



The understanding of the FRAM model can be supported by the analysis of the number of upstream couplings (that is, couplings that arrive at the function through aspects I, R, P, T, C) and downstream couplings of each function (that is, couplings that leave the function from aspect O). The function <assess patient - ICU team> stands out for the number of upstream couplings (8), which points to its exposure to the variability from previous functions. Despite this, the output of <assess patient - ICU team> did not vary, that is, the assessment was accurate and without any delay. This suggests the effectiveness of the upstream functions such as <provide previous medical records>.

The interviewee that reported case A carried out an assessment of the frequency of the unwanted variability sources (Table 4). The variabilities were thought to be either very rare or unusual: on a continuous scale from zero (rarely) to 10 (frequently) the highest score was 4.7, related to the fact that patients from external ICUs are admitted with missing information on the history of their health condition. This tends to delay the start of the function <assess target organs – attending physician>.

Table 4. Assessment of the frequency of the unwanted variability sources – case A

Variabilities	Frequency
Patient with incomplete health records when admitted from other hospitals	4.7 – unusual
Unavailability of tracheostomy cannulas and related materials at the ICU	4.1 – unusual
Patient with breathing difficulties caused by inadequate tracheostomy cannula	3.5 – unusual
Delay on the arrival of the surgical team	2.7 – unusual
Caregivers' lack of knowledge of the right positioning of cannulas	2.1 – very rare
Patient with cannula not perfectly adjusted for several days	1.9 – very rare
Delay for the start of clinical procedures due to lack of supplies, such as cannulas	1.6 – very rare

4.1.3 Analysis of the adherence to theoretical principles - case A

Table 5 presents the relationships between the functions of case A, the resilience abilities, and the complexity guidelines. The ability "to respond" had the strongest relationship with the functions. This is consistent with the nature of case A, which required immediate response to a patient's condition that could deteriorate quickly. That response involved decision-making under uncertainty, learning through trial and error (e.g., when testing the various types of cannulas), and teamwork. These factors were compounded by the infrequent nature of the variabilities (see Table 4), which triggered the need for resilient functions that were likely to be infrequently deployed as well.

By contrast, there was a weak relationship between the functions and the learning ability. This is a concern in light of the infrequent variabilities, since there may not be many opportunities for learning similar lessons and the continuous improvement of the resilient functions. In fact, given the relatively short duration of case A, the professionals had no time for elaborate reflections on lessons learned as the event unfolded. Although several functions had an emphasis on understanding the patient's condition, which is indeed a type of learning, our interpretation was that these functions had the primary objective of responding to an immediate need of the patient.

Table 5. Case A: adherence to theoretical principles. Notes: A: Anticipate; M: Monitor; R: Respond; L: Learning.

Functions	Resilience abilities					Complexity guidelines					
	A	**M**	**R**	**L**	**Mean**	**Slack**	**Visibility**	**Diverse perspectives**	**Gap WAD vs. WAI**	**Unintended consequences**	**Mean**
1. Assess target organs – attending physician	2	4	2	2	**2.50**	0	2	0	0	0	**0.40**
2. Update patient chart	1	2	3	1	**1.75**	0	2	0	1	0	**0.60**
3. Assess patient - ICU team	2	4	2	2	**2.50**	0	2	4	0	0	**1.20**
4. Request multidisciplinary team	2	1	4	1	**2.00**	3	0	2	0	0	**1.00**
5. Assess patient – surgeons	2	4	2	2	**2.50**	0	2	4	0	0	**1.20**
6. Request surgical team	2	1	4	1	**2.00**	3	0	1	0	0	**0.80**
7. Aspirate cannula	1	1	4	1	**1.75**	0	0	0	2	2	**0.80**
8. Carry out evaluation procedure[1]	1	1	4	1	**1.75**	0	2	0	0	0	**0.40**
9. Adjust cannula positioning	1	1	4	2	**2.00**	0	0	0	2	2	**0.80**
10. Test new cannula	1	2	4	2	**2.25**	2	0	0	2	2	**1.20**
11. Pick up supplies at surgical unit	1	1	4	1	**1.75**	4	0	0	0	1	**1.00**
12. Provide previous medical records	2	1	4	3	**2.50**	1	2	2	0	1	**1.20**
13. Provide charts and handoff notes	2	2	4	3	**2.75**	1	2	2	0	0	**1.00**
14. Provide multidisciplinary care	2	1	4	2	**2.25**	3	0	3	1	1	**1.60**
15. Provide beds and supplies	3	1	4	1	**2.25**	2	0	0	1	1	**0.80**
16. Anticipate missing information	4	1	1	1	**1.75**	2	1	1	0	1	**1.00**
17. Know when and where to get help	3	1	4	2	**2.50**	3	1	2	0	1	**1.40**
18. Support co-workers	1	1	4	2	**2.00**	3	0	2	0	1	**1.20**
19. Assess options to stabilize patient	3	1	3	2	**2.25**	3	1	3	1	2	**2.00**
20. Realize the need for immediate action	3	2	3	1	**2.25**	2	1	0	1	1	**1.00**
21. Monitor cannula positioning	3	4	3	2	**3.00**	0	0	2	0	4	**1.20**
Mean	2.00	1.76	3.38	1.67	**2.20**	1.52	0.86	1.33	0.52	0.95	**1.04**

As for the complexity guidelines, the provision of slack resources and diversity of perspectives in decision-making were the most strongly associated with the functions. Slack resources played out in: *(i)* functions aimed at requesting support from other teams, which conveys bringing in extra and partly redundant human resources; *(ii)* functions that involved the anticipation of activities, creating slack in terms of time (e.g.,<anticipate implications of missing information>); and *(iii)* the pickup of cannulas stored in the surgical unit. In turn, the diversity of perspectives was present in several functions due to the multidisciplinary nature of the care provided to the patient. Additionally, diverse perspectives were deployed when records of the patient's medical history and care procedures were obtained and consulted. These documents contained records made by professionals others than those directly involved in case A, thus offering their perspectives.

These two most frequent guidelines are the same identified as the most intensively used in 91 process improvement projects in ICUs, according to the literature review carried out by Bueno et al. (2019) - such interventions had positive results, in general. This suggests that interventions largely arising from self-organization (e.g., case A) are capable of displaying resilience features commonly associated with built-in resilience.

3.4.1.4 Improvement opportunities: case A

Improvements associated with three variabilities are described in this section for the purpose of illustration: "unavailability of tracheostomy cannulas and related materials at the ICU", "patient with incomplete health records when admitted from other hospitals", and "patient with breathing difficulties caused by inadequate tracheostomy cannula".
Regarding the lack of materials, the most salient countermeasure is the storage of a broader variety of cannulas in the ICU, which could have eliminated the need for <pick up supplies at surgical unit>. Therefore, an individual resilient function would be replaced by an organizational resilient function, possibly named <manage stock of cannulas in the ICU>. These changes would support resilient performance at least in two ways, namely by the introduction of slack resources and by the use of organizational functions, which according to Hollnagel (2012) are less likely to exhibit unwanted variability, in comparison to individual functions.

The other two variabilities could benefit from the revision of the handoff protocol between the involved hospitals. For example, missing information in health records could be detected before admission to the new ICU as well as direct contact between care teams at the two ends could be encouraged. Again, these changes would imply lower reliance on individual and team resilience, in favour of organizational support. The resilience ability of anticipation would be clearly benefited as well.

Furthermore, in line with the Safety-II emphasis on the positive, there might be measures to reinforce and sustain effective performance. An opportunity refers to measures that leverage on the ICU multidisciplinary care team, such as the creation of formal moments for the exchange of experiences between professional categories.

3.4.2 Case study B: supply of ventilation masks

3.4.2.1 Description of case B

Case B was reported by a physiotherapist (respiratory/physical therapist) with 16 years of professional experience working at the ICU. The event occurred during the winter period, in which the ICU received an unusually large number of patients in need of non-invasive ventilation (NIV). As a result of that surge there were not enough respiratory masks for NIV for all patients. That was compounded by the fact some equipment had been lent to other units and others were under maintenance. From these latter, some would be discarded as they were stale and there were no spare parts in the market.

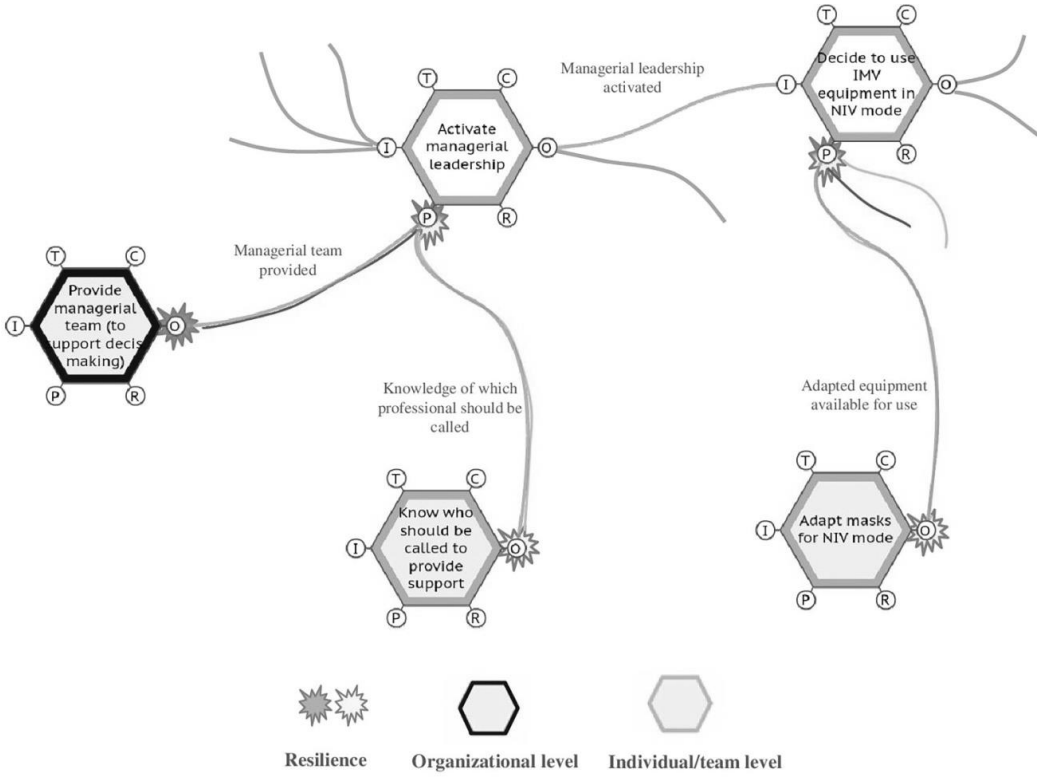
A multidisciplinary team was setup to devise a solution, including representatives from clerical staff, medical, nursing, and physiotherapy areas. This team decided to enhance ICU's capacity to provide NIV by adapting invasive mechanical ventilation (IMV) equipment to the NIV mode. Although this change in use is foreseen in the design of the IMV equipment, the hospital staff did not have previous experience with it.

The multidisciplinary team that conceived this change developed a standardized operating procedure for using the adapted equipment, which was as a basis for training physicians, nursing technicians, registered nurses, speech therapists, and physiotherapists. Unlike case A, which lasted a few hours, case B went on for several months, until the arrival of new materials and equipment that eliminated the need for the proposed adaptation.

3.4.2.2 FRAM model: case B

Figure 3 shows an excerpt of the FRAM model correspondent to case B (see appendix B for the full model), in which the functions' aspects that directly contribute to resilient performance are highlighted. This model consists of 22 functions.

Figure 3. Excerpt of the FRAM model – case B.



As for the analysis in light of the number of couplings per function, the function <activate managerial leadership> stands out with two downstream and five upstream couplings (see Figure 3). The output of that function triggered <decide to use the IMV equipment in NIV mode>. However, the start of <activate managerial leadership> occurred with some delay, as the physiotherapy and administrative employees initially sought to solve the problem by themselves, obtaining equipment that was under maintenance and equipment lent to other units.

An excerpt from the interview with the physiotherapist illustrates how that process evolved: *"we don't have masks to provide NIV and we won't get them anytime soon; we need to make do with the available resources. Then, we realized that the invasive ventilation devices had a non-invasive operational mode. We firstly identified all existing equipment and tagged them as good, useless, and repairable devices...next, we purchased the appropriate masks that fit to these devices. At the same time, we devised a procedure*

on how to connect the patient to the mask; everybody was trained based on this new procedure, especially the physiotherapy team. Over the course of 15 to 20 days we had to adapt everything; however, the procurement processes took months up to the arrival of the new batch of non-invasive mechanical ventilation equipment".

As for the frequency of the unwanted variabilities (Table 6), the physiotherapist pointed out that three of them very frequent. The highest frequency was related to the delay for obtaining supplies due to several procurement processes – this was partly due to the public nature of the hospital, which implied too bureaucratic procedures for purchases. It is also worth considering the context of a university hospital with several hierarchical levels that often represent obstacles to multidisciplinary collaboration practices.

It is worth questioning whether case B was really a successful event. We hypothesize that success in absolute terms, without any ambiguity, is difficult to obtain in events like case B, in which there were organizational impacts that unfolded over months. This clearly differed from case A, when the event evolved over a few hours and there was only one patient and a relatively small number of staff involved.

Table 6. Assessment of the frequency of the unwanted variability sources – case B.

Variability	Frequency
Delay for obtaining supplies due to bureaucratic procurement processes	9.1 – very frequent
Uncertainty in terms of knowing when (and to whom) ask for help in case of lack of supplies	8.0 – very frequent
Staff's lack of knowledge of how to use IMV equipment in alternative mode to promote NIV	7.6 – very frequent
Delay for obtaining supplies from other units	6.0 – frequent
Delay for obtaining supplies from maintenance	5.6 – frequent
Lack of standardized operating procedures for using equipment in alternative operating modes	3.5 – unusual
Need to use IMV equipment in alternative operating mode	2.5 – unusual
Delay on the activation of the physiotherapy team	1.5 – very rare

3.4.2.3 Analysis of the adherence to theoretical principles: case B

Table 7 presents the relationships between the functions of case B, the resilience abilities, and the complexity guidelines. Similarly, to case A, the ability to respond had the strongest relationship with functions. By contrast, in case B the ability to learn stood out with a mean score of 1.68. The excerpt as follows, from the physiotherapist, reinforces the learning dimension of case B: *"a co-worker suggested setting up a step-by-step instruction for adapting the masks...I took photos and devised a users' guide, showing the*

technical details of the device, how it should be installed, etc." Thus, learning was due to the need for training professionals in the use of adapted equipment and disseminating the corresponding technical knowledge. In fact, data on the frequency of the variabilities (see Table 6) suggested that the need for using equipment in alternative mode was unusual, which partly explained the need for the said training.

Table 7. Case B: adherence to theoretical principles. Notes: A: Anticipate; M: Monitor; R: Respond; L: Learning.

