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Indicator Based Framework To Quantify Hospital Resilience

Rossella Marmo[a,b], Bryan T. Adey[b]

[a]*University of Naples Federico II, Naples, Italy*
[b]*ETH, Zurich, Switzerland*

Abstract

This paper addresses the crucial issue of quantifying the resilience of hospitals. Hospitals are critical infrastructures within health systems which must be able to provide service when disruptive events occur, thus they need to be resilient. The aim of this paper is to present a novel indicator-based framework for quantifying the resilience of hospitals, where the indicator values are explicitly connected to the provided service. Qualitative research methods were used to develop the framework, namely literature review and expert opinion. The framework is built upon the following steps: conceptualizing the hospital system, setting service measures, developing resilience indicators, estimating resilience against a specific disruptive event. The hospital system has been conceptualized into four key parts: staff, stock and supplies, space, system, emphasizing their interconnectedness. Twenty resilience indicators describe the essential features of a resilient hospital, regardless of the hazard type, while a set of service measures are used to quantify resilience. Hospital administrators and supervisory organizations can use the results of this paper to rapidly assess hospital resilience, or they can customize the proposed framework by changing service measures and adapting the indicators according to their needs. Finally, they can use the framework to clearly point out the hospital's weaknesses to ensure that improvement actions will have the largest possible impact in terms of resilience. Future applications are needed to test the validity of the framework and they may require adjustments to align with the context and the disruptive event of interest.

Keywords: hospital, service provison, resilience, framework

1. Introduction

The uninterrupted provision of health services through critical infrastructure, such as hospitals, is a matter of life and death. When disruptive events occur, hospitals minimize the impacts of such events on the community by providing emergency and acute care. A disruptive event is here referred to as an event that interrupts normal hospital operations or processes, which is induced by natural, human, or environmental hazards and it can result in emergencies, disasters, or crisis. Given the above, it is important that hospital and supervisory organizations have a clear idea of how hospitals are likely to provide service following the start of a disruptive event until service is fully restored, i.e., their resilience.

A recent scoping review (Khalil et al., 2022), aimed at understanding hospital resilience, analyzed the parts and the capacities of resilient hospitals, which is ultimately the ability to ensure a continuity of essential and critical services to vulnerable populations. This is in line with the idea adopted by this paper, where hospital resilience is referred to as the ability to provide service if a disruptive event occurs.

Health systems and hospitals resilience have been topics of growing interest in the last decade (Truppa et al., 2024). Several conceptual frameworks have been developed; however, they are mostly descriptive and research on how to quantitatively measure hospital resilience is limited (Poroes et al., 2023). This is particularly true in fragile and conflict-affected settings as well as in low- and middle-income countries, where health systems resilience remains largely unexplored and there is little evidence on how to strengthen resilience in practice

(Truppa et al., 2024). At the same time, health systems in such contexts are disrupted by both sudden shocks (e.g., bombing) and chronic stressors (e.g., poverty and violent incidents), which increase the need for resilience measurements.

The assessment methods for hospital resilience can be divided into two main categories: indicator-based and functionality-based (Yu et al., 2022). The former are to be used to capture the complexity and the multidimensional nature of hospital resilience and they tend to qualitative evaluations; the latter formulate and quantify the changes of a performance measure over time, and they need to focus on a sub-set of resilience indicators or hospital parts. Discrete Event Simulation, System Dynamics and Fault Tree analysis are examples of tools used in functionality-based assessment methods.

