

BRHI Building Resilience in Health Infrastructure: An indicator-based framework to assess overall hospital resilience

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Building Resilience in Health Infrastructure

An indicator-based framework to assess overall
hospital resilience

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Summary

Health infrastructure plays a pivotal role during and after crises, providing life-saving care and supporting community recovery. To fulfill this critical function, health facilities must remain resilient, and capable of adapting and maintaining services despite challenges.

This document introduces a comprehensive framework for assessing the resilience of health infrastructure. It is designed to guide humanitarian organisations, local authorities, and health stakeholders in understanding and enhancing the capacity of health systems to withstand and recover from disruptive events.

Developed under the Humanitarian Action Challenge (HAC) research program on “Building Resilience in Health Infrastructure”, a collaboration between ETH Zurich and the International Committee of the Red Cross (ICRC), the framework offers a structured approach to resilience assessment. It integrates system representation, service measures, resilience indicators, and resilience estimation, enabling informed decision-making to prioritize interventions.

System Representation: The framework maps key components influencing resilience—such as human resources, supply chains, the built environment, and organizational structures—and identifies critical factors, like staff-to-patient ratios and backup power capacity.

Service Measures: Defines measurable outcomes reflecting the health facility's performance post-crisis, such as patient survival rates and service recovery time.

Resilience Indicators: Links facility performance to resilience, using baseline scenarios to gauge the impact of changes in infrastructure or operations.

Resilience Estimation: Simulates the effects of specific disruptive events on service delivery, highlighting areas for improvement.

This framework is tailored to humanitarian settings, ensuring relevance in contexts of conflict and protracted crises. It serves as a decision-support tool, empowering stakeholders to address vulnerabilities and strengthen the resilience of health systems holistically.

The framework is expected to provide a clear structured high-level overview of the resilience of hospital systems and facilitate decision-making as to which actions should be taken to improve resilience.

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1 Introduction

1.1 General

Health infrastructures are critical infrastructures whose functionality and safety must always be ensured. In particular, hospitals provide acute and emergency care which saves lives and minimises the impact of potentially disruptive events on communities.

Frameworks for evaluating hospital preparedness exist (see Annex 1). They consist of checklists for assessment, which provide the percentage of fulfilment of a list of indicators as a result. However, frameworks quantifying the service provided by hospitals when a potentially disruptive event occurs are rare. The most widely adopted document for hospital preparedness assessment is the Hospital Safety Index, provided by the World Health Organization - WHO (World Health Organization, 2015). Due to the comprehensiveness of the tool, completing the assessment requires a considerable time investment (Lamine et al., 2023). Additionally, the tool's outcomes may not clearly highlight priority interventions needed to maintain health facility services during disruptive events. As a result, humanitarian actors, local authorities, health facility managers, and risk coordinators may face challenges in interpreting the results and translating them into actionable steps to enhance resilience.

Building on this context, this document introduces an indicator-based framework and accompanying tool for assessing the overall resilience of health facilities (OHFRA). The framework is designed based on the following principles:

- a) **Conciseness is essential:** Enough indicators need to be used to obtain an idea of the resilience and what should be modified to improve it, but not too many indicators so that the results are not easily interpretable and high-level conversations are difficult.
- b) **Resilience must be quantified:** High-level decision-makers can make better decisions when impacts on service of changes to the hospital system can be compared, and this requires quantification.
- c) **Possible improvements to resilience must be seen:** High-level decision makers must see the effect of changes to the system so they can assess whether the effort to make the changes are worthwhile.
- d) **Transparency is essential:** As high-level complete estimates require input from many individuals and many assumptions, the way they have been made must be clear to all involved parties. This increases trust and understanding and makes the assumptions easy to modify if required. Additionally, it ensures that others within the hospital can understand and support the high-level decisions.

This document contains the deliverable of the Work Package (WP) 2 of the research project called *“Building Resilience in Health Infrastructure”*, developed by ETH in Zurich in collaboration with the International Committee of the Red Cross (ICRC). WP2 stands between the rapid resilience assessment checklist, developed in WP 1 which is aimed at providing the status quo of the hospital under analysis, and the mass casualty incident planning tool, developed by WP 3, which is aimed at simulating the hospital functionality over time and stress testing. The WP1 checklist uses many indicators to picture the operational conditions of the hospital, while the OHFRA framework focuses on a subset on them which are directly linked to the service the overall hospital can provide under a hypothetical scenario

of interest. More precise and detailed analysis, conducted at the department level, can be performed by using the WP3 tool. The document contains two main parts: the methodology and the evidence used to build the assessment framework (from Section 1 to Section 5), and a case study which serves as an illustrative example of resilience estimation (Section 6). Annex 5 contains the description of an Excel-based tool to be used to conduct such an estimation.

As in other recently 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 potentially disruptive event occurs. This approach was adapted from recent works on estimating and setting targets for the resilience of transport infrastructure (Adey et al, 2024; Adey et al., 2021; Adey et al., 2016). In this framework, **the better a hospital can provide service when a potentially disruptive event occurs the more resilient it is considered to be.**

Hospital resilience is quantified by using service measures, and it is estimated by using resilience indicators. The resilience assessment is done by comparing the values of service measures at the current operational condition against the values of the service measures at the baseline condition, i.e., the reference operational condition at which the hospital is supposed to work. The resilience assessment framework, described in the following Sections, comprises: (1) system representation, (2) service measures, (3) development of resilience indicators, (4) resilience estimation. Figure 1 provides for a graphical abstract of the framework.

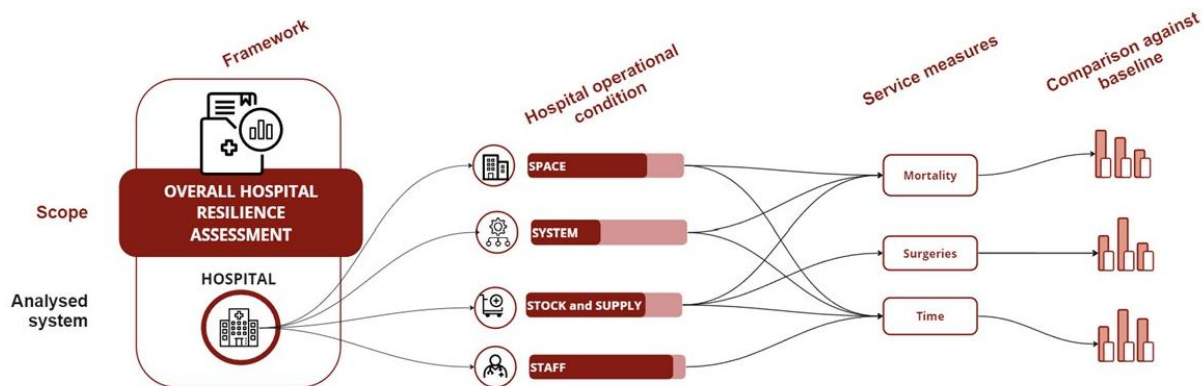


Figure 1. Graphical abstract of the framework

1.2 Tool

A tool has been developed to facilitate the framework application to a real case study. The results of the application are reported in Section 6. This tool aims to facilitate ICRC members and hospital administrators in estimating hospital resilience and guiding decisions to improve it where needed.

The tool is to be used to assess the resilience of hospitals at different levels, from district to university hospitals, while adjustments are needed if it is to be applied to other types of health facilities. New service measures and new resilience indicators might be used to better capture the most relevant outcomes and the operational conditions on which those service measures depend. For example, cancer service facilities might be interested in quantifying the volumes of oncology-related treatments and diagnostic procedures. Once the service measures are set, the relevancy of the resilience indicators is to be checked, also, some indicators can be replaced to ensure that the most relevant hospital operational conditions, i.e., those affecting the service measures of interest, are monitored.

Also, the tool has been developed for assessing the resilience against Mass Casualty Incidents (MCI). For other types of disruptive events the worksheets must also be adjusted.

The most benefits can be gained by applying the tool before the occurrence of a potentially disruptive event to improve hospital preparedness, but it could be used from the early stage to the recovery phase too.

The tool analyses the hospital in its entirety, without looking at specific departments or patient types. It covers all the essential areas of hospital operation management, including workforce availability, built environment condition and spatial availability, essential resources and consumables, administration, and emergency governance. This ability of the tool to cover essential areas of hospital operation management ensures a good level of generalisation.

Using the tool effectively requires a collaborative effort from a multidisciplinary team. Depending on the context, this team may include individuals responsible for facility management, engineering and infrastructure, healthcare coordination, and quality or risk management, ensuring a comprehensive understanding of the facility's operations and specific challenges. However, the ownership¹ of the methodology and tool should lie with local authorities, with humanitarian actors providing essential support and expertise. In a hospital setting for example, this could involve key local stakeholders such as the hospital manager, staff and maintenance team, while humanitarian experts assist with capacity-building and technical guidance as needed.

Instructions on how to use the tool are provided in Annex 5.