Functions	Resilience abilities					Complexity Guidelines					
	A	M	R	L	Mean	Slack	Visibility	Diverse perspectives	Gap WAD vs. WAI	Unintended consequences	Mean
1. Admit and assess patients	2	4	2	2	**2.50**	0	2	0	0	0	**0.40**
2. Search for NIV equipment	1	1	3	1	**1.50**	0	0	0	0	0	**0.00**
3. Request equipment from ICU administration	1	1	2	1	**1.25**	0	1	0	0	0	**0.20**
4. Request equipment from other units	1	1	2	1	**1.25**	2	0	0	0	1	**0.60**
5. Request equipment from maintenance	1	1	2	1	**1.25**	2	0	0	0	1	**0.60**
6. Activate managerial leadership	2	1	3	1	**1.75**	1	1	2	0	0	**0.80**
7. Decide to use IMV equipment in NIV mode	1	1	4	1	**1.75**	4	0	2	1	2	**1.80**
8. Check which IMV equipment has NIV mode	1	2	1	2	**1.50**	2	1	0	1	0	**0.80**
9. Acquire knowledge to adjust IMV equipment for NIV	1	1	2	4	**2.00**	0	1	3	2	2	**1.60**
10. Provide beds and supplies	2	1	4	1	**2.00**	2	0	1	1	1	**1.00**
11. Provide electronic medical records	2	2	4	2	**2.50**	1	2	2	0	0	**1.00**
12. Train caregivers	1	1	3	4	**2.25**	2	2	3	2	1	**2.00**
13. Develop manual for using IMV equipment in NIV mode	2	1	3	4	**2.50**	2	3	2	2	1	**2.00**
14. Make equipment available to all patients	2	1	4	1	**2.00**	2	1	0	1	1	**1.00**
15. Manage supplies and equipment	3	3	2	1	**2.25**	3	3	1	3	1	**2.20**
16. Provide managerial team (to support decision making)	4	1	1	2	**2.00**	4	2	3	1	1	**2.20**
17. Know where to order supplies	1	1	2	1	**1.25**	1	1	0	0	0	**0.40**
18. Know who should be called to provide support	1	1	2	1	**1.25**	1	1	0	0	0	**0.40**
19. Realize importance of new knowledge	2	1	1	2	**1.50**	1	1	2	1	2	**1.40**
20. Search for alternative solutions for lack of equipment	2	1	3	2	**2.00**	3	1	3	0	2	**1.80**
21. Adapt masks for NIV mode	1	1	3	1	**1.50**	4	0	2	1	1	**1.60**
22. Activate the physiotherapy team	2	1	2	1	**1.50**	1	1	3	0	0	**1.00**
Mean	1.64	1.32	2.50	1.68	**1.78**	1.73	1.09	1.32	0.73	0.77	**1.13**

Regarding the relationships between functions and complexity guidelines, findings were similar to case A. Thus, the guidelines related to slack resources and diversity of perspectives had the strongest associations with the functions. The role of slack resources reflects the initial trigger for the event, namely the lack of supplies to cope with a surge in demand. For instance, functions such as <request equipment from maintenance> and <request equipment from other units> were initial attempts, unsuccessful, to obtain slack resources. Data on the frequency of the variability sources suggest that these functions were initially activated because their outputs used to occur with little delay, in comparison to <request equipment from ICU administration>. In fact, these three <request equipment…> functions are redundant to each other, thus also being an example of slack when jointly considered.

In turn, the high frequency of the guideline linked to the diversity of perspectives occurred for two reasons: *(i)* the multidisciplinary nature of the problem, both in terms of the professional specialties and the ICU hierarchical levels involved; and *(ii)* the need for disseminating new knowledge to the workforce, which widened the perspectives of both those who prepared the training and those who attended it.

3.4.2.4 Improvement opportunities: case B

Similarly to case A, improvement opportunities in case B have a correspondence to variabilities. One of these variabilities was a surge in demand, which had consequences for the supply of materials. While the lack of materials was also an issue in case A, in that situation the problem was supply-driven, while in case B it was demand-driven. Therefore, given the difficulty of controlling and anticipating external demand, countermeasures might imply the identification of life-saving supplies, which could have larger safety stocks (i.e., slack resources). Another impactful variability relates to the staff lack of awareness of the alternative mode of functioning of IMV equipment. In this respect, it might be appropriate to assess whether there is similar lack of awareness for other critical equipment, which would demand a general revision of training practices. Preparedness, both in terms of equipment availability and staff apt for using it, is certainly an asset for resilient performance.

As for the reinforcement of good practices, multidisciplinary and collaborative work were also prominent in case B. Therefore, the same improvement opportunity of case A is applicable, namely the creation of formal moments for exchanging experiences between professional categories.

3.5 Discussion

3.5.1 Overall analysis of cases A and B

Both cases indicated the ability to respond as the most strongly associated with functions. This may stem from the CDM, which emphasizes real problems that demand non-trivial responses. It is worth mentioning another CDM implication, visible in case A. Due to the emphasis on challenging events, the CDM can point out variabilities that are not present in everyday work, which is contradictory with Safety-II. Alternative approaches for identifying relevant events with desired outcomes can be adopted, such as the RPET method. According to that method, at the end of each shift (or day) professionals meet and reflect on what went right and what went wrong, based on a checklist of probing questions (Hollnagel, 2019).

As for the guidelines for coping with complexity, both cases indicated the central role of providing slack resources and diversity of perspectives in decision-making. As previously mentioned, Bueno et al. (2019) obtained similar findings in a review of process improvement interventions in ICUs. As for slack resources, their provision is a means of responding to variabilities, either opportunistically while the event unfolds (e.g., borrowing cannulas from the surgical unit) or based on features built-in ahead of time, even if that was not widely known by all employees (e.g., the use IMV equipment in NIV mode). The use of diverse perspectives in decision-making seemed to occur naturally in cases A and B, which involved clinical and managerial multidisciplinary problems. In both cases, the interviewed professionals were not reluctant to ask for support from co-workers with different knowledge and organizational roles.

Still regarding the guidelines, their scores were in general clearly lower than the scores obtained by the resilience abilities. This suggests that, although the guidelines are logically related to those abilities (Bueno et al., 2019), there is not necessarily a cause-effect relationship. This point is reinforced by the presence of several resilient functions that reflect spur-of-the-moment behaviours of the professionals. As discussed by Wachs

et al. (2016) these behaviours have an emergent nature, and they are little amenable to the influence of built-in resilience, such as the design of slack resources. As a drawback, the overuse of that type of resilience may be taken for granted over time and become a source of burnout to healthcare professionals (Smaggus, 2019).

The two markedly different case studies offered insight into the nature of desired outcomes. These differences suggest criteria to categorize events with desired outcomes, according to factors such as the number of actors involved, diversity of these actors, and time elapsed. The greater these factors, the greater the complexity of the event. Complex events require more time for their analysis and may offer opportunities for improvement with an impact on a larger number of functions and people. In this study, according to the mentioned factors, case B is more complex since it involved a large portion of the ICU workforce, with professionals from different hierarchical levels, over several months.

In common, the two cases demonstrated that events with desired outcome did not occur due to the outstanding performance of any professional in particular, rather involving several healthcare workers and hospital units. At the same time, the identified vulnerabilities indicated that desired outcomes should not be conducive to complacency, consistently with FRAM theory conveying that the outcomes could have been different under a slightly different combination and intensity of variabilities (Hollnagel, 2012). Lack of awareness of that point can make investigators susceptible to illusion of control, which is an individual's tendency to overestimate the probability of personal success in random situations (Biner et al., 2009). The proposed approach can play a preventive role in the development of illusions of control.

3.5.2 Evaluation of the main FRAM changes

As presented in Figure 1 (section 3.2), changes to the original FRAM are proposed. Initially, it is worth highlighting the value of referring to functions as "resilient", which bridges a language gap between FRAM and resilience, in addition to providing focal points for the identification of concrete manifestations of resilient performance. Guidance was provided for data gathering and analysis focused on the search for the sources of resilience.

Another change was the analysis of the logical association between functions, resilient abilities, and complexity guidelines. That complements the original FRAM by encouraging abstract analytical reasoning, which supports the identification of emerging patterns and more generalizable practical recommendations – e.g., revision of training practices in general may stem from case B, and multidisciplinary work is certainly an asset to the ICU resilient performance, based on both cases.

In addition, the proposal was made of assessing how frequently the unwanted variability of the output plays out at the same way as it occurred in the event with desired outcomes – a questionnaire was suggested for that assessment. Although quantitative additions to FRAM were proposed by earlier studies (e.g., Bellini et al., 2020) none of them, to the best of our knowledge, was concerned with the mentioned variable – also, the use of questionnaires as a source of data for developing FRAM models has been under explored (Patriarca et al., 2020). Thus, our quantification approach based on questionnaires answered by practitioners is an exploratory attempt of addressing that gap. The case studies indicated the utility of that analysis, which made possible to question a Safety-II assumption that otherwise could be wrongly overgeneralized – i.e., the assumption that variabilities that commonly occur in everyday work underlie both success and failure (Hollnagel, 2014). Case A is a reminder that Safety-II practitioners must also be interested in rare variabilities, which pose threats despite of being identified from events with desired outcomes.

However, we recognize that the analytical effort required by the aforementioned FRAM additions may not pay back to everyday applications of FRAM by practitioners. These additions tend to be more relevant under certain circumstances, such as: *(i)* the analysis of complex events when reasons for successful performance are nontrivial; *(ii)* the analysis of databases of several FRAM models from a same company or sector, aiming at the identification of higher-order patterns; and *(iii)* for research purposes (i.e., the context of this study), when researchers may be interested in understanding why and how resilient performance plays out.

These drawbacks must be put into context when considering that artefacts produced by design science research, such as the adapted FRAM, are generic designs. According to Van Aken et al. (2016) a generic design allows for well-trained and experienced designers to make their own context specific design. The generic design

should be well-documented enough to enable practitioners to use it as a model for making case-specific designs (Van Aken et al., 2016). This means that those applying our proposal might adapt it and even use only portions of it for purposes different than we anticipated – e.g., the suggested questionnaire might be useful for the analysis of accidents based on FRAM.

The need for the proposed changes stemmed from the generic, and fully comprehensible, purpose of the original FRAM, which provides a template for the modelling of socio-technical systems in general. Our research suggests that amendments are useful for the modelling of certain classes of working situations, such as those with desirable outcomes. Furthermore, according to the interviewees that reported cases A and B, the investigation of desired outcomes is likely to be well-accepted by professionals, who would be less concerned with any possible liability.

3.6 CONCLUSION

This article proposed additions to the original FRAM steps in order to make it explicit the role of resilience in the analysis of events with desired outcomes. The main changes were: *(i)* the inclusion of functions explicitly connected to resilience in FRAM models; *(ii)* the analysis of functions according to the four abilities of resilient systems and the five guidelines for coping with complexity – this includes subjective estimates of the strength of the logical relationships between functions, abilities, and guidelines; and *(iii)* a new dimension for assessing the outputs of functions, namely the frequency at which the unwanted variability of the output is expected to occur at the same way as it occurred in the event with desired outcomes. Furthermore, CDM interviews proved to be an effective means for identifying events with desired outcomes, besides providing useful contextual information for the development and interpretation of FRAM models. The proposed approach is expected to be useful for making systems more resilient to everyday work (instead of specific scenarios of failure), in which desired outcomes usually occur despite vulnerabilities that are hidden by those outcomes.

The two case studies demonstrated that the same FRAM model might offer opportunities for learning from both what goes well and what goes wrong. That finding also suggests that completely separate analytical tools for Safety-I and Safety-II may be

unnecessary and even counterproductive. Adaptations of existing tools, such as FRAM, may suffice for encompassing both Safety-I and Safety-II.

Some limitations of this study must be mentioned. First, not all professionals directly involved in the case studies were interviewed, which may have implied some bias. Second, the CDM stresses challenging events that may involve unusual variabilities, rather than everyday variabilities focused on by Safety-II. Third, there was no analysis of the ICU records of adverse events, which could shed light on whether the same variabilities present in desired outcomes were present in negative outcomes, as expected by Safety-II. Fourth, the proposal was not tested for the analysis of prospective future scenarios (only for the analysis of past events), which could support the anticipation of how resilient performance could lead to desired outcomes – that may raise useful questions on how to ensure that the expected performance will occur.

This work gave rise to opportunities for future studies, as follows: *(i)* the identification of emerging patterns from a larger number of case studies, which could set a basis for a taxonomy of successful events; *(ii)* the use of the proposal for the investigation of events identified through tools other than CDM interviews; *(iii)* quantitative and qualitative comparative analysis of contributing factors and variabilities associated with desired and undesired outcomes; *(iv)* the investigation of whether tools originally developed under a Safety-I framework (e.g., root cause analysis) might be adapted for the investigation of desired outcomes; and *(v)* the use of the proposed approach for the investigation of how resilient performance can contribute to desired outcomes in future scenarios.

Disclosure statement

No potential conflict of interest was reported by the authors.

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4. ARTIGO 3: *When resilience is not enough: an exploratory study of Brazilian ICUs during the COVID-19 pandemic*

Abstract

Although the COVID-19 pandemic has challenged the resilience of healthcare services in general, this impact has been most visible in intensive care units (ICUs). This paper presents an exploratory study of how ICUs in Brazil have coped with the unprecedented complexity stemming from the pandemic. Five guidelines for coping with complexity were adopted as a data collection and analysis framework. The guidelines were concerned with slack resources, diversity of perspectives, visibility, work-as-done, and unintended consequences. There were three main sources of data: *(i)* a survey with respondents from 33 ICUs; *(ii)* eight semi-structured interviews with representatives from the micro, meso, and macro levels of healthcare services; and *(iii)* 20 hours of observations of the meetings of a municipal bed management committee. Seventy practices associated with the guidelines were identified, providing a rich perspective of the adaptive strategies. However, the ICUs' resilience was mostly reactive and dependent on societal resilience as they could not influence the high demand for beds. The paper also discusses the notion of running out of resilience, which was part of the ICUs' performance during the pandemic, as well as lessons learned in light of the complexity guidelines.

Keywords: COVID-19, resilience, intensive care units, complexity, Brazil.

1. Introduction

Healthcare services are widely recognized as complex socio-technical systems (CSSs) due to the large number of diverse and interacting elements, such as caregivers, patients, supplies, and equipment (Braithwaite, 2018). High and prolonged demand for hospital care resulting from the COVID-19 (hereafter simply COVID) pandemic has scaled up that complexity to unprecedented levels. Intensive care units (ICUs) have been the most visible facet of healthcare services affected by the pandemic, being the ultimate battleground for struggling people and systems. Despite numerous media reports, there is a need for systematic investigation, using a theoretical framework, of how ICUs have coped with the pandemic. This type of investigation will support the sense making of the role of ICUs in the pandemic, setting a basis for the identification of lessons learned.

This study uses the lens of resilient healthcare, which is the "ability of the healthcare system to adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required performance under both expected and unexpected conditions" (Hollnagel et al, 2013, p. xxv). Indeed, the pandemic has made the need for resilient systems in general, not only in healthcare (e.g., in supply chains, education), dramatically visible (Ivanov, 2020).