The World Health Organization (WHO) has been providing guidelines and tools for hospital safety and functionality assessment; examples are the suite of health service capacity assessments in the context of the COVID-19 (WHO, 2020) and the Hospital Safety Index (WHO, 2015). The Hospital Safety Index is a tool for health authorities and multidisciplinary partners to facilitate the determination of the hospital's capacity to remain safe and operational during a disruptive situation. The tool comprises four modules for assessment: hazards affecting the facility, structural elements, non-structural elements (including architectural and critical systems), and emergency and disaster management. Such a checklist includes 151 items, each of which has three safety rating levels: low, average, and high. The values are aggregated and standardized in such a way that the sum of the scores of the three modules gives a hospital safety index expressed as the probability (percentage) that a facility will be able to function in an emergency or disaster situation. Due to the comprehensiveness of the tool, completing the assessment requires a considerable time investment (Lamine et al., 2023). Furthermore, the outcomes of the tool do not support a straightforward identification of the priority interventions needed to maintain hospital service provision during and after a disruptive event.

Given this background, this paper aims to present an indicator-based framework for overall hospital resilience assessment. The innovative approach to the topic of hospital resilience assessment lies in keeping the assessment agile, thus a limited number of indicators is used, and in the resilience quantification. As in other developed international frameworks (CEN WA 17819, 2021) it is assumed that it is possible to measure the resilience of a system by measuring the reduction in service it provides when a disruptive event occurs. In the proposed framework, hospital resilience is quantified by using service measures, this helps to identify where to intervene to ensure that the interventions will have the largest possible impact in terms of resilience, as explained in the following section.

2. Materials and methods

2.1. General

The framework builds upon the guidelines provided by CEN-CENELEC (CEN WA 17819, 2021) on how to assess the resilience of transport infrastructure to potentially disruptive events. However, the work presented in this paper required to adapt the guidelines to the healthcare field and to operationalise them into four main phases, namely: (1) describe the hospital system, (2) set service measures, (3) develop resilience indicators, (4) estimate resilience.

In general, the resilience assessment is done by comparing the service the hospital can provide at the baseline condition against the service it provides at the current condition. The baseline condition is the condition at which the hospital is supposed to work or the condition at which the hospital organisation would like it to work, while the current condition is the condition of the hospital when the assessment is performed. The condition of the hospital is described by resilience indicators, which are variables affecting the ability of the hospital to provide service when a disruptive event occurs.

The authors used qualitative research methods to develop the framework, i.e., literature review and expert opinion.

2.2. Systematic review

The purpose of the systematic review was to describe the hospital system and to introduce both service measures and resilience indicators. The first screening aimed at: determining the parts of the system which functionality concurs to the overall hospital resilience; establishing potential service measures; identifying a preliminary set of resilience indicators (i.e., promising indicators) for each part of the hospital. Documents related to very slow-onset disruptive events, such as aging population or rising temperatures, were excluded; the same was done for purely medical science and social science documents or for papers focused on the resilience of urban systems and communities.

A second screening served to check the relevancy of the indicators in terms of resilience and to complete their description, e.g., introducing ways to measure and potential values. The second screening was mostly performed by reference and citation tracking or by entering new research questions (e.g., to quantify the impact of a specific indicator on the overall hospital resilience). Figure 1 shows the flow chart of the literature review.

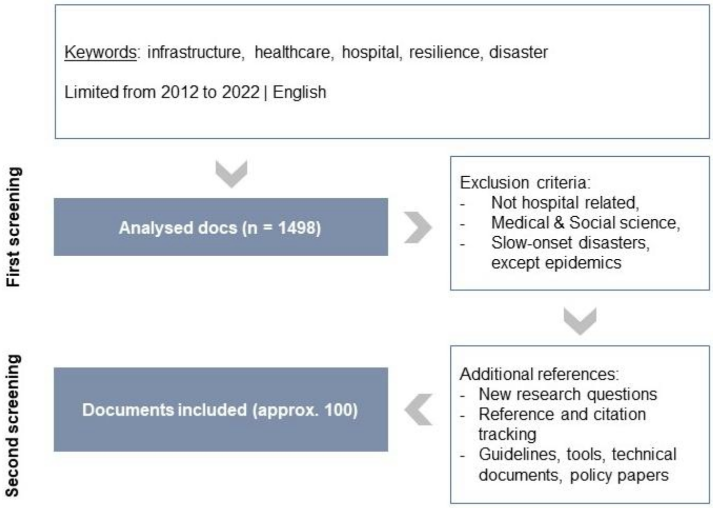

Fig. 1. Keywords and flow chart of the systematic literature review.