¹ The owner of the tool is responsible for its use, including data collection and analysis of the results.

2 System representation

Hospital systems are conceptualised in many ways across the literature, with the aim of organising and describing their complexity. The complexity arises from the interconnection between the many sub-systems (hereinafter called parts) forming a hospital. Such an interconnection changes the behaviour of the overall hospital system and impacts its ability to provide service. The definition of these parts lacks consistency, they have been referred to as “areas”, “domains”, “modules”, etc. Nevertheless, hospital resilience has been commonly related to the behaviour of at least three main parts: structural/constructive, critical systems (e.g., electricity and water), administrative/organisational (WHO, 2015; Fallah-Aliabadi et al., 2022). A recent scoping review on how to define hospital resilience has proposed six parts for conceptualisation (space, staff, stuff, systems, strategies, services). These concur to build resilient capacities (e.g., to absorb, adapt, transform, learn from a crisis) which in turn result in achievable outcomes (e.g., to ensure the continuity of critical services) or system’s attributes (e.g., robustness, redundancy, rapidity, etc.) (Khalil et al., 2022).

The proposed framework uses the following parts for conceptualisation: **Staff, Stock and supplies, Space, System**. It is worth noticing that the checklist developed under the Work Package 1 uses six Ss for conceptualisation, as it aims to assess a vast variety of hospital service-affecting factors, ranging from contextual factors (i.e., societal factors) to auxiliary services (e.g., the kitchen). This level of detail is not deemed to be necessary nor useful to the overall hospital resilience assessment framework here presented. However, it has been ensured that the OHFRA resilience indicators fall within the list of indicators already introduced by the above-mentioned checklist, while some indicators are not used for resilience assessment. For this reason, the hospital conceptual model used in this document refers to four parts only. Annex 2 better describes the connection between the deliverables.

Staff is related to the human resources of the hospital, which are highlighted unilaterally across the literature as one of the most important components of resilient hospital systems (Khalil et al., 2022). The Staff uses consumables and supplies on a daily basis, which comprise basic resources (e.g., electricity, water, fuel etc.) and hospital-specific items (e.g., medical gases, medical items, drug products etc.). These two parts are connected to the built environment characteristics, grouped under Space. Finally, all the previously mentioned parts need to be managed, organised, and coordinated by a System which includes governance, communication, information management, coordination, emergency planning. Figure 2 depicts the hospital system conceptualisation.

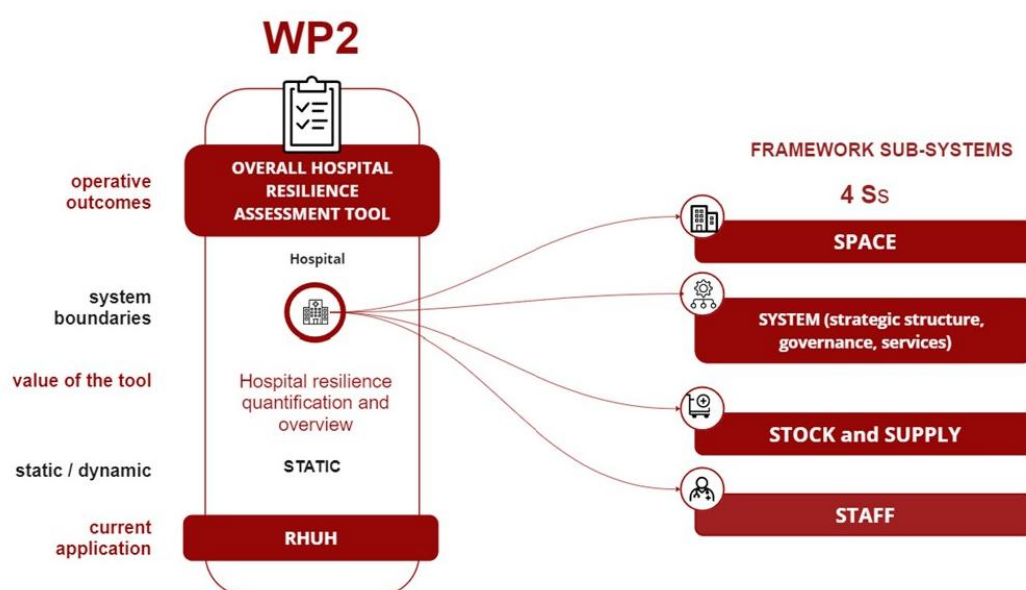


Figure 2. WP2 hospital system conceptualisation

3 Service measures

To evaluate the resilience of hospital systems, it is necessary to define what is expected of them, i.e., the measures of hospital service. The measures to be used depend on the objectives and targets of each specific health facility. They are to be set by the local authority with the support of humanitarian experts and can be setting-related. The changeability of the measures of service enables a high level of customisation and adaptability of the framework here described. References for measures of hospital service were found into the “*Reference Framework for health interventions for wounded and sick, hospital care – version July 2022*” and into the “*Medical Activity Database*”, both widely adopted ICRC tools.

Common variables used to evaluate hospital resilience comprise the number of fatalities, the number of admissions or the number of untreated patients (Khalil et al., 2022). Additionally, as the emergency care provided at the Emergency Department (ED) is of particular importance under disruptive circumstances², the following additional outcomes could be of interest (Rahimi et al., 2017; 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).

² The Emergency Department is often the first responder in case a disruptive event occurs. Acting as a buffer between the pre-clinical setting and more complex care delivery, emergency care is typically characterised by high levels of uncertainty and time-sensitivity of demand for services. It is fair to assume that resilience should be a particularly important characteristic to assess especially in the area of emergency care. According to a recent report regarding the health care system resilience in Europe, emergency care appeared to be among the most common assessed components, together with public health and hospital care.

The measures of service proposed along with possible measurement methods are shown in Table 1. They were identified by the researchers and ICRC members by means of focused group discussion³.

Table 1. Proposed measures of service

Name	Measurement ⁴	Unit	Note
Average mortality rate below 24hrs from admission	Number of fatalities below 24 hrs from admission / number of admitted patients.	%	Admitted patients in this case are all those triaged at the ED, not necessarily hospitalised
Average mortality rate after 24hrs from admission	Number of fatalities after 24 hrs from admission / number of admitted patients	%	These are in-hospital fatalities
Average length of stay	Total daily census / total number of admissions	days	Examples of essential units to be considered: surgical unit, medical unit, HDU areas. ED can be excluded
Average time spent at the ED	Average time from triage to discharge/transfer	hrs	-
Total surgical volume	Total number of surgical procedures done in operating theatres	N	-
Average surgery cancellation rate	Cancelled or postponed surgeries / planned surgeries	%	In case of emergency, planned surgeries comprise emergency surgeries too, which have been scheduled for the next day(s)

4 Resilience indicators

4.1 Overview

No single definition of resilience has been used consistently within the health care literature (EU Expert Group on Health Systems Performance Assessment, 2020), however it has been argued that “the most immediate outcome of a resilient hospital is to maintain its functions and ensure the continuity of essential and critical services” (Khalil et al., 2022). This is in line with the idea that the resilience of a system can be measured by looking at the service provided following the occurrence of a potentially disruptive event in other international frameworks and guidelines (CEN WA 17819, 2021).

For each part of the hospital system (described in Section 2), indicators of how well the hospital system performs have been identified. The indicators, ways of measurement and possible values for them were first identified by reviewing the scientific and grey literature (including policy papers, international tools, guidelines, recommendations, and technical specifications) of the last twenty years. WP1 checklist was considered too and at the end the authors devised a concise set of indicators.

The initial draft of the resilience indicators was discussed with ICRC experts through a questionnaire, with further details provided in Annex 3. Follow-up one-on-one interviews with ICRC experts allowed for additional refinements, particularly regarding measurement methods and potential values. As a result, 21 resilience indicators were finalized, as presented in Table 2. The list of indicators gives a good overview of the functioning of the hospital system without an excessive number of indicators and irrespective of hazard type. More indicators are not used to ensure that the framework is lean and easy to use. The indicators have been selected considering actions that may be taken to enhance hospital performance during the absorptive and recovery phases associated with the occurrence of

³ The meeting was held online on April 12th, 2023, and it involved experts with hospital administration and emergency management background. The authors initially proposed to count the number of in-hospital fatalities and the time the patients spend at the hospital; this was well received by the experts who proposed to add the surgical capacity too.

⁴ The measurement is referred to a unit of time such as months, weeks, days.

disruptive events, including increased demand for assistance, and decreased available resources. The proposed resilience indicators are further described in Annex 4. The Annex contains a detailed list and description of indicators, ways of measurement, indicator values and related meanings.

Possible values for the indicators range from 1 to 4, corresponding to the worst-case scenario and the best-case scenario respectively, as reported in Annex 4. The changes in the values of indicators are associated to changes in the values of the service measures. This document contains examples of how to build such a relationship and a case study to illustrate a quantitative resilience estimation.