While resilience is itself an attribute of CSSs, it is also important to cope with other complexity attributes – e.g., a changing external environment - that push systems out of their normal operating envelope (Patriarca et al., 2018; Righi and Saurin, 2015). However, resilience is an emergent phenomena (Hollnagel, 2014), which means that it cannot be directly assessed (Wachs et al., 2016). This study explores the role of five guidelines for coping with complexity, which are logically connected to resilience and expected to positively influence it (Bueno et al., 2019). These guidelines were originally devised from a literature review conducted by Saurin et al. (2013), which were mostly drawn from the work of seminal human factors and system safety authors. Since then, the guidelines have been used as an analytical framework both in healthcare and in other sectors. Bueno et al. (2019) used the guidelines in a literature review that analysed 91 quality and safety improvement interventions in ICUs. Saurin (2021) used the guidelines for analysing how system-oriented safety theory can be improved based on the lessons learned from the pandemic. Mahmoud et al. (2021) used the guidelines for making sense of resilience during a critical event in the scheduling of a surgical unit. In this paper, we

use those guidelines as a basis for an exploratory analysis of how ICUs have coped with the pandemic. Against this backdrop, two research questions are addressed by this study: (1) What is resilience like in ICUs during the pandemic? (2) What are the practical and theoretical lessons learned for coping with complexity? These questions are investigated in the context of Brazilian ICUs through a mixed-methods research design that includes a questionnaire survey, interviews, and non-participant observations.

2. Background

2.1 COVID in Brazil

Brazil has been severely hit by COVID due to multiple causes that include the fast spread of the SARS-Cov-2 virus to countryside areas as well as failure of implementing prompt and coordinated responses at the federal, state and municipal levels (Castro et al., 2021). In particular, the federal government has been severely criticized for disseminating misinformation and scientific negationism, besides encouraging the use of unproven treatments (Bastos et al., 2021).

The collapse of the hospital care system was also due to the sudden increase in demand and the existence of regional "hospitals deserts" in a country with continental dimensions, especially in the North and North Eastern regions and rural areas (De Souza Noronha et al., 2020). The consequences of such scenario are dramatic: as of the end of April 2021, Brazil has the second-largest number of COVID-related deaths worldwide and an estimated decline for 2020 life expectancy at birth of 1.94 years (Castro et al., n.d.).

According to the National Brazilian ICU registry that comprises data from 655 hospitals, corresponding to 21,868 ICU adult beds (13,578 private and 8,290 public), from March 1st, 2020 to April 21st, 2021, 137,323 of 581,792 ICU admissions (23.6%) were due to COVID. ICU mortality rate from COVID was 29.8% in private hospitals and 53.2% in public hospitals in the period[3]. In addition to the overwhelming demand for admissions amid the COVID surge, Brazilian ICUs also faced a shortage of equipment such as mechanical ventilators, lack of medicines for airway management and sedative drugs that sometimes culminated in waiting periods for as long as three days, thus resulting in patients who died waiting for a bed (Alves, 2021).

[3] https://bit.ly/3nouk7J/. Accessed in April 25th, 2021.

2.2 Guidelines for coping with complexity

Table 1 presents the five guidelines for coping with complexity that have been adopted as basis for this study. Earlier studies of these guidelines in healthcare (Mahmoud et al., 2021; Bueno et al., 2019; Saurin et al., 2018; Righi and Saurin, 2015) addressed the micro (e.g., clinical care at the bedside) and meso levels (e.g., hospital or hospital unit policies), even though results were not explicitly categorized according to those levels. In addition, the use of questionnaires for assessing the uptake of the guidelines only occurred in the study by Righi and Saurin (2015) in an emergency department. Thus, the approach for investigating the guidelines in this study is new as it: *(i)* explicitly accounts for the micro and meso levels, besides the macro level (e.g., public health network); *(ii)* analyses the use of the guidelines in a sample of healthcare services through questionnaires; and *(iii)* focuses on an unprecedented complexity scenario, which is strongly connected to the uncontrolled environment external to healthcare services that has put their capacity under stress for a prolonged period. This context seems to offer an opportunity for advancing the understanding of the guidelines.

Table 1. Guidelines for coping with complexity (Bueno et al., 2019 and Saurin et al., 2013).

Guidelines	Main aspects of the guidelines	Complexity attributes* addressed by the guidelines
Provision of slack resources	Slack is a mechanism for reducing interdependencies and slowing down or eliminating the propagation of variability (Safayeni and Purdy, 1991). This may be obtained through spare resources (e.g. human, technical) which can be called on in times of need (Nohria and Gulati, 1996).	This guideline aims at making processes loosely-coupled, and thus absorbing or dampening the propagation of *variability*. As a drawback, slack may increase the *number and diversity of elements* in the system.
Encouraging diversity of perspectives when making decisions	Diversity of perspectives may help to tackle uncertainty. Agents involved in decision-making should hold complementary skills. Some requirements for the implementation of this guideline are: high levels of trust, reduction of power differentials and identification of apt decision-makers (Page, 2010).	*Diversity* (e.g., demographics of people, level of automation of equipment, etc.) is a key attribute of complexity, and it may offer complementary perspectives of system functioning
Supporting visibility of processes and outcomes	Systems should be intuitive and visibility should be given to both formal and informal work practices (Clegg, 2000). Informal practices may encompass either useful innovations or latent hazards. Visibility should allow for real-time performance monitoring and the free sharing of information (Galsworth, 2017).	This guideline may be useful for coping with any complexity attribute, making these more salient and distinctive from each other. Visibility can also reduce perceived complexity.
Monitoring and understanding the gap between work-as-imagined and work-as-done	Monitoring and understanding the gap between work-as-imagined and wok-as-done may shed light on variability sources that otherwise may be taken for granted. Reasons for the gap	Due to the *dynamic interactions between a large number of diverse elements*, and the resulting *variability*, work-as-imagined is different from work-as-done in CSSs.

	should be investigated, as well as its implications (Hollnagel, 2017).	
Monitoring unintended consequences of improvements and changes	Improvements and changes interact between themselves and with the environment, and this poses opportunities for unintended consequences (Perrow, 1984). These consequences may be benefits, problems, failures, or costs associated with the intervention (Ogrinc et al., 2015).	CSSs have *tightly coupled* processes *interconnected as a network*. Also, these systems are always *evolving* and *interactions* are *dynamic*. Thus, any changes may propagate in unexpected ways and *non-linearly* – i.e. consequences may be disproportionate to the causes.

* The terms in Italics correspond to the attributes of complexity directly addressed by the guidelines.

2.3 Resilient healthcare during disasters

In addition to the investigation of the variability of everyday work, resilient healthcare scholars and practitioners are interested in understanding how healthcare services cope with both natural and man-made disasters (Hollnagel et al., 2019; Braithwaite et al, 2017). These disasters can play out as public health emergencies (e.g., COVID and H1N1 pandemics), which at the international level are declared by the International Health Regulations (Wilder-Smith et al., 2020). Juvet et al. (2021) investigated problematic work situations and resilient strategies during the COVID first wave in Swiss healthcare institutions, based on a questionnaire. The most frequently cited problematic situations involved organizational changes, interpersonal conflicts and high workload.

Emergency management services (EMS) are a setting frequently addressed by resilient healthcare during crises. In fact, everyday work in emergency management resembles a chronic crisis similar to the situation faced by ICUs during the pandemic. Son et al. (2020) identified five tools to enhance resilience in EMS: mapmaking, event history logging, mobile communication applications, integrated information management system, and decision support tools. In turn, Zhuravsky (2019) discussed the contribution of resilient healthcare to the sustained performance of the nursing team in a medical ward in New Zealand over the three months following an earthquake. Their study stressed the learning capability as a key contributor to resilience, contribution of workarounds to the team's resilience, and the importance of reducing the gap between work-as-imagined and work-as-done (Zhuravsky, 2019). Braithwaite et al. (2017) reported how resilient performance played out in an emergency department in Canada, which provided care to a large number of patients from a riot stemming from a major sport event. Although the existing disaster plan formed a structure to work with, the situation demanded substantial

bricolage; lower-order goals were sacrificed for higher-order goals by reducing treatment times and prioritizing essential activities (Braithwaite et al., 2017).

Despite the contributions of earlier studies on resilience during disasters, they were carried out mostly in wealthy countries, which makes the analysis of the Brazilian case another original feature of the present work. Furthermore, none of them simultaneously and explicitly addressed the connections between the micro, meso, and macro levels. The concept of societal safety offers a possible framework for articulating the interactions between those levels. Hoyland (2018) presents a review of societal safety definitions, which is usually described as the society's ability to maintain vital social functions in a variety of stress situations, which implies the creation of favourable physical and psychological conditions for people when society is faced with unknown elements.

3. Method

3.1 Research strategy

A mixed-method approach, including qualitative and quantitative data, was adopted. This research strategy allows for triangulation of data and data sources and is recommended for the investigation of complex phenomena (Harrison et al., 2020). As such, there were two research stages, referred to as quantitative and qualitative. The quantitative stage involved an exploratory survey for the assessment of the five complexity guidelines in ICUs, addressing the micro and meso levels. Exploratory surveys are useful in the early stages of studying a phenomenon and they have some advantages, such as low cost and standardized stimulus to all respondents (Montgomery, 2013). Data analysis followed the survey application and set a basis for the start of the qualitative data collection.

The qualitative stage started with semi-structured interviews with healthcare professionals representing the micro, meso, and macro levels. Seven out of the nine interviewees were respondents of the questionnaire. Furthermore, the qualitative data collection involved non-participant observations of the regular meetings of the municipal bed management committee that is one of the branches of the COVID-19 crisis

management committee in a capital city in Southern Brazil[4]. This contributed to the assessment at the macro level. The joint data analysis from the quantitative and qualitative stages supported the identification of five lessons learned, one for each complexity guideline. Data collection occurred from late September 2020 to mid-February 2021, which encompasses the tail of the first wave and the second wave in Brazil but not the explosive rise in cases during March and April 2021 (Figure 1). The research project was approved by the ethics committee of the teaching hospital linked to the first author's university and informed consent was obtained from all participants.

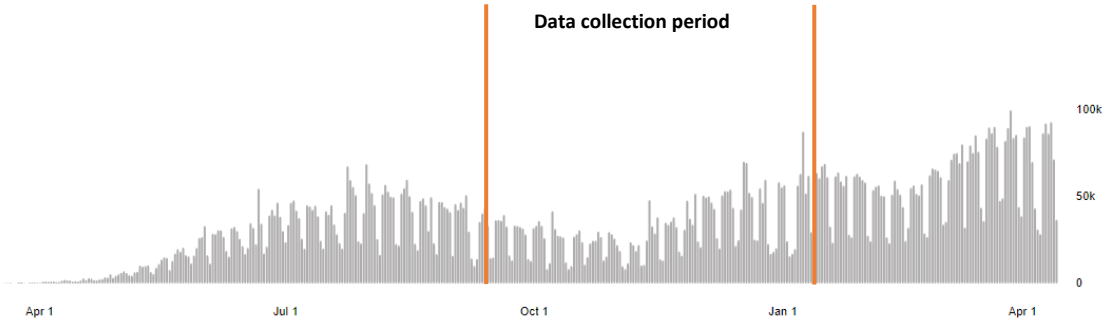

Figure 1. Evolution of COVID cases in Brazil and the data collection period. Source: https://covid19.who.int/region/amro/country/br

As for the epistemological perspective of complexity, a critical realist view was adopted. It combines positivist and constructivist perspectives (Archer et al., 1998) and has been used by other studies on complexity and human factors (e.g., Righi and Saurin, 2015). According to this perspective, while some complexity attributes are independent on the observer (e.g., number of beds, in line with realism), there are multiple valid descriptions, while incomplete, for other attributes (e.g., descriptions of how caregivers interact, in line with constructivism) (Fletcher 2017).

3.2 Quantitative stage

3.2.1 Development of the survey questionnaire

The questionnaire was developed based on an earlier version proposed by Righi and Saurin (2015) for the assessment of the same complexity guidelines in an emergency

[4] This city, which was severely hit by the pandemic, was chosen as the authors live there and had ease of access to the municipal health department.

department. Although the overall structure of both questionnaires is the same, there were changes as a result of: the better understanding of the guidelines in the meantime, due to their application in other studies; the ICU context, which implied the need to use ICU examples along with the questions; and the inputs from two experienced physicians in the questionnaire design (both are co-authors of this paper), which had not occurred in Righi and Saurin (2015). One of these professionals was an intensive care physician (12 years of experience) who was also working at the front-line of care in a COVID ICU. The other (28 years of experience) was an internal medicine and epidemiologist physician that is the head of the clinical risk management department of a major teaching hospital that provided care to COVID patients. A draft of the questionnaire was developed by the other authors, all of whom had previous experience with human factors research in ICUs and other hospital settings, then critically appraised by the two aforementioned physicians. A final version was obtained after several rounds of refining the contents and wording of the questions, aiming at an instrument that was both comprehensive and not too time-consuming for respondents. The structure of the questionnaire is as follows:

(i) Introductory statements with the objective and context of the study as well as information on research ethics;

(ii) Identification of the respondent, including their name and time of experience;

(iii) Twenty questions for the characterization of the hospital and the ICU. Several of these questions were inspired by Soares et al. (2015), which carried out an assessment of organizational characteristics, outcomes, and resource use (ORCHESTRA study) in 78 Brazilian ICUs. In this section, some of the responses were open-ended (e.g., number of ICU beds) while others required a choice from predefined options (e.g., ICU decision-making model, whether closed, open, or shared);

(iv) Twenty-three questions directly related to the five complexity guidelines at the micro and meso levels. These questions were described as statements on the use of the guidelines, accompanied by ICU examples if appropriate. There was a sliding bar with two endpoints: fully disagree (corresponding to zero) and fully agree (100). The distribution of the questions according to the guidelines was as follows: slack resources (6); visibility (4), diversity of perspectives (4), work-as-done (5), and unintended consequences (4). There was also a 24^{th} question, using the same scale, asking the

respondents to indicate the extent to which they agreed with the statement that the ICU was a resilient system;

(v) An open-ended question in which the respondent was invited to describe one or more examples of resilient performance during the pandemic; and

(vi) A field for respondent feedback regarding the utility and clarity of the questionnaire as well as any further comments deemed relevant.

3.2.2. Survey questionnaire: data collection and analysis

The questionnaire was made available on the Survey Monkey platform and a pilot application was conducted with three ICU professionals who were personal contacts of the authors. Next, it was sent out to potential respondents through three main channels: *(i)* participants of the previously mentioned ORCHESTRA project - this invitation was made by the former leading researcher of that project; *(ii)* a list of 25 ICU chief-physicians in the state of Rio Grande do Sul, as one of the authors was a former coordinator of the regional chapter of the society of intensive care physicians; and *(iii)* personal contacts of the authors. Despite these efforts, there were only 33 valid responses[5] (all from different ICUs) from 13 out of the 27 Brazilian States. Three responses were discarded as they were provided either by professionals with too little ICU experience (< 2 years) or the respondent clearly did not understand the use of the scale, assigning scores of only zero or 100 to all questions. Respondents had on average 14.6 years of ICU work experience, ranging from 3 to 38 years. Their distribution according to professional group involved: 23 physicians, 8 nurses, 1 physiotherapist, and 1 nutritionist – 16 respondents had a team or unit management position.

The sample size was too small to produce statistically generalizable results. As such, the purposes of the survey were twofold: *(i)* to provide an exploratory overview of the uptake of the guidelines; and *(ii)* to work as a guide to the gathering and interpretation of qualitative data. The survey results were analysed using descriptive statistics and the Cronbach´s Alpha was calculated for the 24 questions with the sliding bar. An Alpha of 0.96 was obtained, which suggests a reliable instrument (Hair et al., 2014).