2.3. Expert opinion

Expert opinion was used to set service measures, to reach an agreement on the resilience indicators (i.e., on the resilience description, ways to measure, potential values, and the baseline value), and to estimate resilience. Experts from the International Committee of the Red Cross (ICRC) were involved. The ICRC is an independent, neutral organization which protects the lives of victims of armed conflict and violence and provides them with assistance. The ICRC holds an extensive background and experience in terms of hospital functionality and resilience, and their international point of view is of great value for the purpose of the developed framework. The panel of experts was selected to be as heterogeneous as possible: medical opinions (e.g., from emergency doctors, surgeons, public health experts, etc.), technical opinions (e.g., from engineers, architects, etc.) and management opinions (e.g., from hospital managers and unit coordinators) were collected. These perspectives reflect the range of stakeholders who may have an interest in the resilience framework.

Service measures were established by means of a focus group discussion, while resilience indicators were reviewed by means of a questionnaire. In both cases, experts were asked to express their agreement on a five-point Likert scale regarding the relevancy of the topic of assessment, the feasibility of the way of measurement, and the clarity of the description. Furthermore, they left additional comments through textual commentary.

Finally, expert opinion is used to assess the negative effects of a potentially disruptive event on the service measures. The authors built the relationship between indicators and service measures using literature findings, then asked experts for their opinion. This was done by one-to-one interviews which served to collect details on how each indicator can impact the service measures, and they mainly involved healthcare workers with a medical background (e.g., doctors), which is needed to quantify resilience in terms of patient outcomes (e.g., mortality rate, length of stay, etc.). It is important to outline that resilience estimate is done for a specific disruptive scenario and over a specific investigated period. This paper does not present the resilience assessment performed on a real case study and for a specified disruptive scenario, but it explains the methodology to do it, as reported in Section 3.4.

3. The framework

3.1. Hospital system description

The conceptualization of hospital systems varies in the literature, with the goal of organizing and describing their complex nature. Terminology lacks consistency, as hospital sub-systems have been denoted as "areas," "domains," "components," "modules". Despite this diversity, hospital resilience is consistently associated with the behavior of at least three primary parts: structure, critical systems (e.g., electricity and water), and organization (WHO, 2015; Fallah-Aliabadi et al.; 2022). The COVID-19 pandemic underscored the significance of spatial characteristics too, impacting the ability of the hospital to expand its capacities to meet rising demands for assistance (Marmo et al., 2022).

In this paper, the hospital system encompasses four key parts: staff, stock and supplies, space, and the system (see Figure 2). The staff component pertains to the human resources of the hospital, consistently emphasized in the literature as one of the most crucial elements for resilient hospitals. Staff utilizes supplies daily, which include basic resources (e.g., electricity, water, fuel, etc.) and hospital-specific items (e.g., medical gases, medical equipment, drugs, etc.). Staff and supplies are interconnected with the characteristics of the built environment, grouped under the space part. Ultimately, effective management and coordination are essential and fall under the system part.

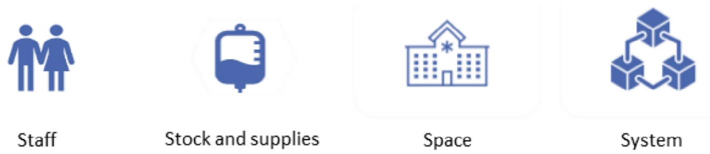

Fig. 1. Hospital parts.