Table 2. Summary of developed resilience indicators per hospital part

1. Staff	2. Stock and supplies	3. Space	4. System
1.1.1 Nurse-to-patient ratio in non-HDU	2.1.1 Emergency power reservoir capacity	3.1.1 Architectural and Structural systems condition and maintenance	4.1 Contingency plan implementation
1.1.2 Nurse-to-patient ratio in HDU	2.1.2 Tertiary power supply availability	3.1.2 Power-related system condition and maintenance	4.2 Information Management System implementation
1.2 Hospital staff well-being and job satisfaction	2.2.1 Emergency water reservoir availability	3.1.3 Water-related system condition and maintenance	4.3 Hospital Acquired Infection incidence rate
1.3 Frequency of emergency management training	2.2.2 Water quality	3.2.1 Bed Occupancy Rate	4.4 Coordination with pre-hospital emergency service and referral system
	2.3 Oxygen stock capacity	3.2.2 Hospital bed surge capacity	
	2.4 Blood shortage	3.3 Fire safety measures adoption	
	2.5 Essential drug products and medical devices shortage		

4.2 Staff

4.2.1 General

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 received. They are further described in Table 10, Annex 4.

4.2.2 Indicators n° 1.1.1 and n° 1.1.2: Nurse-to-patient ratio

Specific indicators: The indicators 1.1.1 and 1.1.2 are the nurse staffing level, expressed in terms of nurse-to-patient ratio, in non-High Dependency Units (HDU) and in HDU (i.e., units where severely ill and in need of constant monitoring patients are treated, such as the intensive care unit).

Background: The nurse staffing level affects all the measures of service considered in this work. Evidence that this is the case can be found in numerous articles. For example, across 38 countries around the world, it has been clarified that higher proportions of nurse staffing level are associated with higher quality of acute and life-threatening care services, in particular the risk of mortality and adverse clinical events (which in turn increase the length of stay) seems to be reduced (Amiri et al., 2017). Nurse-to-patient ratios influence most markedly in-hospital mortality (Driscoll et al., 2018). Indeed, the increase in the mortality rate of mechanically ventilated patients has been associated with lower bed-to-nurse-ratio, regardless of hospital type or admission department (the risk of mortality increases as the number of patients increases above 2.1) (Jung et al., 2020). There are several possible explanations for the sensitivity of hospital mortality of ventilated patients to bed-to-nurse-ratio, such

as the high workload required from the nurses (which in turn causes medical errors and higher length of stay), or the intensive monitoring and reliance on electrical equipment (which can fail). Higher nurse workloads were associated with higher nurse emotional exhaustion, job dissatisfaction, patient mortality, early re-admissions, and longer length of stay (McHugh et al., 2021; Yoon et al., 2022). Specifically, data suggest that Intensive Care Units (ICU) with better staffing had lower annual mortality rates, 1.8% lower when the ratio decreased from 2:1 to 1.5:1 (Checkley et al., 2014). Reducing the number of patients from an average of more than 3.3 to 2 patients per Registered Nurse (RN) in ICUs was associated with a 6% relative decrease in death (Kane et al., 2007). The sensitivity of mortality rate to nurse staffing level is valid in other hospital wards too, each additional surgical patient per RN is associated with an 7% increase in the likelihood of dying within 30 days from admission (Aiken et al., 2002). Also, in surgical patients, the odds of death were 38% less when 1 RN was assigned to 2 or less patients compared with more than 5 patients per shift and a decrease from an average of more than 5 to 2.8 surgical patients per RN was associated with a 35% reduction in mortality (Kane et al., 2007). Finally, low levels of nurse staffing in the ED are associated with patients leaving without being seen, longer ED care time and patient dissatisfaction (Recio-Suacedo et al., 2015). Indeed, waiting time is approximately 20 minutes higher when the ED is out-of-ratio compared to in-ratio nurse staffing levels (Chan et al., 2010).

Ways to measure: There are many ways for measuring the staff availability at hospitals, such as referring to the number of physicians or nurses per inhabitant or considering the number of nurses per hospital bed. However, the example here proposed (Section 5) considers the “nurse-to-patient ratio”. This is the number of patients who a nurse must care for at a time, and it depends on the number of nurses working at the hospital, the number of hospitalised patients, and the work shift. The nurse staffing level is considered to describe the availability of human resources as there is a nexus between the number of nurses, doctors, support staff, administrative personnel etc. The nurse-to-patient-ratio is generally established by law. Otherwise, it is set within the hospital organisation. The indicator proposed here considers the recommendation of the National Nurses United Association⁵, many scientific papers which also informed the definition of the impacts the indicator variability can have on the provided service (Kane et al., 2007; Checkley et al., 2014; Aiken et al., 2002; Yoon, 2022; Chan et al., 2010), and the expert opinion collected using interviews and questionnaire to ICRC members.

4.2.3 Indicator n° 1.3: Hospital staff well-being and job satisfaction

Specific indicator: The indicator hospital staff well-being and job satisfaction evaluates work environment conditions, sense of safety at work, burnout, monetary compensation, staff cohesion and commitment.

Background: Hospital staff, regardless of their level, background, and profession, represent the primary component of any hospital operation, and tension and anxiety among them can result in failure of the healthcare service. This means that the resilience of healthcare service can be compromised if staff members are under excessive pressure. High level of job stress is predictive of burnout and it is associated with high turnover rates, intention to quit the job, absenteeism, and low quality of care, including medical errors (Aiken et al., 2023; Parker & Kuli, 1995; De Hert, 2020). Especially during disruptive times, the mental health of health care workers is at great risk (due to

⁵ National Nurses United is the largest union and professional association of registered nurses in U.S. history. Available at: <https://www.nationalnursesunited.org/about>.

rapid changes in patient volume, clinical roles and ways of working). For instance, during the COVID-19 pandemic a considerable proportion of health care workers have experienced stress, anxiety, depression, and sleep disturbances, which ultimately affects response quality (Søvdal et al., 2021) and absenteeism (Achour et al., 2022). When multiple team members are experiencing factors related to compassion fatigue, burnout and secondary trauma, the impact on care delivery may compound, potentially leading to adverse events (like medical errors) (Achour et al., 2018).

Ways to measure: The indicator is a qualitative measure of job satisfaction and well-being. You could use qualitative methods, such as surveys and interviews, to collect information regarding job satisfaction, wellbeing and ultimately burnout. However, the example exposed in this text (Section 5) refers to monetary compensation, if payments are regularly provided and if salary has lost purchase power. These have been suggested by ICRC experts as a proxy for job satisfaction.

4.2.4 Indicator n° 1.4: Frequency of emergency management training

Specific indicator: The indicator is the frequency of emergency management training and it measures the preparedness of the staff..

Background: Competency plays a significant role in the resilience and continuity of hospital services before, during and after the occurrence of any disruptive event. Staff training and drills enhance hospital preparedness (Kester & Wei, 2018; Khademi et al., 2021). Training courses and drills which cover risk reduction procedures have proved to promote a prompt, efficient and smoother response (Al-Haji et al., 2021; Rehak et al., 2019). Staff need to be briefed, trained and to take part in exercises relevant to their areas of work, such as infection prevention and control or life-saving procedures, thus, ensuring staff competency and safety (WHO, 2020). Existing frameworks consider the number of courses and drills provided (WHO, 2020; Ortiz-Barrios et al., 2020) but training frequency must be considered too, as suggested by literature (Baetzner et al., 2022) and ICRC experts.

Ways to measure: The indicator quantifies the preparedness of staff by measuring the frequency of emergency management training and courses. It is worth noticing that training must be risk-specific and that for the same hazard several courses could be provided (e.g., for clinical management, for security and crowd management, etc.). For example, the developed application (Section 5) considers a Mass Casualty Incident (MCI) of trauma patients, where a triage course and Advance Trauma Life Support (ATLS) training program are used to quantify the impact of training on the service measures. Additional courses might be considered too, such as crowd management for security service, emergency power supply system management for engineers etc.

4.3 Stock and supplies

4.3.1 General

The indicators grouped under the *Stock and supplies* part focus on evaluating the hospital system's capacity for redundancy and resilience regarding essential resources. These indicators assess storage capacity, the availability of alternative supply sources, and the reliability of supply systems. Key aspects include the condition of critical infrastructure (e.g., water supply systems, electrical systems, and life-support equipment) and the presence of protective measures to ensure the functionality of supplies during disruptive events. Indicators are further described in Table 11, Annex 4.

4.3.2 Indicators n° 2.1.1 and n° 2.1.2: Emergency power reservoir capacity and tertiary power supply availability

Specific indicators: The indicators n° 2.1.1 and n° 2.1.2 evaluate emergency power supply capacity (i.e., autonomy of the hospital in case of a failure on the primary line) and redundancy (i.e., presence of a tertiary line in case of a failure on the secondary line).