[5] According to data automatically recorded on the Survey Monkey platform, respondents took on average 12 minutes to answer the questionnaire, and all of them answered 100% of the questions.

3.3 Qualitative stage: data collection and analysis

All survey respondents were invited to participate and seven agreed to be interviewed. Interview questions corresponded to the core part of the questionnaire (i.e., the questions on the complexity guidelines) with the aim of understanding the rationale for the survey responses. An additional joint interview was conducted with two public health officials who were also physicians and played a key role in the bed management committee of ICU beds and non-ICU (i.e., clinical and surgical wards) from the city's health department. The two officials also participated in crisis committees that made decisions on social distancing and population mobility restrictions to locally control the spread of the pandemic. Those interviews had three questions: which are the roles and activities of the committees? Which are the processes involved in the city's ICU bed management system? Which are the benefits, difficulties and criteria adopted for allocating patients to hospitals? The interviews lasted one hour on average and all of them were audio-recorded and fully transcribed. Table 2 summarizes the profile of the interviewees.

Table 2. Profile of the interviewees.

Interviewee	Background / position	Workplace – all in COVID ICUs	ICU experience
1	Intensive care physician	95 beds, public hospital	12 years
2	Nurse	9 beds, public hospital	2.5 years
3	Chief-nurse	18 beds, public hospital	8 years
4	Chief-physician	20 beds, public-private partnership	38 years
5	Intensive care physician/hospital director	42 beds, public hospital	20 years
6	ICU chief-nurse	20 beds, public hospital	14 years
7*	Intensive care physician/public health official	Municipal health department	20 years
8*	Physician/public health official	Municipal health department	22 years
9	Physiotherapist	25 beds, private hospital	4 years

* Joint interview – thus, there were 9 interviewees and 8 interviews.

Another source of qualitative data involved 20 hours of non-participant observations (December 2020 and February 2021) in 10 virtual meetings of the local municipal COVID bed management committee. Since April 2020 meetings have been held every week on Mondays, Wednesdays, and Fridays. The meeting involves 15 technicians from the municipal health department and focuses on the monitoring of a number of indicators, such as bed occupancy rates of ICUs, number of performed COVID diagnosis tests in the local healthcare services, and main outbreaks under way. Each meeting lasted on average two hours and the researchers took notes in real-time when they detected comments related to the use of the complexity guidelines.

Interviews and non-participant observations were continued until data saturation criteria were met, which means that findings started being repetitive and the data produced was regarded by the researchers as sufficient for the purpose of answering the research questions (Ritchie et al., 2003).

A thematic analysis of the qualitative data (i.e., transcripts of interviews, notes from observations, and comments of the survey respondents on the open field for describing examples of resilience), corresponding to approximately 63,000 words, followed the stages proposed by Pope et al. (2000), namely familiarization, identifying themes, coding, charting, and mapping and interpretation. Familiarization involved reading the texts several times in order to gain an understanding of the recurring themes. Next, the themes that had been defined upfront by the researchers were imposed on the data as a heuristic device. The main themes corresponded to:

(i) Resilience practices or conditions associated with the complexity guidelines. These practices or conditions could be created intentionally or non-intentionally, by individuals, teams, and organizations, internal or external to the ICU. In common, and what justifies their connection to resilience, these practices or conditions represent adaptive performance to cope with the pandemic, and therefore they were not part of everyday work (at least not at the same frequency) before that. It is worth noting that the main theme for analysing the complexity guideline on monitoring unintended consequences was not related to resilience practices or conditions. This occurred as the familiarization stage of data analysis made it clear that there were no relevant practices in place for implementing the guideline. By contrast, what was clear was that there were several unintended consequences of using (or choosing not to use) the other guidelines. Therefore, we opted for defining the examples of unintended consequences themselves as the main theme for analysing that guideline; and

(ii) The system level in which the practice or condition played out. The coding criteria were as follows: micro, corresponding to practices or conditions that played out within the ICU premises and did not have any strong dependence on other hospital units and/or hospital top management; meso, when there was strong dependence on other hospital units and/or top management; and macro, when there was a direct interaction or dependence on the environment external to the hospital.

The thematic analysis followed with the coding stage, in which excerpts of text were tagged according to the themes. Three researchers carried out a preliminary coding based on these criteria, separately. Then, codifications were compared in a joint meeting, inconsistencies were detected and a discussion followed until a consensus was obtained. This coding was still further reviewed by another researcher who read all transcripts and was a co-author of all of the earlier studies related to the five complexity guidelines, resulting in additional adjustments. The thematic analysis continued with the charting phase, which synthesized findings from the previous stages. For each complexity guideline, tables were developed (see Results section), presenting the corresponding resilience practices and conditions. An overall analysis of the findings occurred at the mapping and interpretation stage. In total, 30 hours were dedicated to the qualitative data analysis.

4. Results

4.1 Main characteristics of the ICUs

Table 3 presents the main characteristics of the 33 ICUs represented in the survey. They were mostly general ICUs (79%), small-sized (76% had no more than 20 beds), with interdisciplinary rounds (88%), organized as open plan environments instead of single rooms (64%), part of teaching hospitals (64%), and with accredited quality and safety management systems (64%).

Table 3. Main characteristics of the surveyed ICUs.

Criteria	ICU characteristics
Type of ICU	26 ICUs were general. The others were specialized – e.g., infectious diseases, cardiac diseases.
Number of beds	22.8 beds on average, ranging from 7 to 140 beds
Configuration of ICU bays	In 12 ICUs patient bays were arranged as individual rooms
Administration and funding	10 public, 16 private, 7 public-private partnerships
COVID-19 patients	29 ICUs had COVID patients
Decision-making model	4 open: attending physician makes decisions on admission, care, and discharge 10 closed: ICU team makes decisions on admission, care, and discharge 19 shared decision-making
Accreditation	21 ICUs have an accredited quality and safety management system
Teaching hospital	21 ICUs are in a teaching hospital
Palliative care team	13 ICUs have a palliative care team
Multidisciplinary rounds	29 ICUs have multidisciplinary rounds
Average occupancy rate in the last three months before filling out the questionnaire	83.7%, ranging from 45% to 100%

4.2 Provision of slack resources

Table 4 presents both the quantitative and qualitative results for the guideline on slack resources. There were 30 practices or conditions related to this guideline, being 9 related to the micro level, 18 to the meso, and 3 to the macro level. The high incidence of the meso level reflects the fact that ICU slack resources were often borrowed from other hospital units.

Table 4. Results for the guideline "provide slack resources".

Statement	Survey (mean)	Number of excerpts	Resilience practices or conditions	Level
(1) The allocation of people changes as needed and in an agile way, such as, for example, reallocating staff from one area of the ICU to another	66.0	17	Willingness to collaborate with colleagues and offer help regardless of being tired	Micro
			Mixed care teams with at least one experienced staff member in order to counterbalance and support the high number of junior staff	Micro
			Reallocation of staff to COVID units as well as to replace professionals on leave	Meso
			Suspension of elective surgeries to free up staff to COVID patients	Meso
			Leadership support to newly hired employees	Micro
(2) The allocation of material resources changes as needed and in an agile way, such as, for example, reallocating dialysis equipment and supplies from one area of the ICU to another	74.0	34	Transformation of regular wards and other areas into ICUs for COVID patients – scaling up capacity several times during the pandemic	Meso
			Adaptation of existing ICUs to the needs of COVID patients – e.g., changes in the air-conditioning and air filtering system, installation of negative pressure systems in patient rooms	Micro
			Repurposing of drugs, tools, and equipment	Micro
			New protocols for donning and doffing personal protective equipment (PPE)	Micro
			Borrowing equipment and supplies from other ICU and non-ICU units	Meso
			Use of kits with supplies for intubation	Meso
			Acquisition of modern technologies for monitoring vital signs	Meso
			Location of COVID-ICU physically distant from non-COVID units	Meso
(3) Caregivers have adequate time availability to carry out their activities, without excessive haste or too many simultaneous tasks	58.2			
(4) There are extra or standby human resources that can be quickly deployed, and these are available in sufficient quantity to cope with unforeseen events	42.8	9	Overtime work	Micro
			Hiring of new professionals, offering attractive salaries	Meso
			Cancellation of holidays	Meso
			Acceleration of capacity expansion projects under way	Meso
			Patients over 70 or mentally/physically impaired are allowed to have a full time caregiver companion at the ICU	Micro
(5) There are extra or standby material resources that can be quickly deployed, and these are available in sufficient quantity to cope with unforeseen events	60.1	12	Sterilization and reuse of face masks for caregivers	Meso
			Acquisition of extra supplies	Meso
			Construction of makeshift hospitals	Meso
			Transfer of COVID patients from overcrowded ICUs in some Brazilian states to other states	Macro
			Donations of equipment and supplies (e.g., ventilators, PPE) from private companies and non-governmental organizations	Meso

			Hospital setup its own lab for the processing of COVID tests, in order to reduce reliance on external agents	Meso
(6) There are protocols, training or technological support for the early detection of the need for changing the care plan (e.g., early detection of the need for palliative care, of sepsis, of mobilizing the patient to facilitate rehabilitation)	55.9			
Others		5	Own financial slack to pay higher prices for scarce supplies	Meso
			Financial support from governments	Macro
			Staggered times for using the staff room in order to prevent gatherings	Micro
			Changes in the routes of access of employees to the hospital in order to prevent contagion	Meso
			Reduction in the demand for other diseases like flu and trauma accidents; this released capacity	Macro
			In the hospital processes and areas related to the admission of external patients, all protocols are based on the worst-case scenario – i.e., patient is assumed to be infected by COVID-19	Meso
	Overall mean: 59.5	78 in total		

Statement (4), which is related to the availability of human resources, obtained the lowest score in the whole questionnaire (42.8). Indeed, the shortage of clinical professionals has been widely recognized as a major problem during the pandemic and this was also pointed out by all interviewees. For example, interviewee #1 (intensive care physician) reported that "*the number of ICU beds more than doubled while the number of physicians increased by 50% or 60%...let´s say that before the pandemic I cared for six patients and now there are ten…it may look like a small difference but the implications are large because I spend much time with each patient*". Lack of staff was compounded by the stressful working conditions as reported by interviewee #9 (physiotherapist): "*professionals are tired of working with uncomfortable PPE for long hours and coping with so many deaths".*

Insufficient staff also implied that professionals had to share their time across hospital units and ICUs. Interviewee #9 illustrates this point: "*I was working at the ICU and then I was requested to provide immediate support at the emergency department…I was unable to quickly return to the ICU and had to make an arrangement with the ICU staff so as they could care for the patients I could not see".*

The higher score (60.1) obtained by statement (5), which is related to the availability of material resources, might reflect the timing of the survey application, which occurred several months after the start of the pandemic and before the major rise

in March and April 2021. All interviewees mentioned that the lack of supplies was more common during the early stages of the pandemic, when there were notorious problems of lack of PPE and drugs such as those necessary for the sedation of patients. Resilience practices that addressed these shortages included the replacement of the standard drugs by others with similar purpose and the development of new protocols for the sterilization and reuse of PPE such as face masks.

Interviewee #5 (hospital director) reported that lack of supplies was a particularly serious issue in public hospitals as these used to maintain low inventories due to scarce financial resources. The report as follows illustrates his viewpoint: "*I doubt that there is a healthcare setting that demands more resilience than a public hospital in which you work with very little financial slack…you need to live one day at a time"*.

In turn, the highest score related to this guideline (74.0) was obtained by statement (2), which was related to the dynamic management of material resources. The key dimension of this statement, across the micro, meso, and macro levels, was clearly related to the management of ICU capacity. The evolution of the pandemic, with highs and lows in the number of infected people, implied cycles of closing and opening ICU beds. At the micro and meso levels, common resilience practices involved the repurposing of facilities such as recovery rooms and the suspension of elective surgeries, which released not only material supplies but also staff. At the macro level, COVID hubs were created in some hospitals and patients with comorbidities (e.g., obesity) were directed to specialized hospitals. The two interviewed officials (#7 and #8) perceived that the public health system could effectively be managed as a network and make the best use of the overall capacity due to the centralized governance of the municipal bed management system, in contrast to the capacity management of private hospitals, which was fragmented.

Overall, the guideline on slack lies at the core of the pandemic response, which from the viewpoint of the provision of healthcare services might be framed as a race between capacity and demand. Both capacity and demand changed frequently over the course of the pandemic, which posed the challenge of capacity being always ahead of demand, which in turn rose significantly at short notice. For instance, in three weeks during February/March 2021, the number of ICU beds occupied by COVID patients in

the studied capital city rose from 282 to 866[6]. A substantial portion of this addition of beds was only possible through the improvisation of non-ICU beds and the opening of ICU beds without full-time intensive care physicians.

4.3 Diversity of perspectives in decision-making

Table 5 presents the results related to the guideline on diverse perspectives. There were 15 practices or conditions, being 8 at the micro, 5 at the meso, and 2 at the macro level. The scores obtained by statements (9) and (10) were clearly lower than those of statements (7) and (8). As for statement (9), concerned with the consideration of the opinions of patients and their next-of-kin, the relatively low score (56.1) reflects the condition of ICU patients, who have limitations in their ability to play an active role. Despite this, an example of consultation mentioned by three interviewees (#3, #4, and #6) refers to the decision of intubating patients, which is usually a last resort and associated with high mortality rates. Another factor that may have made the consultation of patients and their families difficult was the low number of ICUs that had a palliative care team – 13 out of 31. However, the formal existence of such a team is not exclusive to providing palliative care as highlighted by the following remark of interviewee #5: "*regardless of not having a palliative care team we follow the principles of palliative care when appropriate"*.

Table 5. Results for the guideline "diversity of perspectives in decision-making".

Statement	Survey (mean)	Number of excerpts	Resilience practices or conditions	Level
(7) Decision-making about the plan of care takes into account the impacts on other units of the hospital (e.g., implications of discharge for the wards, implications for the sectors that perform medical exams).	68.0	1	Caregivers in overcrowded emergency departments and primary care units need to make hard decisions on the priority patients to be sent to overcrowded ICUs	Macro
(8) Decision making about the plan of care is multidisciplinary	67.3	2	Frequent meetings between ICU management and leaders in order to build a shared understanding of the care protocols and prevent the spread of misinformation	Micro
			Interdisciplinary rounds at the bedside	Micro
			Palliative care team at the ICU	Micro
(9) Opinions of patients and family members are accounted for in healthcare decision-making.	56.1	6	Patient and family members are consulted for critical decisions such as whether or not resort to intubation	Micro
			Patients are given the opportunity to make video calls to family	Micro

[6] https://infografico-covid.procempa.com.br/

(10) Interventions to improve ICU management and patient care protocols are developed by multi-professional teams and, if relevant, involving representatives from other units of the hospital.	52.6	5	Participation of representatives from several professional categories in the design of the clinical pathway of COVID patients	Micro
			Daily meetings between ICU management and staff in charge of managing supplies	Micro
			Weekly meeting involving the municipal department of health and hospital representatives in order to discuss the status of bed occupancy and the need for resources	Macro
Others		6	ICU management committee requested opinions from hospital units when necessary	Meso
			Hospital top management frequently present at the front-line, listening to the opinions of caregivers and showing that they can trust them for support	Meso
			Open environment and good communication between professionals from different specialties	Micro
			Counselling services to ICU staff	Meso
			Rotation of some employees across COVID and non-COVID areas in order to reduce the stress of those primarily allocated to COVID areas	Meso
			Quick setup of training program for new hires, using both on-site and distance learning	Meso
	Overall mean: 61.0	20 in total		

On the other hand, the fairly high score of statement (8), which was concerned with multidisciplinary decision-making for the plan of care (67.3), might have benefited from the existence of daily interdisciplinary rounds in 28 out of the 33 ICUs. The importance of statement (8) was acknowledged by interviewee #5: "*it is unacceptable an ICU physician who does not know that a (e.g.,) physiotherapist is as important as any other professional"*.