3.2. Service measures

Service measures reflect the expectation of the hospital organization and are used to quantify the resilience. Common variables comprise the number of deaths, the number of admissions, and the number of untreated patients (Khalil et al., 2022). Additionally, as the emergency care provided at the Emergency Department (ED) plays a pivotal role under disruptive circumstances, the following outcomes can be of interest too (EU Expert Group on Health Systems Performance Assessment, 2020): average waiting time from triage to first meeting with a physician; average time spent at the ED (from triage to discharge/transfer). Finally, during disruptive scenarios, hospitals are expected to ensure continuity of life-saving services like surgeries. Table 1 reports the measures of service that were determined after consultation with the panel of experts.

Table 1. Measures of hospital service.

Name	Measurement	Unit
Average mortality rate below 24hrs from admission	Number of fatalities below 24hrs from admission / number of admitted patients.	%
Average mortality rate after 24hrs from admission	Number of fatalities after24hrs from admission / number of admitted patients.	%
Average length of stay	Total daily census / total number of admissions	days
Average time spent at the ED	Average time from triage to discharge/transfer	hrs
Total surgical volume	Total procedures done in operating theatres	N
Average surgery cancellation rate	Cancelled or postponed surgeries / planned surgeries	%

3.3. Resilience indicators

Twenty indicators have been developed considering actions that may be taken to enhance hospital ability to cope with a disruptive event, including increased demand for assistance and decreased available resources. The indicators development included their description, ways to measures, potential values and related meaning. Potential values for the indicators correspond to the worst-case scenario and the best-case scenario respectively. For example, the indicator named "Nurse-to-patient ratio in non-High Dependency Units" assumes the value 1 to indicate a low staffing level, corresponding to 1 nurse to more than 12 patients, while the value 4 corresponds to 1 nurse to 8 patients, indicating a higher staffing level. The changes in values of indicators are associated to changes in values of the service measures. The indicators are listed in Table 2 and Table 3. The tables report the description of the indicators and the ways of measurement, while potential values and meanings are not reported for the sake of brevity.

The indicators grouped under the *Staff* part are aimed at assessing the availability of human resources, their well-being and job satisfaction and the emergency management training they receive. In particular, the nurse staffing level is associated to increased mortality, longer stays and waiting times (Chan et al., 2010; Driscoll et al., 2018; McHugh et al., 2021). High level of stress among the healthcare workers is predictive of burnout, absenteeism, and low quality of care (De Hert, 2020), this is particularly true under disruptive scenarios which pose high risks on mental health (Achour et al., 2022). Finally, training and drills ensure staff preparedness, which in turn impacts fatalities and time spent at the ED (Baetzner et al., 2022; WHO, 2015).

The indicators grouped under the *Stock and supplies* part are aimed at assessing robustness and redundancy of the supply of essential consumables. Indicators are measured in terms of days of autonomy or in terms of stock out days, conveniently. Loss of power and water have immediate effect on hospital service provision (Achour and Miyajima, 2020). Emergency and acute care are disrupted when the hospital runs out of water and electricity, resulting in lower patient safety and quality of care. This is also valid for other essential stocks, such as blood, oxygen, and drug products (EAHP, 2023; Giannou and Baldan, 2010) which are needed for performing surgeries and saving lives.

The indicators grouped under the *Space* part are aimed at assessing the reliability and the safety of infrastructure by looking at their physical condition. They also comprise the capacity to expand bed availability and the fire safety measures. Authors who studied the loss of hospital functionality in case of earthquake (Achour and Miyajima, 2020) outlined that hospitals were evacuated mainly because of architectural damage and failures of critical systems (e.g., plumbing system and medical equipment). Availability of beds is of primary importance to ensure continuity of admissions and operations, this is associated to increased mortality, longer waiting times and hospital stays. Dynamic models can be used to understand and formulate the relationship between bed availability and hospital functionality (Khanmohammadi et al., 2018; Li et al., 2020; Trucco et al., 2022). Finally, fire safety must be guaranteed under all circumstances, as hospital facilities are extremely difficult to evacuate and the damage caused by fires is of great magnitude (Jang et al., 2022).