Background: Loss of power functionality can have an immediate effect on hospital service (Achour & Miyajima, 2020). Indeed, power is needed for many essential emergency services, such as lifesaving procedures, surgeries and a multitude of medical activities which change the values of the measures of hospital service. Power loss at healthcare facilities is directly associated to an increased odd of mortality. For example, in the aftermath of the Hurricane Irma (Florida, 2017) power loss was associated to an increase in mortality in nursing homes, with a roughly 25% increase in mortality at 7 days after landfall. Neither age nor stay status significantly modified these results (Skarha et al., 2021). Further findings from the Sub-Saharan region of Africa revealed a positive association between the frequency of power outages and in-hospital mortality, with the risk for mortality estimated to increase by 43% for each day the power was out for over 2 hours (Apenteng et al., 2016). Given the relevancy of power availability at hospitals, many guidelines and regulations require hospitals to have a backup strategy in case of power loss. Based on NFPA-110 (Standard for Emergency and Standby Power Systems⁶), hospitals require a minimum of 96 hours of fuel oil (storage) supply for an emergency standby power plant. In particular, operating theatres and Intensive Care Units require minimum two separate sources of power — one from the normal power distribution and one from the emergency source (NFPA, 2022). The Health Technical Memorandum 06 provided by NHS, England, suggests assessing the ability to maintain essential supply in the event of not only primary failures but also secondary failures. An example here may be a standby generator failing to start (second-line fault) on a supply blackout (first-line fault). The provision of tertiary supplies (Uninterruptible Power Supply and local batteries) is mentioned as a suitable risk mitigation strategy at least for a short period of time (e.g., some minutes) (NHS, 2017).

Ways to measure: The indicators are to be measured together with the hospital technical department. You can refer to an emergency plan or to other technical documentation regarding the presence of an emergency power supply system if available, otherwise, you can estimate the power supply autonomy and the presence of a tertiary line by means of interviews with the head of the technical department or key technical staff. The indicator value is expressed in terms of days of autonomy, considering the services you want to provide under the analysed disruptive scenario and the number of generators needed to do that. For example, the hospital might have 2 days of autonomy if you want to run 4 generators per time to provide all the critical services, but it might double its autonomy if, under extreme circumstances, it is decided to run 2 generators at a time for providing essential services only (e.g., emergency care, emergency surgery, intensive care). Finally, the reliability of the emergency power supply system can be affected by the condition and the location of it. For this reason, you should decrease the indicator value if only corrective maintenance is performed on the alternative source of power (e.g., generators) and if this is in a vulnerable area to the specific analysed event (e.g., an

⁶ This is a Code provided by the National Fire Protection Association. Available at: <https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=110>.

underground basement is a vulnerable area to floods, generators placed outside the hospital building or on the roof top might be vulnerable to shelling).

4.3.3 Indicator n° 2.2.1 and 2.2.2 Emergency water reservoir capacity and water quality
Specific indicators: The indicators n° 2.2.1 and n° 2.2.2 evaluate emergency water reservoir capacity (i.e., autonomy of the hospital in case of a water supply interruption) and water quality (i.e., water safety testing).

Background: Data show that healthcare capabilities are degraded 67% - 99% within two hours of water service loss (Achour & Miyajima, 2020). It is important then to ensure that critical water supply is not compromised. The Hospital Safety Index (WHO, 2015) suggests hospitals have a water reservoir sufficient for at least a specific minimum time, e.g., 72 hours, for medical and domestic uses, in addition to a water reserve for fires. Typically, water storage is in cisterns or reserve tanks on the ground floor and elevated tanks (WHO, 2015). Water reservoir volume should be determined considering the water usage under different scenarios, examples of emergency water storage and usage estimates are provided by the CDC (Centers for Disease Control and Prevention and American Water Works Association, 2019). Apart from the availability of water, water quality is also of primary importance. For example, unsafe water is responsible for 72% of diarrhoea deaths among children younger than 5 years across the globe (Global Burden of Disease, 2018). Nosocomial waterborne infections cause significant increases in the mortality rate. ICRC experts suggested analysing the burden of *Pseudomonas aeruginosa* (PA) specifically. This can increase both the number of fatalities and the time a patient spends at the hospitals, indeed, an estimated 1400 deaths occur each year in the United States because of waterborne nosocomial pneumonias caused by PA alone (Anaissie et al., 2002). Blood transfusion, mechanical ventilation, ICU admission are risk factors of mortality among patients with PA bacteraemia (Zhang et al., 2020) and the mortality rate associated to PA infection is about 26-28% (Babich et al., 2020; Zhang et al., 2020). Moreover, the additional length of stay due to the acquired infection is of 7-12 days (Kaier et al., 2019; Jia H et al., 2019). However, most waterborne nosocomial infections are preventable by means of treatment and purification technology. For this reason, the indicator 2.2.2 evaluates the frequency of water quality checking, the existence of a reporting system and a programme for water quality checking.

Ways to measure: The indicator 2.2.1 is expressed in terms of days of autonomy of the water reservoir assuming that it cannot be refilled within 3 days. A technical evaluation is needed to estimate such autonomy and it is recommended to involve the head of the technical department or key technical staff in the assessment. It could be relevant to assess the maintenance and the location safety too, Whereas applicable, the period of autonomy can be evaluated assuming that only emergency services are kept during extreme circumstances. The indicator 2.2.2 is a qualitative measurement of safety measures adoption and implementation, based on document reviews and interviews with quality and risk managers. It is important to check that plans and programs for water quality control exist and are implemented regularly, tests are performed at least each 6 months and that the results are documented and available.

4.3.4 Indicator n° 2.3: Oxygen stock capacity

Specific indicator: The indicator evaluates the oxygen stock capacity in terms of days of autonomy.

Background: Medical gases at hospitals are used for a variety of procedures and treatment, such as respiratory support and ventilation, anaesthesia, and lab applications. The loss of medical gases

provision (e.g., due to a failure of the distribution system or due to an exhausted reservoir) is directly linked to the loss of surgical capacity, intensive care and eventually to an increased number of fatalities. Experts involved in the definition of this indicator suggested limiting the assessment to oxygen availability, as this is commonly available in ICRC settings, while other kinds of gases are rare. The relevancy of oxygen availability is clear, it is needed for performing surgeries and other lifesaving emergency procedures and it is used for treating patients with pneumonia or hypoxia. Thus, oxygen availability is strictly linked to mortality and number of surgeries performed. It is also true that oxygen restrictions can cause an increase in the length of stay for those patients requiring life support treatments.

Ways to measure: The indicator is to be measured together with the stock manager by means of document reviews and interviews. The WHO (WHO, 2015) argues for planning for long-term stock capacity, as the delivery of medical gases are infrequent. However, the capacity of medical gases stock must be evaluated considering hospital characteristics and the consequences of each specific disruptive event, in terms of service needed and increased demand for assistance. For example, the case study described here assumes that three days of oxygen autonomy are sufficient, considering both the type of event (i.e., an MCI) and the hospital infrastructure, which is equipped with an oxygen generator system. The capacity of the oxygen stock is expressed in days of autonomy (assuming that the stock cannot be refilled within 3 days). Both central supply tanks and portable cylinders and concentrators can be used for assessment.

4.3.5 Indicator n° 2.4: Blood shortage

Specific indicator: The indicator evaluates the number of days over a month with the shortage of blood units or its components.

Background: The aim of blood transfusion is to save lives or to prevent significant morbidity, it heavily affects the mortality rate and the surgical volumes. Especially during conflicts, the availability of blood saves lives, this is true for bullets, fragments, burn injuries, and peripheral injuries. Indeed, 28% of patients injured by mines required blood transfusion (Giannou & Baldan, 2010). However, blood supply chain management presents major challenges, related to shortage and wastage of blood products.

Ways to measure: The indicator is measured by counting the number of days blood units were not available at the hospital during the last month. This evaluation requires collaboration with key staff responsible for the hospital's blood bank operations, ensuring accurate data on bloodstock levels and supply chain performance. You can count the bloodstock capacity in terms of days of autonomy or you can monitor the stock-out days, the latter is to increase the chances of detecting a problem in the blood supply chain.

4.3.6 Indicator n° 2.5: Essential drug products and medical devices shortage

Specific indicator: The indicator evaluates the number of days over a month with shortage of essential drug products and medical items.

Background: Drugs, life-support equipment and other medical items must be maintained and stored. In Europe, medicine shortages resulted into delays in care or therapy, cancellation of care, suboptimal treatment and increased length of stay (EAHP, 2023). The availability of medicines can heavily affect the absorptive and responsive capacity of hospitals. This is also suggested by the COVID-19 experience,

where many healthcare systems and consequently hospitals faced a shortage of personal protective equipment (Khademi et al., 2021). The level of demand for medical instruments and pharmaceuticals must be verified for each disruptive event, considering the types of services provided and the additional demand for assistance. ICRC experts suggested considering anaesthetics (used to perform surgeries), intravenous (IV) fluids (directly linked to mortality) and antibiotics (associated to increased length of stay) to quantify the impact of this indicator on the values of service measure.