Despite this recognition, the score obtained by statement (10) suggests that diverse perspectives are considered less when it comes to decisions related to the overall ICU management and development of care protocols (52.6). The novelty of COVID helps to explain why an expanded participatory decision-making process has been difficult during the pandemic. Interviewee #5 (hospital director) shed light on that difficulty when saying that "*everyone has an opinion, everybody turned into an expert overnight because of the information available on the media…and I need to make hard decisions amid all sorts of opinions…furthermore, caregivers did not easily accept working with substandard number of staff…it was very hard to be a manager during the pandemic because in addition to new problems, existing ones quickly came to the surface".* For similar reasons, interviewee #2 (chief-physician) remarked that, although there was a committee that canvassed the opinions of professionals, he would make the final decisions because he would be legally responsible for the outcomes.

Another dimension of the guideline on diverse perspectives is related to the individual reactions to the pandemic. According to interviewee #2, "*there was a wide variety of reactions of staff, some of them were desperate thinking that they would die…others did not take the situation as seriously as they should. I needed to reassure the staff every day that we were doing our best"*. This report acknowledges the importance of professional psychological support to staff - 12 out of the 33 ICUs had a dedicated psychologist - as well as to the role of leaders as moderators of the diverse perspectives.

Threats to the consideration of diverse perspectives were also identified from the qualitative data. One of these stemmed from the large number of inexperienced professionals hired to cope with the surge in demand. According to interviewee #3 (chief nurse) "*although nurse technicians attended a 2-week induction training, it was not uncommon that they were unable to perform simple procedures…furthermore, they were very insecure and frightened, asking for our help quite often; this took our time".* Interviewee #2 (nurse) made a similar remark: *"many professionals were on their first job, no experience with critically ill patients, and of course no experience with COVID…then you can imagine, it was chaotic, terrible…experienced professionals* (who worked in these areas full of new employees) *did not want to return after seeing the chaos".* These reports indicate a downside of diverse perspectives; namely, when there is a wide knowledge gap between team members the benefits of the exchange of opinions and information is mostly unidirectional, from the most to the least competent people.

4.4 Visibility of processes and outcomes

Table 6 presents the results for the guideline on the visibility of processes and outcomes. There were 14 practices or conditions, being 12 at the micro, 1 at the meso, and 1 at the macro level. The prominence of the micro level reflects the operational character of most visibility practices, which are directly targeted at the ICU staff. The two highest scoring statements of the whole questionnaire were related to this guideline. Statement (13) scored 89.2, which suggests that accessibility to information about the treatment and condition of each patient was not seriously compromised by the high number of patients. Similarly, workplaces remained clean and tidy in general as indicated by statement (11), which scored 80.5. These positive results might reflect practices that were solidly implemented in most ICUs before the pandemic (e.g., electronic medical

records and housekeeping) and that resisted the scenario of scarce resources, suggesting evidence of organizational resilience. In addition, 21 out of the 33 ICUs had some form of national or international accredited quality and safety management system; six hospitals had achieved Joint Commission accreditation. Thus, practices associated with housekeeping were probably in place partly due to accreditation requirements.

The low cost and ease of use of some practices related to visibility might also explain their use. Interviewee #9 (physiotherapist) illustrated this point when commenting on the whiteboard displaying information on the patient health condition: "*it is a reliable means of communication…let's say that a nurse has just arrived to start their shift, they can have a look at the board and then they know what to do, they know whether the patient had any obstruction, if they have secretion, and so on".*

Table 6. Results for the guideline "visibility of processes and outcomes".

Statement	Survey (mean)	Number of excerpts	Resilience practices or conditions	Level
(11) Workplaces are clean and tidy, without unnecessary items such as used syringes, empty medicine bottles, used gloves, among others.	80.5	4	Housekeeping practices	Micro
			Dedicated teams for cleaning beds	Micro
(12) The results of performance indicators (e.g. occupancy rate, mortality rate, etc.) are widely disseminated, through means such as posters, electronic panels, whiteboards, brochures, meetings.	51.0	4	Boards and monitors in circulation areas spaces with results of indicators	Micro
			Computerized system for recording and supporting the analysis of a number of metrics associated with the pandemic evolution at the city level	Macro
(13) Information about the treatment and condition of each patient (e.g., exams, vital signs, medical records, prescriptions, care plan) are easily accessed by caregivers.	89.2	7	User-friendly electronic charts	Micro
			ICU layout that facilitates visualization of all beds from the nursing station	Micro
			Use of digital technologies for the remote monitoring of vital signs of patients – e.g., charts directly connected with monitors of vital signs can be updated with little delay	Micro
			Whiteboard that displays handwritten information on the health condition and acuity of each patient – it is filled out by physicians, physiotherapists and other professionals	Micro
			Visual devices at the bedside in order to identify patients under mechanical ventilation	Micro
(14) Real-time information on the ICU status as a whole (e.g., number of hospitalized patients, number of patients waiting for beds, professionals on duty) is easily accessed by caregivers.	63.0	7	WhatsApp groups for the exchange of information between caregivers. These groups are usually divided by professional category.	Micro
			Web cameras for tele-monitoring patients beds	Micro
			Updated information on the ICU status available at the hospital intranet	Micro
Others		5	FM/AM radio brought by nurses to the ICU. It plays music and news to patients who accept this offer.	Micro
			Separate and signalled flows for COVID-19 patients since the hospital reception	Meso
	Overall mean: 70.9	27 in total		

On the other hand, statement (12) had a fairly low score (51.0) suggesting that the results of performance indicators related to the overall ICU performance are not effectively disseminated. It is possible that this type of information, if available, is accessible mostly to managers. This is a drawback for resilience as the ability of the front-line professionals to anticipate threats and opportunities is hindered. Also, the rationale of decisions made by leaders may be unclear to other professionals as they do not have the whole picture of the ICU performance.

The role of digital technologies for the implementation of this guideline is also worth highlighting. In particular, despite the utility of electronic dashboards for displaying performance indicators, a drawback came to light during the observations of the meetings of the municipal bed management committee. Amid contrasting views regarding the extent of the mobility restrictions to be applied, some committee participants who were in daily contact with the front-line of care felt that some of the top health officials did not fully grasp the extent of the dramatic situation experienced at the front – one of the meeting participants reported that it was necessary "*to see with their own eyes*" in addition to looking at the dashboards that guided the meetings.

4.5 Monitoring and understanding work-as-done

Table 7 presents the results for the guideline on work-as-done. There were 11 practices or conditions, all of them related to the micro level. This makes sense as the work-as-done of interest to this study occurred within the ICU premises. Statement (17) obtained the highest score (67.1), which may reflect the use of voluntary incident reporting systems as a relatively common practice in healthcare services. However, we did not investigate the extent to which these systems remained effective during the pandemic. Although caregivers had less time to make reports, the higher number of patients and the scarcity of supplies may have implied a rise in the number of reporting opportunities.

Table 7. Results for the guideline "monitoring and understanding work-as-done".

Statements	Survey (mean)	Number of excerpts	Resilience practices or conditions that support the monitoring and understanding work-as-done	Level
(15) Professionals know when, why, and how to adapt or fill in gaps in standardized operating procedures	52.7	2	Training of newly hired professionals	Micro
(16) There are routines to check reality against what is prescribed in care plans, protocols, and policies. Examples of possible routines: quality audits, meetings to compare expected versus actual performance.	53.4	3	Audits	Micro
			Daily meetings of staff	Micro
(17) There are systems for voluntary reporting of incidents, abnormalities, or other relevant situations, such as unprofessional behaviour of co-workers.	67.1	4	Anonymous reporting system that electronically sends the report directly to the supervisor of the worker observed in an unsafe behaviour/condition	Micro
(18) There are routines to learn from what goes well or from normal everyday variability. Possible examples: short meetings at the end of the working day (i.e. after action reviews), reporting systems for the dissemination of good practices.	44.5	6	Learning from experience on what works or not as the pandemic evolves and experience accumulates	Micro
			Constant monitoring of changes in the profile of patients, which changed during the pandemic	Micro
			Realistic simulation	Micro
(19) Changes in ICU management and patient care protocols are preceded by a study of how work actually occurs in practice, knowing its variability, constraints, and difficulties.	46.2			
Others		5	Training and simulation of donning and doffing PPE	Micro
			Active search for patients with multi-resistant germs (in order to cope with an outbreak) and daily dissemination of results to teams	Micro
			Physiotherapy team provides theoretical and practical training to the nursing team in clinical procedures	Micro
			Revision of existing protocols, making them closer to work-as-done	Micro
	Overall mean: 52.8	20 in total		

By contrast, statement (18), concerned with learning from what goes well and normal everyday variability, had the second lowest score (44.5) of the whole questionnaire. This is unsurprising as healthcare services are known for their reactive safety management approach, which focuses on learning from failure (Braithwaite et al., 2020). Furthermore, this drawback is possibly part of a broader lack of emphasis on understanding work-as-done as indicated by the low score of statement (19) – 46.2, which is concerned with studying work-as-done before making changes in management and care protocols.

However, statements (18) and (19) are limiting to some extent as they refer to "routines" and "study", which convey a structured learning approach. In fact, the pandemic has certainly been a period in which caregivers have learned from what goes well, particularly in terms of clinical practice – e.g., not rush to intubate patients and use prone positioning. Interviewee #2 (nurse) exemplified this point when saying that *"nowadays we recommend that patients hospitalized in the wards self-prone, that is, that they sleep lying on their stomach in order to improve ventilation".* Interviewee #9 (physiotherapist) provided another learning example related to prone positioning: according to her, the time taken to prone a patient reduced from 40 to 15 minutes during the pandemic.

In turn, the low score obtained by statement (15) – 52.7, suggests that the gap between work-as-imagined and work-as-done may have grown wider during the pandemic. This is hypothesized to have occurred for reasons such as:

(i) The prolonged period working under restrictive rules, which tends to produce fatigue. Interviewee #5 (hospital director) remarked that "*there is a limit to human resilience"* and that it was hard to convince the staff that "*we would continue working under restrictions and strict procedures for a long time";* and

(ii) Lack of knowledge and doubts of professionals regarding the clarity and applicability of the new work-as-imagined. For example, interviewee #1 (physician) reported that, despite protocols that established separate pathways for COVID patients, there were doubts because sometimes the patient did not know whether they were infected.

4.6 Monitoring and understanding unintended consequences

Table 8 presents the results for the guideline on unintended consequences. Eight examples of unintended consequences were identified: 3 at the micro, 1 at the meso, and 4 at the macro level. The survey scores were in general low and the overall mean was the lowest (45.4) among the five guidelines. To some extent, these low scores reflect the difficulties of the pandemic period, in which overloaded professionals had little time for the analysis of barriers and risks of changes (statement 21, score 46.1) as well as for collecting data on performance indicators (statements 22, score 46.8 and 23, score 44.5). In turn, the low score of statement (20) – 44.1 – is particularly worrying as rapid cycles of small-scale experimentation would be even more relevant in face of changing

pandemic demands. These survey results further justify the different coding approach for the qualitative data related to this guideline (see section 3.3) as we could not identify resilience practices or conditions that supported the guideline implementation. Table 8 presents unintended consequences that mostly arise from the use of the other guidelines.

Table 8. Results for the guideline "monitoring and understanding unintended consequences".

Quantitative findings: Statement		**Mean**
(20) Changes in ICU management and patient care protocols are made firstly on a small scale and rapid cycles, before large-scale implementation.		44.1
(21) As part of planning changes in ICU management and patient care protocols, there is a formal analysis of barriers and risks.		46.1
(22) When there are changes in ICU management and patient care protocols, multiple performance indicators are gathered for assessing the outcomes, contributing to the identification of unintended consequences.		46.8
(23) When there are changes in ICU management and patient care protocols, the outcomes are monitored over the medium (months) and long term (years), rather than just in the immediate post-intervention period.		44.5
Overall mean		**45.4**
Qualitative findings: examples of unintended consequences	**Level**	**N. of excerpts**
Fatigue from chronic high workload and prolonged period of vigilance and discipline for complying with new procedures	Micro	5
Frustration and anxiety of caregivers as they are unable to provide care to all those who need it, having to prioritize certain patients	Micro	2
Facilities transformed into ICUs posed constraints that could not be overcome – e.g., L-shaped room that hindered visibility, lack of space for the installation of utilities, little space in-between beds	Meso	3
Patient companions at the ICU were not collaborative with caregivers – e.g., giving unauthorized food to the patient	Micro	1
Patients resist to seek for emergency services and medical care as they fear being infected – this further deteriorates their health condition	Macro	2
Staggered times for using the staff room and discouragement of gatherings could hinder informal social interactions that could be useful for resilient performance	Micro	1
Extra ICU capacity, facilities and workforce after the end of the pandemic – this is a positive potential unintended consequence	Macro	2
Backlog of patients with untreated diseases due to suspended elective procedures	Macro	3
Patients transferred from other states could spread new variants of the virus	Macro	1
Total		20

Unintended consequences were frequently a result of using the guideline "provide slack resources". This makes sense as the addition of slack changes the nature of the interactions between the system elements (Perrow, 1984). For instance, interviewee #2 (nurse) reflected on the unintended consequences of staggered times for using the ICU staff room: while it prevented gatherings, and therefore created slack, it hindered informal social interactions between caregivers, which could be useful for resilience.

In addition, there were unintended consequences stemming from the adaptation of facilities to provide slack. In order to increase capacity, ICU beds were created in areas not originally designed for that purpose. Therefore, there were practical constraints to the adaptation of the buildings. Interviewee #1 (physician) offered an example of this situation: *"in those areas not designed for ICUs, the work organization is much more*

difficult…the space to do the daily activities is more restricted…it was possible to provide care, but it was certainly worse". A similar point was made by interviewee #2 (nurse): *"the ICU format is not straight, it is an 'L'…some beds are distant and not visible from the nursing station….how are we going to see these patients on the other side?"*

Slack also implied unintended consequences when resources were transferred from one part of the system to another. This is exemplified by the suspension of elective surgeries and outpatient consultations during the most critical moments of the pandemic; this freed up staff and facilities to treat COVID patients. Interviewees #7 and #8 (public health officials) stressed that the health condition of many non-COVID patients deteriorated due to the postponement of clinical care, which led to a demand surge after the regular procedures were reinstated, adding to the high workload from COVID patients. Overall, it seems that the observed unintended consequences were not necessarily unexpected but accepted as a price to be paid for short-term goals. Decision-makers either implicitly or explicitly opted for the course of action judged as most effective and morally acceptable in face of the circumstances.