The indicators grouped under the *System* part are aimed at assessing the preparedness of the hospital from an administrative point of view, and they cover risk management, contingency planning, information management, coordination with the broader health system. A contingency plan contains many modules to ensure a prompt response and the continuity of service provision, such as patient management and stockpiling critical resources (WHO, 2022). According to the ICRC experts, a missing plan can jeopardize emergency operations, causing an increase in the mortality rate. Similarly, a reliable information management system is needed to track available resources and allows timely and transparent communication. Lack of coordination with pre-hospital care providers and referral system is directly linked to an increase in the mortality rate. This is related to the opportunity of transferring patients who cannot be treated as well as controlling emergency arrivals to avoid the congestion of the ED. Finally, inadequate infection prevention and control is responsible for increased morbidity and mortality (Maki and Zervos, 2021).

Table 2. Resilience indicators.

Part	Indicator name	Description	Ways to measure
Staff	Nurse-to-patient ratio in non-HDU units	It evaluates the number of nurses per patient in non-high dependency (non-HDU) units.	Average monthly staff nurse census / average monthly patient census.
Staff	Nurse-to-patient ratio in HDU units	It evaluates the number of nurses per patient in high dependency (HDU) units. .	Average monthly nurse census / average monthly patient census.
Staff	Hospital staff well-being and job satisfaction	It evaluates if staff well-being and job satisfaction are supported. Examples of means of support are regular provision of salary; salary purchasing power.	Qualitative evaluation based on document review, walkover survey and interviews.
Staff	Frequency of emergency management training	It evaluates if the staff is frequently trained for contingency management.	Qualitative evaluation based on document review and interviews.
Stock and Supplies	Emergency power reservoir capacity	It evaluates the number of days of power autonomy assuming that the main power supply system is out of service.	Capacity of back-up power generation system expressed in days.
Stock and supplies	Emergency water reservoir capacity	It evaluates the duration expressed in days of the water reservoir assuming that the main water supply chain is out of service.	Capacity of back-up water reservoir expressed in days of autonomy.
Stock and supplies	Water safety control	It evaluates the frequency of water safety checking, the existence of a reporting system and a plan for water safety checking.	Technical evaluation based on document review, interviews with the quality and the engineering departments.
Stock and supplies	Oxygen stock capacity	It evaluates the duration expressed in days of oxygen stock assuming that you cannot replenish your stock.	Capacity of oxygen stock in terms of days.
Stock and supplies	Blood stock shortage	It evaluates the number of days over a month with shortage of blood units or blood components.	Stock-out days over a month.
Stock and supplies	Essential drug products and medical items shortage	It evaluates the number of days over a month with shortage of essential drugs, medical items.	Stock-out days over a month.
Space	Architectural and structural maintenance and condition	It evaluates the condition of structural and architectural elements of the building.	Technical evaluation based on building inspections.
Space	Power related system maintenance and condition	It evaluates the condition of electrical system including power generation systems and power-related systems.	Technical evaluation based on building inspections.
Space	Water-related system maintenance and condition	It evaluates the condition of water-related systems, including water treatment plant, water reservoir, plumbing system.	Technical evaluation based on building inspections.
Space	Bed occupancy rate	It evaluates the average bed occupancy of hospital units.	Average daily census/ opened beds per day in HDU areas.
Space	Hospital bed surge capacity	It evaluates the capacity to increase the number of opened beds. It includes operational measures and infrastructural adaptation.	Number of additional opened beds/ total number of opened beds.
Space	Fire safety measures adoption	It evaluates if safety in case of fire is provided by means of: 1) fire detecting system and firefighting system; 2) presence of fire response team in the hospital; 3) evacuation plan available and implemented; 4) fire training and education sessions.	Technical evaluation based on building inspections, surveys, and documents review.
System	Contingency plan implementation	It evaluates the presence, the testing and upgrading of an emergency contingency plan to respond to emergencies and disasters that have the potential of occurring within the hospital and community.	Technical evaluation based on document reviews, surveys, and interviews.