Ways to measure: The indicator is measured by counting the number of days during a month with shortage of essential drug products and medical devices. To evaluate the indicator, it is recommended to have a list of essential items of interest and collect the information with the support of the pharmacy, head nurse and stock manager. This document refers to IV fluids, anaesthetics, antibiotics shortages as this is a good indication of potential supply chain and stock management issues. An alternative way for measurement is to refer directly to emergency kits (e.g., the weapon wounded kit for surgical team) stored at the hospital, although these change according to the hazard type and might not be always available.

4.4 Space

4.4.1 General

The indicators grouped under the Space part are aimed at assessing the physical condition of the building, the bed occupancy rate, the capacity to increase the bed number, the adopted fire safety measures. These indicators consider the impacts the physical environment can cause on hospital functionality at the highest level of modelling (i.e., the entire building). The proposed indicators are further described in Table 12, Annex 4.

4.4.2 Indicator n° 3.1.1, n°3.1.2, n°3.1.3: Architectural and structural systems maintenance and condition; electrical system maintenance and condition; water related system maintenance and condition

Specific indicator: Indicator 3.1.1 evaluates the performed maintenance and the condition of architectural and structural elements, indicator 3.1.2 evaluates the performed maintenance and the condition of electrical components and distribution line, indicator 3.1.3 evaluates the performed maintenance and the condition of plumbing system. The indicators refer to the entire hospital.

Background: The Hospital Safety Index pays great attention to the condition of structural and non-structural components as their deterioration is assumed to affect hospital safety (WHO, 2015). Specific studies have been conducted to quantify the loss of hospital functionality due to poor building conditions. Achour et al. (Achour & Miyajima, 2020) studied the loss of hospital functionality in case of an earthquake. Apart from the seismic metrics and intensity, hospital age is a factor that has a potential connection with loss of functionality. However, good maintenance is what kept hospitals performing well despite their age. Hospitals were evacuated mainly because of architectural damage and damage to critical systems, including medical equipment.

Ways to measure: A technical evaluation is needed to measure these indicators. The buildings should be inspected for signs of deterioration, cracks and deformation which affect safety and functionality. It is advised to involve the head of the technical department or key technical staff in the evaluation process and to get information about the time to restore services (based on past failures) and the type

of maintenance performed. Indeed, if only corrective maintenance is performed, it is advised to decrease the indicator value as the systems lose reliability.

4.4.3 Indicator n° 3.2.1, n°3.2.2: Bed occupancy rate and bed surge capacity

Specific indicator: The indicators evaluate the bed availability by looking at the bed occupancy rate and by assessing the capacity to surge the number of opened beds. Opened beds are intended to be equipped and staffed.

Background: Bed availability is of primary importance when the demand for assistance suddenly increases, it allows smooth processes through the entire hospital, and it boosts the admission rate and the emergency care too, since if the emergency department is congested, new arrivals cannot be admitted and treated. A missed admission can lead to increased morbidity and mortality. Bed occupancy rates are positively associated with overall and surgical mortality (Bosque-Mercader & Siciliani, 2022). The causal relationship between the two is complex and depends on many other variables. These include the fact that certain treatments can no longer be performed or are delayed. Moreover, the number of health care workers remains relatively stable despite occupancy variation (Sharma et al., 2022). Emergency department statistics collected over 90 days, in England, were used to identify a correlation between inpatient bed occupancy and ED waiting times longer than 4 hours (Paling et al., 2020). In a full hospital, with 100% bed occupancy, the proportion of patients waiting over 4 hours in an ED was 9 percentage points higher than at 85% occupancy level (Paling et al., 2020). As bed occupancy increased, the length of stay in the ED increased, indicating an imbalance between demand and capacity when bed occupancy increased (Ugglas et al., 2020). Other data suggest that when hospital occupancy increased by 10%, the median ED length of stay for admitted patients increased by 18 minutes (Forster et al., 2003). The indicator n° 3.2.2 evaluates the bed surge capacity, considering both non-HDU areas and HDU areas as during a mass casualty event a significant proportion of patients (2.5–34%) will require critical care (Rubinson et al., 2008). Recent experiences have outlined that the surge of critically ill patients can necessitate a tripling or a doubling of intensive care bed capacity, as it happened in New York (Keene et al., 2021) and North Europe (Chew et al., 2021) due to COVID-19. US studies suggest that 20% of a hospital's operating bed capacity can be mobilized within a few hours (Hick et al., 2004). Also, in a systematic review of disaster surge capacity, most studies classified an increase in surge capacity of 15–35% as "acceptable" (Hick et al., 2014).

Ways to measure: The bed occupancy rate is an information commonly monitored at hospitals, you can refer directly to ward reports to check it. This evaluation is to be done together with key medical staff, such as the head nurses and hospital unit coordinators directly involved in the hospital unit activities. If you need to calculate it from scratch, you can use the following: average daily census divided by the opened beds per day. It is advised to refer at least to the last month. To evaluate the hospital bed surge capacity, you can check contingency plans, whereas available, since this is commonly assessed during the preparation of the plans. The indicator n° 3.2.2 is calculated by dividing the number of additional beds which can be opened by the total number of beds opened during normal circumstances. Surge capacity comprises many aspects, such as additional specialized staff, medical equipment, and ICU space to provide timely care for a large influx of additional patients. Several strategies can be adopted to expand bed capacity, for example by discharging noncritical patients (i.e., reverse triage) it is possible to free up space for new arrivals within a few hours. Some patients could be referred to other facilities and the remaining demand for beds can be addressed by placing additional beds and stretchers in existing wards as well as corridors, lobbies and spare rooms. A mass

casualty incident requires an immediate surge of beds, so the evaluation should be referred to the beds which can be made available within a few hours from the first arrival at the ED on the day of the disruptive event. A slow-onset event, like an epidemic, allows major engineering and organisational adaptations, so the evaluation can comprise transforming existing wards and external areas as well as setting up additional facilities, as suggested by the COVID-19 experience (Marmo et al., 2022).

4.4.4 Indicator n° 3.3: Fire safety measures adoption

Specific indicator: The indicator evaluates if safety in case of fire is provided by means of the following: 1) fire detecting system and firefighting system (e.g., smoke sensors, fire compartments, extinguishers, presence of water reservoir for fire etc.); 2) presence of fire response team in the hospital; 3) evacuation plan available and implemented (e.g., emergency exits and routes are indicated, evacuation routes are free of obstacles; presence of emergency light system etc.); 4) fire training and education sessions. Safety measures must be adopted at least in the following areas: patients' rooms and treatment areas (e.g., HDU, OT) and areas at high risk of fire (e.g., kitchen and storage of inflammable items).

Background: The hospital must be completely protected against fire since this type of hazard can stop services in a hospital when they are most needed. Hospitals are buildings which are extremely difficult to evacuate; therefore, the most important aspect of fire safety is to have the best means of prevention and protection in place (WHO, 2015). The consequences of a fire on the measures of hospital service differ according to the location of the event. However, major problems can occur when a fire occurs in patient treatment areas, especially critical units and operating theatres (Kelly et al., 2021). A recent study from South Korea (Jang et al., 2022) reported the consequences of a fire breaking out in a mechanical facility generating a large amount of smoke which spread to all hospital floors and injured many patients by smoke inhalation. In particular, around 1/3 of inpatients were affected by the fire, 95% of them reported shortness of breath, ¼ required admission to ICU. Smoke inhalation alone increases mortality of 20% and if pneumonia is present too then mortality increases of 60%. (Shirani et al., 1987). Length of stay increases of about 60% due to inhalation injuries (AbdelWahab et al., 2018).

Ways of measurement: The indicator qualitatively evaluates the presence of means of prevention and protection in case of fire, and it is based upon building inspections, surveys and documents review (at a given time). This evaluation is to be done together with key technical staff. This indicator is not to be intended to evaluate the risk of fire but serves as a measurement of the hospital capability of providing service in case of fire, scenario which can be caused by many events (e.g., earthquake, violent intrusion etc.).

4.5 System

4.5.1 General

It has been reported that a competent management has a great impact on hospital preparedness, response, and recovery capacity (Khademi et al., 2021). This includes disaster planning, risk assessment, incident command system, logistic and financial management, coordination and communication, infection surveillance. All these capacities can be grouped into the System part and

evaluated by means of the following indicators: contingency plan implementation, Information Management System (IMS) implementation, coordination with pre-hospital emergency service and referral system, Hospital Acquired Infections (HAI) incidence rate. These indicators are further detailed in Table 13, Annex 4.

4.5.2 Indicator n° 4.1: Contingency plan implementation

Specific indicator: The indicator evaluates the presence, testing and upgrading of an emergency contingency plan to respond to a potentially disruptive event that may occur within the hospital and community. The evaluation includes mitigation and preparedness measures as well as response and recovery strategies (e.g., command committee definition, identification of critical services and related needs, identification of roles and responsibilities, listing and stocking emergency kits, human resources surge plan, emergency protocols etc.).