5. Discussion

5.1 What resilience looks like in ICUs during the pandemic

Using the five complexity guidelines as an analytical framework, this study shed light on what resilience looks like in ICUs during the pandemic. Although 70 resilience practices or conditions were identified, several of these are clearly not applicable to every day complexity (e.g., addition of several new beds at short notice). These results reinforce the need for understanding what resilience looks like in a pandemic as the corresponding adaptive strategies differ even when compared to other types of disasters - e.g., contagion by infectious diseases is not such a serious concern when coping victims from mass casualty accidents.

Nine unintended consequences also surfaced, meaning that the resilience practices were at best approximate adjustments (Hollnagel, 2012) due to the high interconnectivity and trade-offs that characterize healthcare services (Braithwaite et al., 2020). Figure 2 presents the total number of practices, conditions, and unintended consequences according to the micro/meso/macro levels and the corresponding guidelines. Although the data in Figure 2 is obviously not generalizable, it is presented as an illustration of the

potential utility of this type of analysis in larger datasets, provided any patterns are identified from them – e.g., slack resources are more likely to be found in other hospital units (i.e., meso).

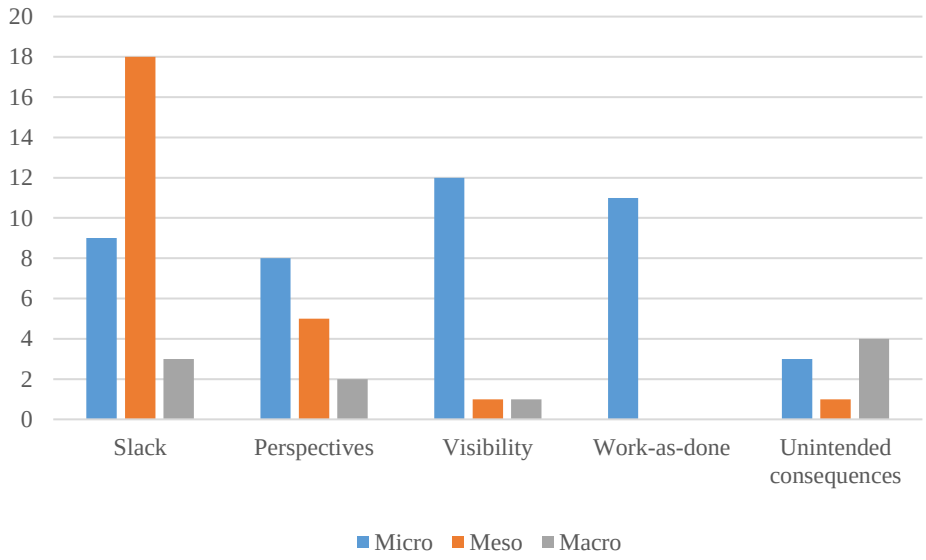

Figure 2. Number of practices, conditions, and unintended consequences according to the complexity guidelines.

Some of the unintended consequences played out at the macro level as a result of practices deployed at the micro and meso levels. Similarly, some practices adopted at the macro level certainly influenced the two other levels. This makes clear that the performance of the three levels is intertwined and the isolated optimization of any of them is likely to be ineffective in the long-term, which is consistent with the proposal of Berg et al. (2018).

However, despite all efforts of people and systems, results (and knowledge publicly available on the pandemic) suggest that distinctive features of ICU resilience during the pandemic were that it was not enough to support desirable performance and that running out of resilience was part of everyday work during a prolonged period. These features are not self-evident in earlier descriptions of resilience that mostly focus on everyday work under “normal” times and more or less acute and short-lived crises (Patriarca et al., 2018).

As for the concept of running out of resilience, it was evidenced by: *(i)* the lack of effective treatments and the consequent high mortality rates compromised the production of the required outputs (i.e., healed patients), which is a key dimension of resilience (Hollnagel et al., 2013); *(ii)* healthcare professionals who could not cope with the stressful working conditions – Azoulay et al. (2020) reinforce this point as they found that the pandemic had an overwhelming psychological impact on intensivists, who experienced distress due to sub-optimal decision making and provision of substandard care; and *(iii)* mismatches between capacity and demand, which highlighted the finite nature of slack resources – this point had also been noted by Anderson et al. (2016) as a key for resilient healthcare. Certainly, resilience was insufficient rather than non-existent. Indeed, if resilience was completely absent the ICUs would cease to provide services, which did not occur. This conclusion is supported by the survey results which indicated a fairly high agreement level (65.3) with the following statement: "this ICU is a resilient system, that is, it adapts and achieves the expected results despite adverse and unanticipated conditions".

Thus, the concept of running out of resilience can be framed as instantiations that play out in the form of unwanted events such as an adverse event or a professional that resigns. Furthermore, resilience in disasters such as the pandemic tends to degrade slowly (Woods, 2015) as margins get smaller and smaller over the course of hours, days and weeks, rather than following a step function. This proposition is supported by the model of critical care surge capacity planning proposed by Hicks et al. (2014), which poses pandemics at the extreme of operating conditions, requiring ICUs to expand at least three times (200%) their usual capacity for a prolonged period.

The reliance of healthcare services on human performance, which is arguably more adaptive than technological artefacts, is likely to be a reason for the graceful degradation during the pandemic. A more general implication of this insight is that, similarly to what occurs with technical infrastructures (e.g., Dunn et al., 2018 on electricity networks, and Zobel and Khansa, 2012, on cyberinfrastructures), there might be patterns of resilience curves for different sectors and disasters types. The identification of these patterns might guide the prioritization of resilient strategies (e.g., slow degradation offers more opportunities for learning while the events are still unfolding,

while brittle step functions call for pre-planned responses) as well as the identification of benchmarks for intra and inter-sector learning.

5.2 Lessons learned in light of the complexity guidelines

The prominent role of the guideline on **slack** resources was clearly related to the mismatch between ICU capacity and demand. Both the quantitative and the qualitative data showed that qualified caregivers were the key slack resource as it was harder to obtain in comparison to other resources. ICU staffing shortages have also been a major problem in the US during the pandemic, in which contingency plans include the use of ICU telemedicine (Harris et al., 2020). Furthermore, slack resources were commonly found beyond the ICU boundaries such as staff from other hospital units and beds in other hospitals. In fact, the pandemic led to the creation of units and teams practicing intermediary assistance between ICU and non-ICU wards – e.g., in non-ICU wards dedicated to the care of COVID patients, non-invasive ventilation devices and high-flow nasal catheters have been used in an unprecedented way (interviewee # 1). This situation corresponds to the concept of "ICU without walls", which is based on two premises: *(i)* the collaboration of all staff involved in patient care during hospitalization; and *(ii)* technological support for the early detection of patients at risk of deterioration throughout the hospital, based on the assessment of vital signs and/or laboratory test values (Gordo and Abella, 2014).

Thus, the guideline on slack deals with a tangible dimension of complexity management that involves decision-making on the right amount and mix of resources (Spearman and Hopp, 2020). Despite this, our critical realist standpoint (Archer et al., 1998) means that the observer's perspective matters – e.g., although ICU beds in a certain geographical area are not regarded as slack resources for ICUs from distant regions in the view of individual hospital directors, they might be seen as such by public health officials. This example indicates that any resource can play a role as slack depending on the circumstances. Additionally, slack can be either designed (i.e., a resource is planned ahead of time to cope with predefined variabilities) or opportunistic (i.e., a resource plays a role as slack even though that was not their original purpose) (Saurin and Werle, 2017). This backdrop sets the stage for the following lesson learned:

Lessons learned related to slack: capacity addition to healthcare services such as ICUs must encompass a wide mix of designed and opportunistic slack resources, which are likely to be out of the boundaries of the service focused on. Caregivers are likely to be the major slack resource as they enable the use of other resources and cannot be easily made available at short notice with the required competence level.

Regarding the guideline on **diverse perspectives**, it best represents the constructivist side of the adopted philosophical view of complexity. Both the advantages and disadvantages of diverse perspectives were probably amplified during the pandemic (Saurin, 2021) as the disease was new and there were many stakeholders (e.g., healthcare providers and firms) with partly conflicting objectives. On the one hand, the use of diverse perspectives was exemplified by the use of creativity to problem-solving and multidisciplinary care not only to patients but also to providers (e.g., counselling services and closer support from leaders). On the other hand, drawbacks of diverse perspectives were highlighted such as the creation of new meetings for the exchange of information and the effort spent to fight the spread of misinformation originated from the external environment (e.g., unproven treatments) – these drawbacks can be interpreted as costs of collaborative work (Goorden et al., 2014). The analysis of this guideline also pointed to an apparent paradox in light of the law of requisite variety that applies to complex systems. This law states that a system can only be stable if the number of states of its control mechanisms is equal or greater than the number of possible states of the system (Ashby, 1991). The possible system states, in this case, might be represented by the profile of the patients, which were cared for in ICUs dedicated to a single disease (i.e., COVID). It is hypothesised that this relatively low variety of patient profiles demanded a disproportional variety in terms of medical viewpoints, tentative treatments, and support from other healthcare services. Thus, it seems that the law of requisite variety misses the novelty of the system state – i.e., if variety is low, but novelty is high, the control mechanisms must be both varied and novel. The lessons learned on this guideline are presented below.

Lessons learned related to diversity of perspectives: the benefits of diverse perspectives apply not only to patient care but also to the well-being and safety of providers. Furthermore, novel situations make the diversity of perspectives even more important, despite the possible low diversity of the process to be controlled. Also, a

portion of the coordination costs stemming from this guideline involves the resources spent to fight against perspectives that add unnecessary complexity.

In turn, the guideline on **visibility** took advantage of both digital technologies (e.g., WhatsApp groups) and work organization measures (e.g., housekeeping). However, the role of the former approach was not strongly emphasized by the interviewees, which is to some extent contrasting with the potential of digital technologies for supporting resilience. Borsci et al. (2018) argue that digital technologies might be an effective moderator of the trade-off between resilience and efficiency. Tortorella et al. (2021) carried out a survey with experts and concluded that the resilience of ICUs and emergency departments are the ones most likely to benefit from those technologies.

The statements related to the visibility guideline obtained the highest average overall score in the survey, which may be due to reasons such as: *(i)* the importance of visibility under conditions of high uncertainty (Beynon-Davies and Lederman, 2017) *(ii)* the invisible nature of the main hazard (i.e., the virus) which makes the visibility of proxy indicators (e.g., patient with symptoms, number of COVID tests) even more important than in normal times (Saurin, 2021); *(iii)* the pre-existence of solid visibility practices as a result of past improvement initiatives; and *(iv)* the large number of inexperienced employees, who can benefit even more from easy access to reliable information – although, it is possible that these employees were unable to fully exploit the available information. As a drawback, visibility can be a source of additional stress (Bernstein, 2017) to caregivers as they are aware of the deteriorating condition of patients and systems and can do little about it. Based on this context, the lessons learned on visibility are summarized below.

Lessons learned related to visibility: reliable, real-time, accessible, and easily interpretable information on the status of healthcare services are realistic goals during crises such as the pandemic. Digital technologies and quality and safety management systems help to make those goals achievable. By contrast, a large number of inexperienced professionals poses a barrier to the exploitation of the visibility benefits, while at the same time demanding visual management strategies tailored to their needs. Another barrier stems from the availability of information not translating into effective action-taking, which can be a source of frustration and discredit of visibility practices.

As for the guideline on **work-as-done**, the novelty, resource scarcity, and time pressure posed by the pandemic were catalysers for learning by doing (e.g., prone positioning and intubation timing). In fact, similar situations occur in other sectors such as in aviation (Carim Junior et al., 2016), even though the corresponding crises are acute rather than chronic. As a result, work-as-imagined was probably frozen in its pre-pandemic form while work-as-done evolved at a fast pace. This learning experience is likely to inform the design of more realistic standardized operating procedures and training programs post-pandemic. However, the high workload and insufficient staffing were hindrances for the full exploration of the learning possibilities. Indeed, slack of time is critical for reflection and learning (Lawson, 2001) – statement (3) was related to the said slack and had a low score (58.2). The lessons learned related to this guideline are summarized below.

Lessons learned related to work-as-done: learning by doing in face of resource scarcity and novelty such as in the pandemic is to some extent inevitable and desirable. However, systematic efforts for monitoring and learning from work-as-done might be even more important during crises, although that may require slack resources such as external consultants, staff from units not directly involved in the crisis, and spare time for reflection.

The guideline on **unintended consequences** shared commonalities with the guideline on work-as-done in terms of the low survey scores and implementation difficulties due to effort required for data collection and analysis. Despite these difficulties, major unintended consequences at the macro level stemming from the use of the other guidelines were certainly anticipated by policy-makers such as the creation of a backlog of patients with untreated diseases due to suspended elective procedures. In principle, awareness of these consequences would make it possible to mitigate their impacts when they played out.

On the other hand, there were more subtle unintended consequences at the micro level – e.g., lack of informal social interactions as a result of limits to gatherings in areas such as staff rooms; inadequacies in the built environment of areas where new ICUs were installed. The corresponding lessons learned are summarized below.

Lessons learned related to unintended consequences: similarly to the mitigation strategies deployed at the societal level (e.g., lockdowns), ICUs and hospitals also adopted simple measures in the sense of stopping activities such as elective surgeries, which drastically and quickly reduced complexity. Therefore, unintended consequences have a fractal nature (Song et al., 2006) as their nature was similar across scales – e.g., hospitals lost revenue due to cancelled surgeries similarly to businesses losing revenues due to lockdowns; caregivers suffered pandemic fatigue while there was an expected growth of mental illnesses in the population in general (Ornell et al., 2020). Public acknowledgment of this fractal nature could be explored as a means of fostering empathy in society and reducing the previously mentioned counterproductive perspectives of some agents. Furthermore, an active search for non-obvious unintended consequences stands out as another learning opportunity. That search benefits from the imagination of the work system designers and risk analysts (Adamski and Westrum, 2003), particularly in all decisions that involve the provision of slack resources. Slack has a disruptive potential by adding new elements (e.g., beds), reallocating elements (e.g., staff) or separating existing elements (e.g., social distancing). As a consequence, slack amplifies the potential for unintended consequences (Perrow, 1984).

6. CONCLUSIONS

This study offers an exploratory investigation of what resilience in ICUs looks like during the COVID pandemic in Brazil and presents lessons in light of guidelines for coping with complexity. As for the nature of resilience, this paper introduced the concept of running out of resilience, which describes how a socio-technical system can work in a crisis-mode, producing substandard outcomes, for a prolonged period. The chronic mismatch between capacity and demand lies at the heart of running out of resilience. In the pandemic, dealing with that mismatch clearly requires societal resilience, which means that the ICU resilience is dependent on the resilience of the society at local, national, and international levels.

The characterization of resilience set a basis for five lessons learned, each corresponding to one of the complexity guidelines. These lessons contribute to the better understanding of the guidelines, which can support their assessment and implementation in contexts other than the pandemic.

Two practical implications of this study can be highlighted: *(i)* the development of a list of 70 resilience practices, which can be used as a source of ideas not only for ICUs but also for other healthcare services; and *(ii)* the survey questionnaire, which is a potential new resilience assessment tool that can be applied both in individual ICUs aiming at continuous improvement and in large samples of ICUs aiming at the identification of trends and benchmarks.