Table 3. Resilience indicators (continued).

Part	Indicator name	Description	Ways to measure
System	Information management system implementation	It evaluates if an information management system is implemented to keep track of resources availability and patient data.	Technical evaluation based on document reviews, surveys, and interviews.
System	Hospital Acquired Infection incidence rate	It evaluates the incidence of Hospital Acquired Infections (HAIs) among hospitalized patients.	Quantitative evaluation based on document review.
System	Coordination with pre-hospital emergency service and referral system	It evaluates if the hospital can collaborate with external healthcare providers and with pre-hospital emergency care providers.	Qualitative evaluation based on document reviews and interviews.

3.4. Resilience estimation

The resilience estimation is made for a specified disruptive scenario and over a specified period. First, the baseline condition of the hospital must be clearly defined, which implies identifying the indicator values at the baseline condition. Also, it is necessary to define a set of scenarios deriving from the occurrence of one or more potentially disruptive events, such as the yearly expected mass casualty incident, and the 50-years expected mass casualty event. Once the scenarios are set, the experts are to assume that the hospital has the baseline values of the indicators and estimate what they believe would be the effect of a potentially disruptive event on the measures of service. They are then to re-estimate the effects of the same potentially disruptive event on the measures of service changing the values of the indicators (i.e., estimating the likely increase/decrease in service from the baseline). Finally, they can estimate the hospital resilience by calculating the difference between two estimates, referred to the baseline condition and to the actual values respectively.

The estimation of the changes in values of measures of service can be expressed qualitatively (e.g., a low, moderate, high change) or quantitatively. If a qualitative approach is used, it is suggested to translate the qualitative estimation into quantitative ranges (such as 50%, 100%, 200%). Either way it is possible to create a graph and compare the estimations made for each indicator on a given measure of service (see Figure 3). This way the assessment not only makes it clear the reason for a lack of resilience, but it can also be used to identify where to intervene to ensure that it is clear which interventions will have the largest possible effect on resilience. An example of result of qualitative resilience estimation is given in Table 4 and Figure 3. It can be seen in Table 4, that the changes in the indicator values are converted into changes in the values of the measures of service, e.g., mortality rate. It can also be seen that the lack of fuel for emergency power generation causes a threefold increase in the mortality rate compared to the baseline condition. This means that, in this illustrative example, while planning for resilience enhancing interventions, it is of high priority to invest in a fuel reservoir to supply the hospital in case of black out. It is also important to note that the costs of intervention are not included here.

Table 4. Example of impacts of indicator values on the mortality rate.

Part	Indicator	Indicator value	Meaning	Impact on mortality rate
Staff	Nurse-to-patient ratio in HDU units	1	1:12	Slight increase
		2	1:10	Slight increase
		3[b]	1:8[b]	No change[b]
Stock and Supplies	Emergency power supply reservoir capacity	1	No fuel reservoir	High increase
		2	Fuel reservoir lasts few hours	High increase
		3[b]	Fuel reservoir lasts 3 days[b]	No change[b]
Space	Bed surge capacity	1	Not assessed	Moderate increase
		2	20-40%	Slight increase
		3[b]	More than 40%[b]	No change[b]
System	Coordination with pre-hospital emergency service and referral system	1	No coordination	Moderate increase
		2	Informal coordination	Slight increase
		3[b]	Formal coordination[b]	No change[b]

Current condition; [b]Baseline condition. High increase means +200%, moderate increase means +100%, slight increase means +50%.