Background: Studies on hospital system resilience consistently highlight planning and management among the top strategies to improve operations and ensure continuity of service (WHO, 2022). The contingency plan is activated when the number of ill or injured exceeds the normal capacity to provide the quality of care required. A contingency plan contains many modules for ensuring a prompt response, including patient management, crowd management, internal and external coordination, ensuring basic resources and stockpiling critical items (e.g., emergency kits). According to ICRC experts involved into the definition of this indicator, even if a contingency plan is adopted, available resources at the hospital might not be enough to fully implement the plan, and this is typically related to the lack of medical supplies. Thus, a contingency plan which cannot be fully implemented can cause a high increase in mortality within few hours from its activation. Cimellaro et al. (Cimellaro et al., 2017) suggested that there is a reduction of waiting time at the ED of 96% for the yellow codes and of 75% for the green codes respectively when the emergency plan is activated in case of an earthquake. In the referred study the triage coding system uses colours for differentiating severely ill patients (red and yellow) from non-critical patients (green).

Ways to measure: the indicator n° 4.1 is a qualitative evaluation of emergency management strategies to be performed by means of document reviews, surveys, and interviews with key medical staff, such as hospital unit coordinators and head nurses, who should be aware of the existence of a contingency plan. If a plan exists, the key staff designed to coordinate its implementation it is to be interviewed. The evaluation includes mitigation and preparedness measures (e.g., risk and vulnerability assessment to be performed and reported regularly, related documents establishing strategies to mitigate the identified risks, the establishment of an Incident Command Group, identification of critical services and related needs etc.). Response and recovery activities must be considered too (e.g., recognition of triggering events for the activation of the response plan, hospital surge plan, triage procedures definition, coordinating the internal and external information flow, appointing a post-disaster office etc.).

4.5.3 Indicator n° 4.3: Information Management System

Specific indicator: The indicator evaluates if an Information Management System (IMS) is implemented to keep track of resource availability and patient data. Resources include personnel, beds, stocks and supplies. Patients' medical record files should contain all the relevant information to identify the patient, to support the diagnosis, to justify the treatment, and to document the course and results of treatment. IMS can be digital or paper-based.

Background: Timely and reliable information enables an effective response to a disruptive event (Ismail et al., 2020). Strengthening hospital resilience requires efficient facility-level information systems and management. Information systems should support all the hospital activities, all preparedness strategies, and all interventions to optimize service delivery (WHO, 2022). Secure, private, and efficient health data management supports more precise diagnoses, prognoses, and public insights (Ismail et al., 2020). Finally, strengthening hospital information systems allows data-driven decisions and transparent and timely communication with relevant stakeholders (WHO, 2015). When no IMS is adopted and implemented at hospital, you can assume that essential drug products, medical items, blood, oxygen, and even basic resources such as fuel and water, might miss for a relatively short period of time (according to the lead time).

Ways to measure: Technical evaluation based on document reviews, surveys, and interviews with key technicians and medical staff, such as information system managers, whereas available, and technical staff and hospital unit coordinators who are the users of the IMS.

4.5.4 Indicator n° 4.3: Hospital Acquired Infections incidence rate

Specific indicator: The indicator evaluates the incidence of Hospital Acquired Infections (HAIs) among hospitalised patients.

Background: Hospital-acquired infections represent one of the most frequent adverse events during health care delivery and they cause morbidity and mortality worldwide (Maki & Zervos, 2021). Inadequate Infection Prevention and Control (IPC) is a determinant of poor-quality care delivery and health services disruption, particularly in lower-income settings. The WHO global report on IPC shows that where infection prevention and control cost-effective practices are followed, 70% of hospital-acquired infections can be prevented. Out of every 100 patients in acute-care hospitals, 7 patients in high-income countries and 15 patients in low- and middle-income countries will acquire at least one healthcare-associated infection during their hospital stay. On average, 1 in every 10 affected patients will die from this infection (WHO, 2022). The impact of HAI is so big that, in EU countries, disability and premature mortality caused by the most common hospital acquired infections are twice those caused by other common infectious diseases (Cassini et al., 2016). The excess length of stay attributable to HAI has a great variability according to the type of pathogen and patient conditions (Stewart et al., 2021; Green et al., 2014). Surgical Site Infection (SSI) is the most frequent HAI in Low- and Middle-Income Countries (LMIC), with a pooled incidence of 11.8 per 100 surgical procedures. Compared with patients undergoing surgery who do not have a surgical site infection, those with a surgical site infection are hospitalized approximately 7 to 11 days longer (Seidelman et al., 2023). In France, patients experiencing a HAI following surgery had a significantly increased mortality risk (4.15-fold) and an increased length of hospital stay (threefold) (Lamarsalle et al., 2013).

Ways to measure: The indicator is a quantitative evaluation based on document review. The risk management or quality management departments are to be involved in this evaluation. It is recommended to look at least at the last three months to have an idea of the average hospital-acquired infection incidence rate. In the case-study described in Section 6 the indicator relates to Surgical Site Infection incidence rate and related impacts.

4.5.5 Indicator n° 4.4: Coordination with pre-hospital emergency service and referral system
Specific indicator: The indicator evaluates if the hospital system is able to collaborate with external healthcare providers and with pre-hospital emergency care providers.

Background: Mechanisms to coordinate with national and local authorities are needed to ensure that consistent decisions are taken in case of emergency (WHO, 2020). Coordination with external facilities and pre-hospital services is related to the opportunity of transferring patients as well as controlling emergency arrivals. External coordination can decrease the demand for assistance in a hospital either due to the distribution of patients among available facilities or due to transfer, after admission, to other facilities if the hospital does not have the required resources to cope with that demand. Lack of coordination is directly linked to an increase in the mortality rate.

Ways to measure: Qualitative evaluation based on document review and interviews with key medical staff, such as hospital unit coordinators. In the best-case scenario, the hospital has formal mechanisms and agreements in place to provide a coordinated and integrated response to disasters. It is worth noticing that also the safety of telecommunication systems and the existence of alternative means of communication influence hospital system resilience (WHO, 2015). However, the proposed indicator assumes that basic communication means are available.

5 Resilience estimation

The resilience estimation is made for a specified potentially disruptive event and over a specified period. It is necessary to identify a set of potentially disruptive events of interest, such as the yearly expected mass casualty incident, the ten years expected mass casualty incident and the fifty years expected mass casualty incident. For each event, the resilience is then estimated. This requires experts, especially key medical staff, to estimate the loss of service provision assuming that each event occurs, i.e., what they believe would be the effect of the event on the values of the service measures. The service measures estimation is done over a specified period (e.g., over one week).

The values of the service measures are to be estimated, first, at the baseline condition, which is representative of how the hospital is supposed to work, whereas standards of performance are available, or how the hospital organisation wants it to work. The indicators explained in the previous section are used to describe the baseline condition. Expert opinion is needed to reach an agreement on the potential values of the indicators which comprise the baseline, prior to proceeding further. Experts can comprise key medical and technical staff working at the hospital under analysis, as well as Wathab and Health delegates from ICRC. At the baseline condition, the hospital is supposed to provide a certain service, quantified by certain values of the measures of service, such as a mortality rate lower than 5% or time spent at the ED lower than 2 hours.

The values of the service measures are then to be estimated again, using different indicator values. This is done by determining the relationship between unit changes in each indicator value on each measure of service (i.e., estimating the likely increase/decrease in service from the baseline).

Finally, the experts can estimate the hospital resilience, by calculating the difference between the two estimates, referred to the baseline condition and to the current 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 the result of qualitative resilience estimation is given in Table 3 and Figure 3. It can be seen in Table 3, 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 a blackout. It is also important to note that the resilience estimation does not account for interdependence among the various indicators nor the costs of intervention are considered.

Table 3. Example of impacts of indicator values on 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
		<u>3^b</u>	<u>1:8^b</u>	<u>No change^b</u>
Stock and Supplies	Emergency power supply reservoir capacity	<u>1</u>	<u>No fuel reservoir</u>	<u>High increase</u>
		2	Fuel reservoir lasts 1 day	High increase
		3 ^b	Fuel reservoir lasts 3 days ^b	No change ^b
Space	Bed surge capacity	<u>1</u>	<u>Not assessed</u>	<u>Moderate increase</u>
		2	20-40%	Slight increase
		3 ^b	More than 40% ^b	No change ^b
System	Referral system	1	No coordination	Moderate increase
		<u>2</u>	<u>Informal coordination</u>	<u>Slight increase</u>
		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%.			