Limitations of this study must be mentioned. First, the complexity of the pandemic and its evolving nature make it impossible to fully capture its resilience manifestations even when restricted to ICUs. This limitation was compounded by the impossibility, for safety reasons, of conducting observations of work-as-done within the ICUs premises. Second, there was also a limitation to the Brazilian context and the sample size of the survey was small. These drawbacks were counterbalanced by the mixed-method research design and data gathering while events were still occurring, which provided authentic findings. Third, there was no quantitative evaluation of the correlation between the scores obtained in the survey and the quality and safety outcomes of the ICUs. Fourth, there are other relevant theoretical lens for exploring the human factors implications of the pandemic on healthcare services, in addition to the complexity guidelines – for example, system thinking based frameworks (e.g., system dynamics, functional resonance analysis method) and naturalistic decision-making could be useful.

There are opportunities for future studies resulting from this work, such as: *(i)* similar investigations of how other healthcare services, such as emergency departments and primary care, coped with complexity during the pandemic; *(ii)* the use of the questionnaire as a tool to be applied on a regular basis, in order to support the identification of general trends, benchmarks, and cross-country comparisons; *(iii)* the gathering of data on the ICUs safety and quality outcomes during the pandemic, in order to assess correlations with the uptake of the guidelines; *(iv)* the development of an open access computational platform for the voluntary upload of resilience practices from around the world; *(v)* a deeper study of the role of specific resilience practices during the pandemic, such as those related to bed management; (*vi)* the analysis of the pandemic from other relevant human factors lens; and *(vii)* the development of frameworks for assessing and influencing the resilience of healthcare services in light of societal resilience.

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5. CONCLUSÕES

5.1 Atingimento dos objetivos propostos

O objetivo principal dessa tese foi identificar e classificar práticas para lidar com a complexidade em UTI Adulta, em situações normais e de crise. Considerando apenas os artigos 1 e 3, focados respectivamente em intervenções de melhoria de processos em situações normais e na pandemia de COVID-19, 110 práticas foram identificadas (40 no artigo 1 e 70 no artigo 3). Essas práticas podem servir como fonte de ideias para gestores de UTIs que enfrentem situações similares às relatadas nos artigos. As práticas ligadas ao provimento de folgas tiveram papel preponderante em ambos os artigos, indicando que a gestão da complexidade em UTIs segue princípios similares em situações normais e situações de crise, no que diz respeito à necessidade de haver recursos extra bem como quanto à necessidade de rápida reconfiguração does recursos existentes. De outro lado, os resultados não apontaram uma incidência alta de consequências não planejadas, as quais seriam esperadas visto que a adição de recursos folga pode implicar em aumento de complexidade. Possíveis razões para a falta de equivalência entre o uso de recursos folga e o registro de consequências não desejadas podem envolver: (i) a natureza de muitas folgas, especialmente aquelas ligadas a melhorias de processos, que implicam em liberação de recursos (por exemplo, espaço, pessoal) sem adição de recursos extra; (ii) a falta de avaliações de médio e longo prazo acerca dos efeitos da introdução dos recursos folga.

Por sua vez, os três objetivos específicos foram os seguintes: (i) identificar o quanto os projetos de melhoria de processos nas Unidades de Terapia Intensiva adulta, relatados na literatura, estão alinhados às diretrizes de gestão de complexidade em SSTC; (ii) propor uma abordagem para investigação de eventos com resultados desejados em SSTC, a qual inclua a análise do papel das diretrizes de gestão de SSTC; (iii) identificar e classificar as práticas de resiliência organizacional em UTIs adultas brasileiras durante a pandemia de COVID-19, bem como lições aprendidas sob a perspectiva das diretrizes de gestão de complexidade.

Para atender ao primeiro objetivo específico, realizou-se uma revisão sistemática detalhando as diretrizes de complexidade propostas por Saurin et al., (2013) porém, em ambientes de cuidados aos pacientes. Para elaboração deste artigo foi importante a utilização do PRISMA, uma metodologia capaz de auxiliar na organização e construção da revisão. Essa revisão após a aplicação do PRISMA obteve 91 artigos e todos estes artigos foram realizados rounds de análises para cada artigo e cada pesquisador teve de ponderar a utilização das diretrizes para cada artigo encontrado. Este primeiro material da tese foi importante para compreensão da sistematização dessas diretrizes em ambientes de unidades de terapia intensiva adulta. Foi neste contexto que os resultados encontrados neste primeiro artigo apresentam consistências à resiliência no qual está teoricamente ligada às diretrizes e, portanto, pode ter sido intuitivamente adotada pelas intervenções em alguma medida. Como principais resultados encontrados em respostas as questões do artigo, conclui-se que as diretrizes foram consideradas totalmente aplicáveis e intuitivamente, ao invés de explicitamente adotado pelas intervenções. As diretrizes referentes ao trabalho imaginado e às consequências não intencionais foram as mais difíceis de serem identificadas nos artigos, pois as mesmas tinham uma natureza mais abstrata. Dessa forma, essas duas diretrizes podem possivelmente ser enquadrados como meta-diretrizes, no sentido de que permeiam as outras três diretrizes abordadas no primeiro artigo. Outro resultado encontrado no artigo um, demonstrou que a resiliência pode ser conectada as cinco diretrizes instintivamente pelas intervenções adotadas em cada umas delas.

Para o envolvimento do segundo objetivo específico da tese se deu com a utilização do *Funcional Resonance Analisys Method* (FRAM) em ambientes complexos de UTIs adulta e a utilização das diretrizes de Saurin et al., (2013). Este artigo aborda lacunas quanto a novos procedimentos para desenvolvimento de modelos FRAM no contexto do safety II em casos que ocorreram em ambientes da UTI’s com desfechos positivos. O estudo realizado com base em casos de sucessos pode resultar em situações em que os profissionais antes não ponderavam de forma significativa conforme apontado na proposição do artigo dois que é a utilização destes casos de sucesso em reuniões com a equipe envolvida no desfecho do mesmo. Essa utilização se prevaleceu no intuito de buscar enxergar a resiliência das ações nestes ambientes complexos e tentar descobrir

como estas mesmas resiliências podem afetar de tal maneira que o desfecho pode ser positivo ou negativo em diversos casos por meio da inserção das diretrizes propostas por Saurin et al., (2013). Para tanto, este estudo é considerado como estudo de caso em uma unidade de terapia intensiva adulta onde foram realizadas observações *in loco*, observações não participativas, aplicações de roteiros, questionários e entrevistas com profissionais envolvidos na UTI para compreender as lacunas da resiliência sobre estes ambientes.

De acordo com o terceiro objetivo específico da tese, o artigo três foi composto pela construção de uma análise exploratória para compreender as situações de UTI's do Brasil quanto ao enfrentamento da complexidade na pandemia. As abordagens utilizadas são de métodos mistos, onde se busca compreender as diretrizes propostas por Saurin et al., (2013). A contribuição dessas análises práticas resilientes se deu a nível micro, meso e macro identificados de acordo com as diretrizes propostas no estudo. Como resultados destes níveis, algumas das consequências indesejadas ocorreram no nível macro como resultado de práticas implantadas nos níveis micro e meso. Da mesma forma, algumas práticas adotadas no nível macro certamente influenciaram os outros dois níveis. Isso deixa claro que o desempenho dos três níveis está interligado e a otimização isolada de qualquer um deles tende a ser ineficaz em longo prazo, o que é consistente com a proposta de Berg et al. (2018).

O cenário que a pandemia originou conforme o estudo em questão é considerado de muita resiliência. Para isso o artigo também discute o esgotamento dessa resiliência e informação bem como as lições aprendidas à luz das diretrizes de complexidade.

5.2 Limitações

No primeiro artigo as limitações de espaço impostas pelos periódicos científicos podem ter mascarado a real extensão em que as diretrizes foram seguidas pelas intervenções. Também é possível que informações importantes relacionadas às diretrizes estivessem faltando nos documentos simplesmente porque o foco do estudo estava em outro lugar. Em segundo lugar, o efeito do nível de adoção das diretrizes sobre os resultados das intervenções não foi avaliado.

Para as limitações do artigo dois, destaca-se que nem todos os profissionais diretamente no estudo foram entrevistados; não houve uma análise sobre os possíveis eventos adversos da UTI's e a proposta do artigo não foi aplicada para cenários futuros, apenas para análise envolvendo eventos passados. Outra limitação a ser considerada foi o tempo necessário para a coleta das informações, como os profissionais desejados tinham pouco tempo a dispor refletiu também na busca por novos casos para que o artigo pudesse ser finalizado.

Quanto as principais limitações para o artigo três, podem ser destacadas como o efeito da complexidade na pandemia, COVID-19 e sua natureza evolutiva que tornaram impossível capturar totalmente suas manifestações de resiliência, mesmo quando restrito a UTIs; O tamanho da amostra foi pequeno para pode realizar avaliações mais robustas sobre as UTI's assim como não houve avaliação quantitativa da correlação entre os escores obtidos na pesquisa e os resultados de qualidade e segurança das UTIs.

5.3 Pesquisas futuras

Em decorrência do artigo 1, as sugestões de pesquisas futuras envolvem testar o nível de adoção das diretrizes como indicador antecedente de resiliência na área da saúde. Isso deve ser precedido do desenvolvimento de um sistema de medição das diretrizes, que poderá tomar a proposta do artigo 1 como ponto de partida.

A partir do artigo 2, uma possibilidade de pesquisas futuras envolve a investigação de eventos com desfecho positivo por meio de outras ferramentas que não as entrevistas do CDM.

Por fim, a partir do artigo 3, sugere-se o uso do questionário como uma ferramenta a ser aplicada regularmente com o intuito de apoiar a identificação de tendências gerais, benchmarks e comparações entre países bem como um estudo mais aprofundado do papel de práticas específicas de resiliência durante a pandemia, como aquelas relacionadas ao gerenciamento de leitos.

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APPENDIX 2.1. Processes focused on by the interventions

Studied process	Frequency
Direct patient care	
Drug prescription and administration	9
Protocols of care: central line-associated blood stream infections	7
Palliative care	6
Patient nocturnal sleep and relaxation	4
Protocols of care: weaning, pain and delirium monitoring	3
Rehabilitation of mechanically ventilated patients	3
Protocols of care: sedation assessment and management	3
Protocols of care: ventilator-associated pneumonia	2
Protocols of care: septic shock	2
Protocols of care: glycaemic control	1
Protocols of care: unplanned extubation	1
Chest radiographs	1
Tracheostomy management	1
Management of postoperative atrial fibrillation	1
Enteral nutrition	1
Mobilisation of patients	1
Total	**46**
Support processes	**Frequency**
Safety management and safety reporting systems	8
Patient transportation from ICU to other areas (e.g. operating room, radiology, wards)	7
Care planning and controlling	7
Ward rounds	6
Family-centred care and family visits	5
Handover of patient information	4
Telemedicine	4
Process of training and teaching	4
Inter-facility patient transfers	3

Bed management	3
Patient discharge from ICU to non-critical care wards	1
Hand hygiene	1
Readmission avoidance	1
Total	**54**

Source: Authors.

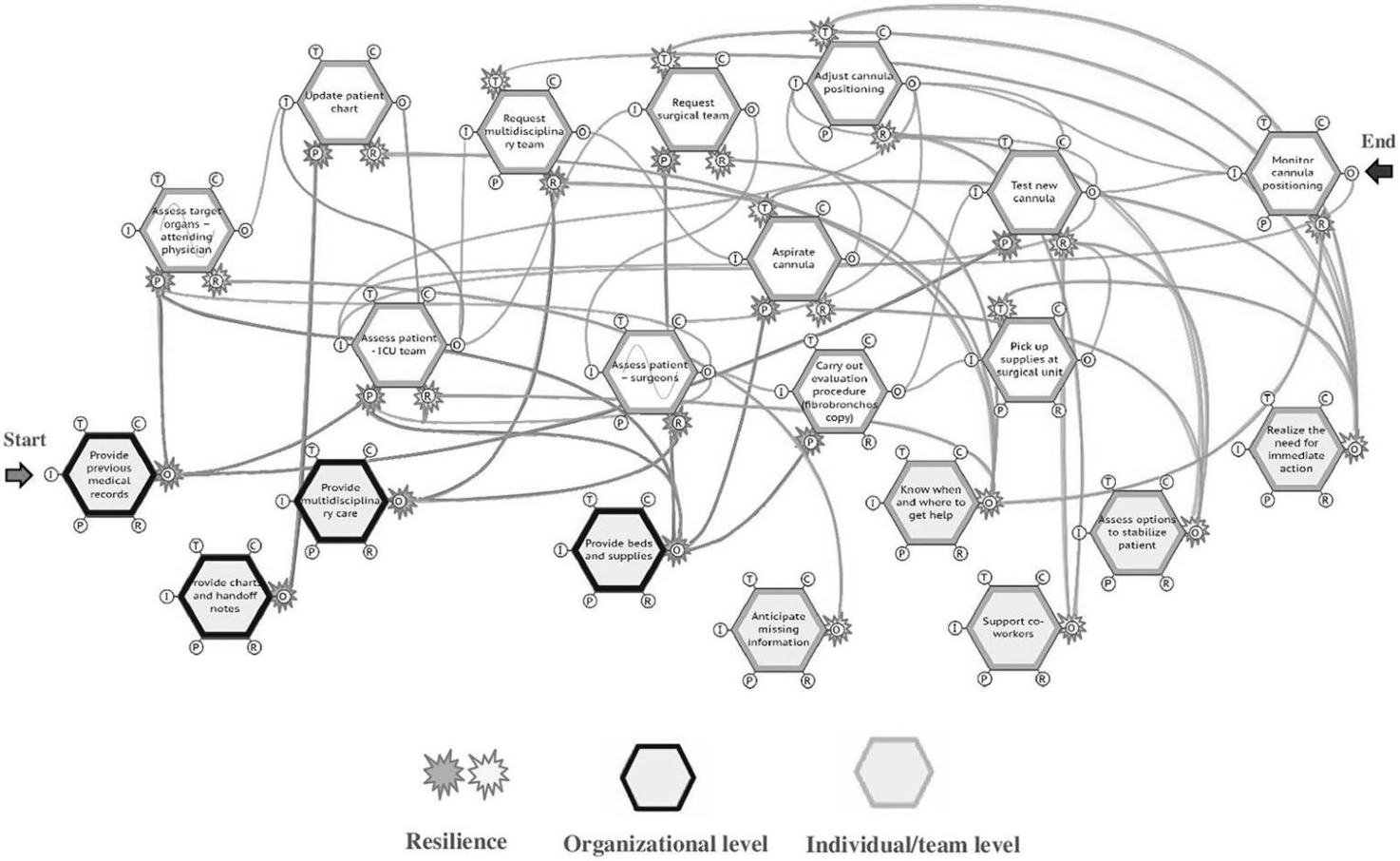
APPENDIX 2.2. Intervention practices

Intervention practices	Frequency
Checklists, documentation, policies, and standardization of protocols of care, rounds, and handovers	40
Training and education	23
Reminders and alerts: posting of expected activities and outcomes; real-time automatic trigger alerts associated with laboratory abnormalities to identify Drug-Related-Hazardous-Conditions; alerts included in the electronic health information systems	18
Rapid-cycle testing; PDCA cycle	10
Safety reporting systems	8
Participatory action research and change management models	5
KPI indicators, performance measurement, and performance feedback	4
Six Sigma, DMAIC	3
Process surveillance	3
Supplies availability	3
Elimination or reduction of redundant and non-adding value steps in the transportation of patients from ICU to other areas	3
Accountability without assigning blame	3
Consensus building and clinical communities: different ICUs from different hospitals working towards common goals	3
Active support from leadership, administrative support	2
Process mapping	2
FRAM	1
Fishbone diagram	1
FMEA	1
Creation of facility-specific path to achieve outcomes	1
Decrease the hierarchical power differences between physicians and nurses	1
Extended visitation in ICU	1
Sedating music	1
Eyes masks and ear plugs for facilitating sleep	1
Analysis of ICU demand profile	1
Palliative care consultation	1