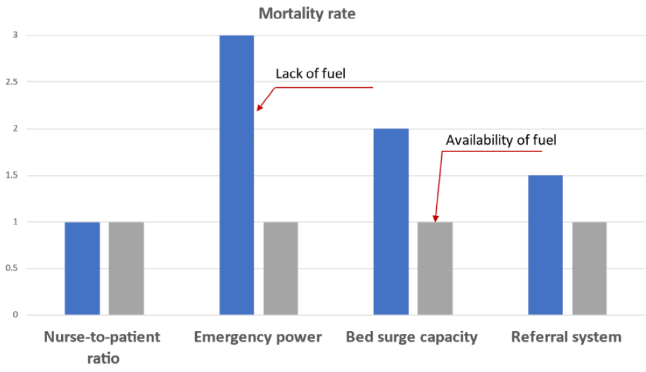

Fig. 2. Illustrative example of mortality rate estimation for a specified event, period, and indicator values.

4. Discussion

This paper presents a novel and agile indicator-based framework for overall hospital resilience. By comparing the presented results with what the literature proposes, it is possible to derive the following strengths of the framework:

- Unlike other checklists and descriptive tools, this framework quantifies resilience by connecting indicator values with service measures, offering a measurable approach to assessing hospital resilience. This was done before using simulation-based models, but the broad picture provided by this framework is difficult to achieve with detailed models.
- The structured estimation approach provides transparency, which is crucial for decision-making processes. Also, the quantitative approach facilitates a high-level discussion between hospital managers, unit coordinators and supervisory organizations on how to strengthen hospital resilience. Indeed, the results obtained from the framework can clearly identify potential weaknesses, facilitating prioritization of interventions for improved preparedness.
- The framework is focused on the essential features of a resilient hospital, maintaining a low computational time. Expert opinions primarily guide the estimation, and the framework is fortified by a strategic collaboration between medical staff, administration, and technical expertise.

The framework presents criticalities too:

- While merging medical, administrative, and technical points of view allows a better understanding of the hospital condition, the issue of identifying a responsible party for the framework application remains. This implies that a coordinator for hospital condition assessment (e.g., the risk manager) is needed, while a panel of experts from both supervisory and hospital organizations (e.g., managers at strategic and operational levels) must lead the resilience estimation, including identifying disruptive events of interest, setting service measures, and understanding the consequences of poor hospital conditions on the ability to provide service.

5. Conclusion

This paper addresses the issues of ensuring continuity of hospital service provision during disruptive events like earthquakes, floods, explosions, and bombings. Recognizing their pivotal position, both hospitals and supervisory organizations must assess hospital resilience. This paper reports the development process and the structure of an indicator-based framework for hospital resilience assessment, which includes conceptualising hospital system, setting service measures, developing resilience indicators, estimating resilience.

The framework's novelty lies in quantifying resilience by connecting indicator values with service measures, ensuring a concise yet broad assessment. Unlike other checklists, it avoids too many details while addressing essential features. Resilience quantification, typically done through simulation-based models, achieves a broader perspective with this framework, maintaining efficiency and low computational time.

Designed for hospital managers and advisory organizations, the framework facilitates assessing hospital functionality under specific disruptive scenarios. Results pinpoint potential weaknesses, aiding prioritization of interventions and enhancing preparedness for disruptive events. Both resilience indicators and service measures are customizable, allowing adaptation to unique organizational goals and context. Flexibility in selection enables a highly adaptable framework, accommodating variations in measurement based on the application's context.

Acknowledging a reliance on expert opinion, the paper considers the ICRC's expectations, aligning with the goals and experiences of organizations working in fragile and conflict-affected settings. Potential future users might want to change the set of indicators and service measures to better depict new issues, related, for example, to epidemics or chronic diseases. It must be also considered that any new application will require the revision of the assumptions behind the resilience estimation. However, the proposed structured way for estimation will guide future applications and will provide transparency, which is essential for decision making.

An application of the proposed framework will be presented in the next future. It will contain further details on the indicators and specifications on how to estimate resilience with reference to a real case study and a disruptive scenario of interest.

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