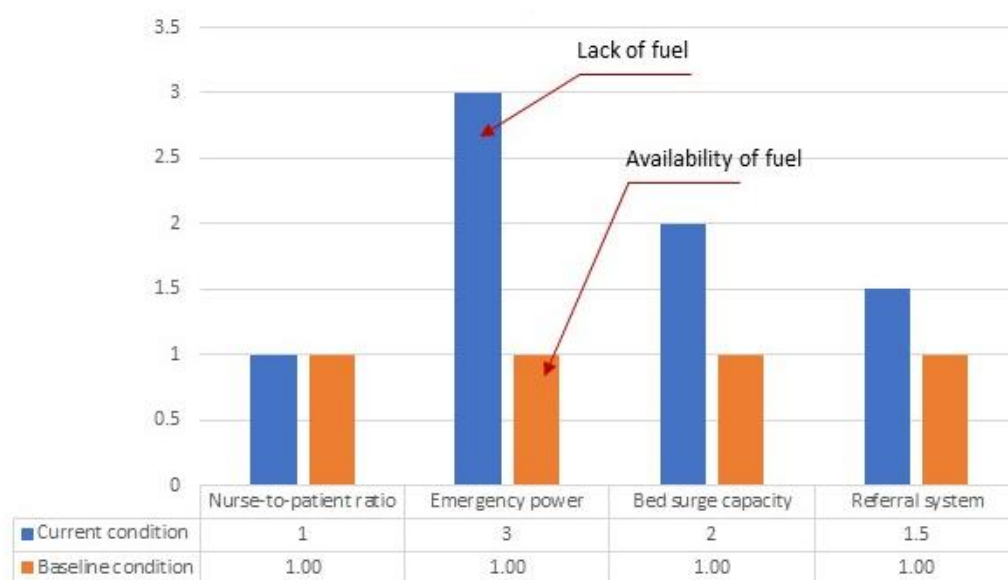


Figure 3. Example of estimation of mortality rate for a certain event over a defined investigated period

6 Case study: Rafik Hariri University Hospital, Beirut, Lebanon

6.1 General

This section summarizes the results of the resilience assessment performed for the Rafik Hariri University Hospital (RHUH), located in Beirut, Lebanon. This facility has been used as a case study to test the applicability of the resilience indicators, to provide an example of resilience estimation, and to test the overall value of the proposed framework.

This example was developed with the aid of the ICRC Lebanese delegation. The data and information used were collected over one year (from October 2022 to October 2023), through focus groups, questionnaires, interviews, workshops, document review, analysis of hospital information management database, and field visits at the RHUH.

The hypothesis used to perform the assessment were discussed with the ICRC Wathab and Health delegates, so that years of expertise guided the assessment and verified the soundness of the results.

The sections below report what was done for the RHUH case study following the main steps of the framework previously presented.

6.2 System representation

First, information regarding the RHUH and the data reported in Table 4 were collected to describe the system. The table contains a list of the information used to describe the service the RHUH is providing today⁷, which served as a starting point for estimating the service it can provide under potentially disruptive events. Nure monthly reports and hospital information system were accessed and analysed. The values of the service measures were set referring to the month prior to the assessment. Documents review was complemented by interviews with key medical staff, such as hospital unit coordinators and head nurses.

Then, the ICRC experts, together with the hospital staff, suggested to explore a mass casualty incident as a potentially disruptive event. The reason behind this choice was related to the occurrence of a similar event few years ago and there was a shared interest in estimating the current hospital resilience under the same circumstances. This consists of a sudden increase in arrivals at the ED. The main expected patient type is a trauma patient, who is the victim of an explosion. The explosion is considered to happen far from the hospital, so that hospital resources are not diminished due to the event. The details of the potentially disruptive event are reported in Table 5.

⁷ Data refers to October 2023.

Table 4. Hospital characteristics

Hospital data, without disruptive event			
	Value		
Item	N	%	Note
Number of opened hospital beds	207	100	Excluded: Private clinic and primary care, Delivery, Dialysis, Mental health
Number of inpatient beds for medical-surgical adult patients	59	28	Data from nurse's monthly report
Emergency department beds	38	18	Data from nurse's monthly report
Number of beds in HDU areas	44	21	Intensive care - According to nurse's monthly report
Other beds	67	33	
Number of existing operating rooms	8		Data from nurse's monthly report
Current service measures values, without a disruptive event			
Item	Value		Note
Average mortality rate below 24hrs from admission (%)	0.2		Data from nurse's monthly report and hospital information management system
Average mortality rate after 24hrs from admission (%)	5.2		Data from nurse's monthly report and hospital information management system
Average Length of Stay (days)	8.29		Data from nurse's monthly report and hospital information management system
Surgeries performed per day (n)	10		Data from nurse's monthly report
Average time spent at the Emergency Department (hrs)	24.00		Data from nurse's monthly report
Surgery cancellation rate (%)	5.41		Data from nurse's monthly report
Additional required information			
Item	Value		Note
Average n° patients requiring oxygen (%)	21		Hypothesis: entire HDU needs oxygen
Average n° patients requiring blood transfusion (%)	12.50		Data from hospital blood bank report
Average n° patients requiring antibiotics (%)	10.00		Hypothesis
Average n° of arrivals at the ED per day (n)	30		Data from nurse's monthly report
Emergency surgeries performed per day (n)	5		Data from nurse's monthly report

Table 5. Description of the potentially disruptive event

Description of the event			
Item	Value		Note
	days		
Investigated period	3		This is the investigated period for resilience assessment
	n°	%	
Total arrivals at the ED on the day of the event	200	100	Example
Red patients	40	20	Example
Yellow patients	60	30	Example
Green patients	100	50	Example
Expected mortality rate below 24hrs (%) on the day of the event	20	10	Data from experts with medical background
Additional required information			
Item	Value		Note
	n°	%	
Patients requiring surgery within 24hrs from admission	100	50	Pessimistic hypothesis: 100% Red and 100% Yellow

6.3 Service measures

The expected values of the service measures, reported in Table 6, were estimated by discussing the matter with ICRC experts and RHUH staff, given the disruptive scenario described above. The estimation was done considering the RHUH at its baseline condition, as discussed in the next section.

Table 6. Expected measures of service at the baseline condition under the disruptive circumstances described above.

Expected measures of service under disruptive event		
Item	Value	Note
Investigated period (days)	3	This is the investigated period for resilience assessment
Average mortality rate below 24hrs (%)	19	Calculated as the average over the admissions. It also contains non-incident related mortality (of the following days)
Average mortality rate after 24hrs (%)	5.00	Example
Average Length of Stay (days)	8.2	Example
Average time spent at the Emergency Department (hrs)	7	Calculated as the average over the admissions. Be aware that on the first day the hospital speeds up the processes at the ED, but from the second day it goes back to the "normal" treatment velocity.
Surgeries performed over the investigated period (n)	40	This considers the event victims' surgeries, to be performed within 24-48 hours, and additional emergency surgeries (on the following days).
Average surgery cancellation rate over the investigated period (%)	50	Calculation: elective volumes (about 20 surgeries) divided the performed ones (55 emergency surgeries).

6.4 Resilience indicators

Hospital staff and ICRC delegates were consulted to define the baseline and the current condition for the RHUH. Table 7 contains an extract of the performed condition assessment, for example, at the baseline condition the RHUH would like to have a surgical site infection incidence rate less than 5%, but it currently is more than 10%.

Table 7. Examples of resilience indicators

Part	Indicator name	Description	Values	Meaning
Staff	Patient-to-nurse ratio in non-High Dependency Units	It evaluates the number of nurses per patient in non-High Dependency Units	1	1:12 or more
			2	1:10-1:12
			3	1:8-1:10
			<u>4^b</u>	<u>1:8 or less^b</u>
System	Hospital Acquired Infections incidence rate	It evaluates the incidence of Hospital Acquired Infections among hospitalised patients. Surgical Site Infections are used for this assessment.	<u>1</u>	<u>10% or more or reports are not available</u>
			2	5-10%
			4 ^b	Less than 5% ^b
^b baseline condition, <u>current condition</u>				

The connection between indicator values and values of measures of service for the analysed case study was established by literature findings and expert opinion, involving both ICRC doctors and technical staff. Details are reported in Table 8.

Table 8. Changes in values of the measures of service according to the changes in values of indicators

Part	Indicator name	Mortality rate <24hrs	Mortality rate >24hrs	Length of stay	Time spent at the ED	Surgeries performed
Staff	Patient-to-nurse ratio in non-HDU	No evidence. This is due to the fact that the ED has been considered part of HDU.	+1 patient per nurse → +20% increase in mortality of inpatients into non-HDU	+2 patients per nurse → +20% increase in length of stay in non-HDU	+2 patients per nurse → +20 min	No direct impact, however, staff availability in OT is considered to estimate the maximum surgical capacity. The maximum surgical capacity has two major limiting factors: number of available OTs and surgical team.
Staff	Patient-to-nurse ratio in HDU	As on the right. The ED has been assumed to be part of HDU.	+1 ICU patient per nurse → +10%	As above	As above	
Staff	Well-being and job satisfaction	Same as having 1 additional patient per nurse in non-HDU.	Same as having 1 additional patient per nurse in non-HDU.	Same as having 1 additional patient per nurse in non-HDU.	Same as having 1 additional patient per nurse in non-HDU.	No direct impact.
Staff	Frequency of emergency management training for hospital staff	If ATLS ⁸ training is not provided the mortality rate increase of +100%	If ATLS training is not provided the mortality rate increase of +100%	No impact.	If ATLS training is not provided the mortality rate increases of +20%	No impact.