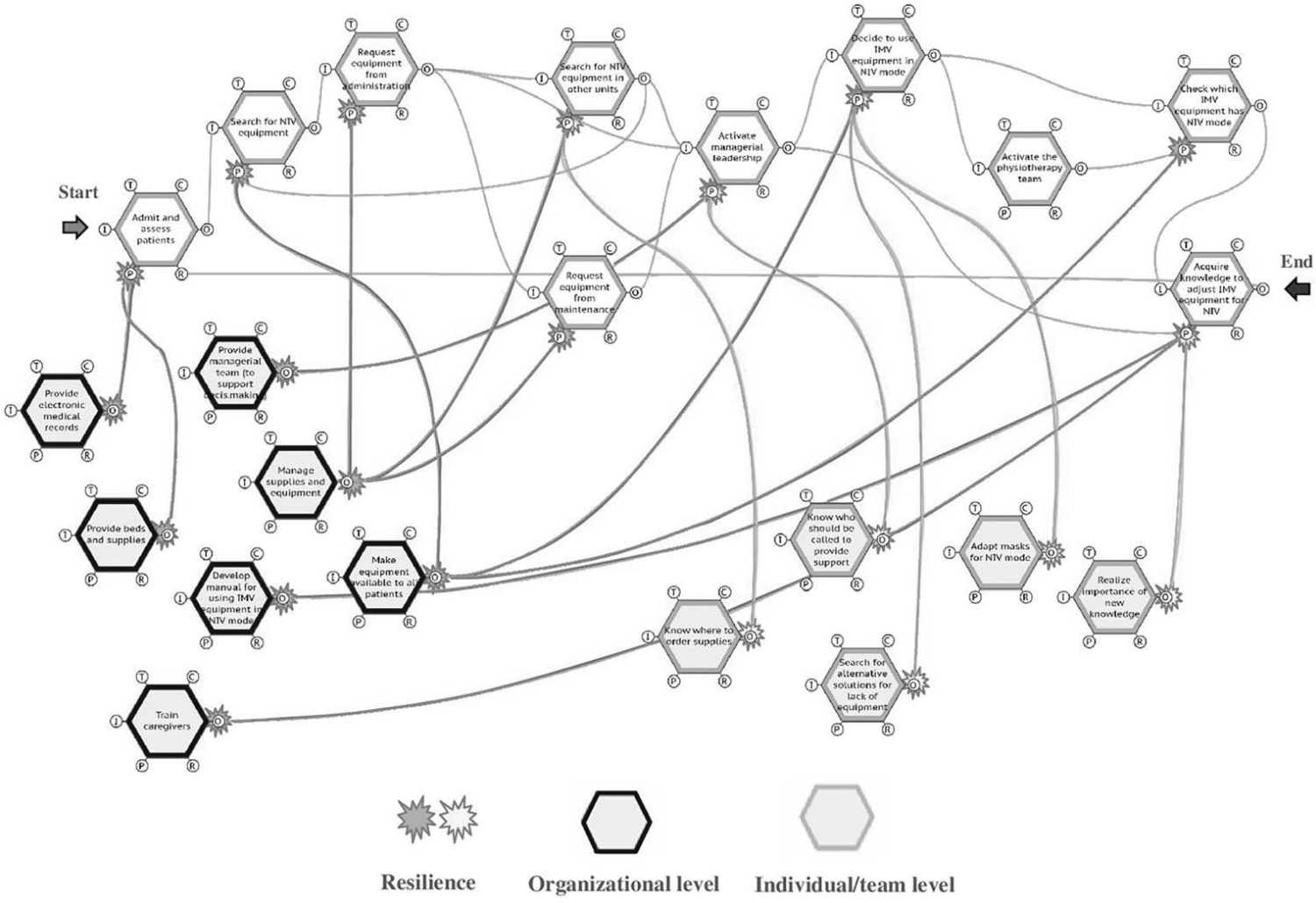
Performing the patient assessment in the ICU setting instead of in the radiology department	1
Computerized decision support systems	1
Total	**142**

Source: Authors.

APPENDIX A. 2.1.2 – Complete FRAM model for case A



APPENDIX B. 4.2.2 – Complete FRAM model for case B



APÊNDICE A3 – Questionário aplicado à UTI-adulta

Este estudo integra o projeto de pesquisa intitulado “Desenvolvimento de Novos Métodos para Gestão de Operações em Sistemas de Saúde”, aprovado pelo comitê de ética em pesquisa do Hospital de Clínicas de Porto Alegre com o CAAE: 79424617.0.0000.5327, e destina-se avaliar uso de diretrizes para gestão de sistemas complexos em unidades de terapia intensiva e a relação com indicadores de desempenho.

O estudo faz parte da tese de doutorado do aluno, Wagner Pietrobelli Bueno (wagner.bueno@ufrgs.br), sob a supervisão dos professores, Tarcisio Abreu Saurin (saurin@ufrgs.br), Priscila Wachs (wachs.priscila@gmail.com), Ricardo De Souza Kuchenbecker (rkuchenbecker@hcpa.edu.br) e Marcio Manozzo Boniatti (mboniatti@hcpa.edu.br).

Caso o hospital em que você trabalhe possua mais de uma UTI, pedimos que considere apenas a UTI em que trabalhas para responder aos questionamentos. O tempo estimado para responder ao questionário é 20 minutos. As informações relatadas são confidenciais.

Obrigado pela participação!

1. Identificação do respondente.

Nome:

E-mail:

Cargo:

Tempo de experiência em UTI’s em geral:

Tempo de experiência na UTI em que estás trabalhando atualmente:

2. Descrição do hospital e da UTI.

Nome do hospital:

Local do hospital (cidade/Estado):

Quantos leitos tem na UTI em que você trabalha:

Essa UTI trata pacientes com COVID-19 (indicar Sim ou Não)?

3. Em relação à administração e financiamento do hospital, ele é majoritariamente:

Privado ( )

Público ( )

Parceria público-privada ( )

4. O hospital é de ensino, universitário ou afiliado a universidade?

Sim ( ) Não ( )

5. O hospital possui certificação de acreditação hospitalar?

Sim ( ) Não ( ) Qual?_____

6. Existe uma equipe multiprofissional de cuidados paliativos?

Sim ( ) Não ( )

7. O seu hospital é centro de referência (especializado ou de alto volume) em qual área?

AVC ( )

Câncer ou hematologia ( )

Transplantes de órgãos ( )

Trauma ( )

Cirurgia cardíaca ( )

Neurocirurgia ( )

Nenhuma ( )

Outro (especifique)_____

8. Tipo da UTI.

Geral/mista ( )

Cirúrgica ( )

Clínica ( )

Neurológica ( )

Outro (especifique)_____

9. Os leitos da UTI são configurados em quartos individuais em sua totalidade?

Sim ( ) Não ( )

10. Modelo de tomada de decisão na UTI.

Fechado (a equipe da UTI decide a internação, alta e o manejo do paciente na UTI) ( )

Aberto (o médico assistente decide a internação, alta e o manejo do paciente na UTI) ( )

Decisões compartilhadas ( )

11. Existem rounds multidisciplinares nessa UTI?

Sim ( ) Não ( )

12. Qual o número de médicos dedicados exclusivamente à UTI?

Número de médicos:

13. Qual o número de enfermeiros dedicados exclusivamente à UTI?

Número de enfermeiros:

14. Qual o número de técnicos de enfermagem dedicados exclusivamente à UTI?

Número de técnicos de enfermagem:

15. Há suporte de fisioterapeutas dedicados exclusivamente à UTI?

Sim ( ) Não ( )

16. Há suporte de farmacêuticos dedicados exclusivamente à UTI?

Sim ( ) Não ( )

17. Há suporte de psicólogos dedicados exclusivamente à UTI?

Sim ( ) Não ( )

18. Há suporte de nutricionistas dedicados exclusivamente à UTI?

Sim ( ) Não ( )

19. Há suporte de fonoaudiólogos dedicados exclusivamente à UTI?

Sim ( ) Não ( )

20. Há suporte de dentistas dedicados exclusivamente à UTI?

Sim ( ) Não ( )

21. Considerando os últimos três meses, indique a taxa de ocupação da UTI, usando duas casas decimais.

Mês anterior:

Dois meses atrás:

Três meses atrás:

22. Os ambientes de trabalho são limpos e organizados, sem itens desnecessários como seringas usadas, frascos de medicamentos vazios, luvas usadas, dentre outros.

Discordo totalmente totalmente

Concordo Totalmente totalmente

23. Os resultados dos indicadores de desempenho (ex: taxa de ocupação, taxa de mortalidade, etc.) são amplamente divulgados, por meios como cartazes, painéis eletrônicos, quadros brancos, folhetos, reuniões.

_____

Discordo totalmente Concordo Totalmente

totalmente totalmente

24. Informações sobre o tratamento e condição de cada paciente (ex: exames, sinais vitais, prontuário, prescrições, plano de cuidado) são acessadas facilmente pelos profissionais assistenciais.

_____

Discordo totalmente Concordo Totalmente

totalmente totalmente

25. Informações em tempo real sobre a situação da UTI como um todo (ex: número de pacientes internados, número de pacientes aguardando leito, profissionais disponíveis) são acessadas facilmente pelos profissionais assistenciais.

_____

Discordo totalmente Concordo Totalmente

totalmente totalmente

26. A distribuição de recursos humanos é alterada conforme a necessidade e de modo ágil, como, por exemplo, realocar profissionais de uma área da UTI para a outra.

_____

Discordo totalmente Concordo Totalmente

totalmente totalmente

27. A distribuição de recursos materiais é alterada conforme a necessidade e de modo ágil, como, por exemplo, realocar equipamentos de diálise e suprimentos de uma área da UTI para outra.

_____

Discordo totalmente Concordo Totalmente

totalmente totalmente

28. Há recursos humanos extra ou em standby, em quantidade suficiente para lidar com imprevistos e que podem ser acionados rapidamente.

_____

Discordo totalmente Concordo Totalmente

totalmente totalmente

29. Há recursos materiais extra ou em standby, em quantidade suficiente para lidar com imprevistos e que podem ser acionados rapidamente.

_____

Discordo totalmente Concordo Totalmente

totalmente totalmente

30. Os profissionais tem adequada disponibilidade de tempo para realizar suas atividades, sem pressa excessiva ou muitas tarefas simultâneas.

_____

Discordo totalmente Concordo Totalmente

totalmente totalmente

31. Há protocolos, treinamentos ou tecnologias para detecção precoce da necessidade de mudar o plano de cuidado (ex: detecção precoce da necessidade de cuidados paliativos, de sepse, de mobilizar o paciente para facilitar a reabilitação).

_____

Discordo totalmente Concordo Totalmente

totalmente totalmente

32. A tomada de decisão sobre cuidados dos pacientes leva em conta os impactos em outras unidades do hospital (ex: implicações da alta para as enfermarias, implicações para os setores que realizam exames).

_____

Discordo totalmente Concordo Totalmente

totalmente totalmente

33. A tomada de decisão quanto as intervenções de cuidado é multidisciplinar.

_____

Discordo totalmente Concordo Totalmente

totalmente totalmente

34. Pacientes, familiares e/ou cuidadores são incluídos nas tomadas de decisões assistenciais.

_____

Discordo totalmente Concordo Totalmente

totalmente totalmente

35. Intervenções para melhoria da gestão assistencial e do atendimento aos pacientes são desenvolvidas por equipes multiprofissionais e, se pertinente, com representantes de outras unidades do hospital.

_____

Discordo totalmente Concordo Totalmente

totalmente totalmente

36. Os profissionais sabem quando, porque e como adaptar ou preencher lacunas nos procedimentos operacionais padronizados.

_____

Discordo totalmente Concordo Totalmente

totalmente totalmente

37. Existem rotinas para comparar a realidade com o previsto nos planos de cuidado, protocolos e políticas. Exemplos de possíveis rotinas: auditorias de qualidade, reuniões para comparar planejado versus realizado.

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Discordo totalmente Concordo Totalmente

totalmente totalmente

38. Há sistemas de relato voluntário de incidentes, anormalidades ou outras situações relevantes, tais como conduta não profissional de colegas.

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Discordo totalmente Concordo Totalmente

totalmente totalmente

39. Há rotinas para aprender com o que dá certo ou com a variabilidade normal do dia-a-dia. Possíveis exemplos: breves reuniões de reflexão acerca do dia de trabalho, sistemas de relatos e disseminação de boas práticas.

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Discordo totalmente Concordo Totalmente

totalmente totalmente

40. Mudanças na gestão assistencial e no atendimento aos pacientes são precedidas por estudo de como o trabalho realmente ocorre na prática, conhecendo a sua variabilidade e dificuldades.

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Discordo totalmente Concordo Totalmente

totalmente totalmente

41. Mudanças na gestão assistencial e no atendimento aos pacientes são realizadas em pequena escala e ciclos rápidos, antes da implantação em grande escala.

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Discordo totalmente Concordo Totalmente

totalmente totalmente

42. Como parte do planejamento de mudanças na gestão assistencial e no atendimento aos pacientes, há uma análise formal de barreiras e riscos.

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Discordo totalmente Concordo Totalmente

totalmente totalmente

43. Quando há mudanças na gestão assistencial e atendimento aos pacientes, diversos indicadores de desempenho são coletados, contribuindo para a identificação de efeitos inesperados.

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Discordo totalmente Concordo Totalmente

totalmente totalmente

44. Quando há mudanças na gestão assistencial e atendimento aos pacientes, os efeitos são monitorados no médio (meses) e longo prazo (anos), ao invés de apenas no período imediato pós-intervenção.

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Discordo totalmente Concordo Totalmente

totalmente totalmente

45. Os pacientes estão seguros nessa UTI.

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Discordo totalmente Concordo Totalmente

totalmente totalmente

46. Os profissionais estão seguros nessa UTI.

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Discordo totalmente Concordo Totalmente

totalmente totalmente

47. Essa UTI é um sistema resiliente, ou seja, ela se adapta a condições adversas e não antecipadas, atingindo os resultados esperados.

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Discordo totalmente Concordo Totalmente

totalmente totalmente

48. Por favor, forneça pelo menos um exemplo de desempenho resiliente, no nível do sistema da UTI (por exemplo, medidas para lidar com a pandemia de coronavírus).

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49. Você gostaria de receber um resumo dos principais resultados dessa pesquisa?

Sim ( ) Não ( )

50. Registre nesse espaço, se desejar, comentários ou sugestões relativas a essa pesquisa (por exemplo, quanto a clareza e relevância das questões, quanto ao tempo de preenchimento, etc.):

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