⁸ ATLS: Advanced Trauma Life Support course.

Table 8 (continued) - Changes in values of the measures of service according to the changes in values of indicators

Part	Indicator name	Mortality rate <24hrs	Mortality rate >24hrs	Length of stay	Time spent at the ED	Surgeries performed
Staff	Frequency of emergency management training for hospital staff	If triage training is not provided → +100% increase in mortality rate	If triage training is not provided → +100% increase in mortality rate	No impact.	If triage training is not provided → time increase of 20%	No impact.
Stock & supplies	Emergency power reservoir capacity	Each day without power leads to the death of at least the patients requiring lifesaving treatment at the ED and emergency surgery (because surgery is cancelled when there is no power)	Each day when power outage is more than 2 hrs mortality rate increases of 43%.	The length of stay is increased by each day the power is lost (so 1 day without power means 1 day more at the hospital)	No impact.	No power → no surgery.
Stock & Supplies	Tertiary power supply availability	No impact.	Loss of ICU.	No impact.	No impact.	No impact.
Stock & Supplies	Emergency water reservoir capacity	Patients requiring surgery have high risk of dying.	Patients requiring surgery have high risk of dying.	The length of stay is increased by each day the water is lost (so 1 day without water means 1 day more at the hospital. This is valid for the survivors) ⁹	No impact.	No water → no surgery
Stock & Supply	Water quality control. Pathogen considered: pseudomonas aeruginosa.	No impact.	ICU is at risk and the mortality rate of PA infection is about 20-30%.	Length of stay increases of additional 12 days.	No impact.	No impact.
Stock & Supplies	Oxygen availability	Each day without oxygen leads to the death of patients requiring emergency surgery and lifesaving treatment at the ED (because surgery is cancelled when there is no oxygen)	Loss of ICU.	No impact. ¹⁰	No impact.	No oxygen → no surgery

⁹ Example of service which might be canceled if there is no water: endoscopies, dialysis, auxiliary services (labs, pharmacy, kitchen, sterilisation, laundry, cleaning), no ventilation, no environment cooling or heating.

¹⁰ It is well known that oxygen limitation can increase the length of stay of patients requiring oxygen support, however quantifying this impact without considering specific patient characteristics and volumes is hard.

Table 8 (continued) - Changes in values of the measures of service according to the changes in values of indicators

Part	Indicator name	Mortality rate <24hrs	Mortality rate >24hrs	Length of stay	Time spent at the ED	Surgeries performed
Stock & Supplies	Blood shortage	Shortage of blood leads to the death of the event victims labelled as red after triage.	Shortage of blood leads to the death of the patients requiring blood transfusion (among the pool of the non-event related victims)	No impact.	No impact.	No blood → no surgery
Stock & Supplies	Essential drug products and medical items shortage ¹¹	Each stock out day leads to the death of at least the people needing lifesaving treatment at the ED.	Each stock out day → +50% mortality of surgical and critical patients.	Each stock out day of antibiotics leads to 50% increase in length of stay for patients requiring antibiotic therapy.	No impact.	No anaesthetic drugs → no surgery.
Space	Architectural and structural systems condition and maintenance	No impact. The analysed MCI is not causing a stress on the safety and integrity of the building, thus this indicator is not affecting hospital resilience.				
Space	Power-related system condition and maintenance	A very deteriorated system can cause power loss of 8 hours.				
Space	Water-related system condition and maintenance	A very deteriorated system can cause water loss of 8 hours.				
Space	Bed occupancy rate (BOR)	Red and Yellow patients who do not receive a bed within 4 hours die.	+10% BOR → +10% increase in mortality	No impact.	+10% BOR → +20 minutes at the ED	No impact.
Space	Hospital bed surge capacity	As above.	No impact.	No impact.	As above.	No impact.

¹¹ It is assumed that lack of IV fluids at the emergency department can cause the immediate death of the event victims; the lack of antibiotics increases the mortality rate after 24 hrs from admission as well as the length of stay; the lack of controlled drugs does not allow to perform surgeries. Please note that in the count of the fatalities occurring after 24hrs from admission, the authors are considering also those potentially occurring outside the investigated period.

Table 8 (continued) - Changes in values of the measures of service according to the changes in values of indicators

Part	Indicator name	Mortality rate <24hrs	Mortality rate >24hrs	Length of stay	Time spent at the ED	Surgeries performed
Space	Fire safety measures adoption ¹²	10% of High Dependency Unit can die.	Mortality increases by 20% for 30% of in-patients	30% of inpatients have an increased length of stay by 60%.	No impact.	No impact.
System	Contingency plan implementation	No contingency plan means not having essential drug products for one day.				
System	Information Management System implementation	No IMS means not having a basic resource for half day (pick the maximum impact among power, water, oxygen, blood, drug products).				
System	HAIs incidence rate ¹³	No impact.	Worst case scenario: 15% of surgical patients have 4 times higher risk of dying.	Worst case scenario: 15% of surgical patients have 3 times higher length of stay.	No impact.	No impact.
System	Referral system	No impact.	If transfer not available, patients for whom the demand for surgery cannot be met at the RHUH die.	No impact.	If transfer not available the impact is like having +10% Bed Occupancy Rate.	No impact.

6.5 Resilience estimation

The results are shown in the form of a graph where you can compare the service the hospital system is supposed to provide against the service it is able to provide given its current operational condition.

Figure 4 shows the average mortality rate below 24 hours from admission at the baseline condition (19%) and at the current condition (varying according to indicator values). The average is calculated upon the number of arrivals at the Emergency Department (it is not an average over time). The baseline mortality rate is calculated considering the number of patients arriving at the Emergency Department on the day of the event (200) and related mortality rate (10%) and the number of patients arriving at the Emergency Department on the following two days (60) and related mortality rate (2%). Moreover, the baseline mortality rate takes into account the additional number of fatalities that can occur due to bed unavailability considering a surge capacity of more than 30% (which is the baseline bed surge capacity). In the example presented here, when the hospital system expands its bed capacity by 30% there are still 28 patients on the day of the event for which the demand for beds is unmet, leading to

¹² Fire impacts imply the following assumptions: a certain number of hospitalised patients survive the fire and receive treatment at the RHUH (they are not transferred) but due to smoke inhalation their length of stay is increased.

¹³ This example considers the impact of surgical site infections only.

an increased mortality rate below 24 hours from admission at the baseline condition. This is due to the hypothesis that Red and Yellow patients who do not receive a bed die.

Once the average mortality rate below 24 hours from admission is estimated, it is possible to compare it with the mortality rates associated to other resilience indicator values (i.e., to the mortality rate that below-baseline conditions can cause).

In Figure 4 you can see that the “emergency power reservoir capacity” indicator is causing a high increase in the mortality rate compared to the baseline condition. Indeed, at the baseline condition, the hospital system is supposed to have a fuel autonomy of three days, while at the current condition it has a few hours autonomy. The absence of a fuel stock leads to the lack of power on the day of the event which heavily compromises the provision of life-saving treatments to red and yellow patients, the same happens during the following two days, when emergency surgeries cannot be provided.

You can also see that the “frequency of emergency management training” indicator is associated with a high increase in the mortality rate compared to the baseline condition. The hospital system is supposed to provide emergency training at least once per year, but at the time of the assessment the emergency training was performed more than two years ago. This is supposed to increase the mortality rate below 24 hours from admission of 100% (as reported in Table 8).

There are also other topics of concern, such as the hospital system currently having a contingency plan, but without dedicated resources, while at the baseline condition it is supposed to be able to fully implement the plan. Also, the hospital system is currently able to expand its bed capacity by around 20% which causes an increase in the mortality rate on the day of the event compared to the mortality rate linked to a bed surge capacity of around 30%.

The below-baseline bed surge capacity (15% vs 30%) causes an increase in the average mortality rate below 24 hours from admission. Indeed, 56 patients (either Red or Yellow) are supposed not to receive a bed on the day of the event due to the limited bed surge capacity compared to the baseline bed surge capacity which can reduce the unmet demand for beds to 28 patients.

The hospital system has a very low safety in case of fire, and even if the unfortunate event of fire, on the same day of the mass casualty incident, is unlikely, the occurrence of such an event cannot be excluded and the expected damage is high. It is assumed that when the hospital system has a very low safety in case of fire (i.e., the value of the indicator n°3.3 is equal to 4) a fire happens in high dependency units and that 10% of critical patients can die, while at the baseline condition, it is assumed that the hospital has all the protective measures needed to ensure patients survival.

The nurse-to-patient ratio in high dependency unit is supposed to be equal to 1:3, while it equals 1:4 at the moment the assessment is performed. Below-baseline staffing level is associated with an increase in mortality as explained in Table 8.

Finally, the hospital system faces issues in stocking water, indeed, due to the limited municipality provision the hospital system has two days of autonomy in case of water disruption, while at the baseline condition, it is supposed to have three days of autonomy. With regard to water, you can also see that the “water-related system condition and maintenance” indicator is associated with an increase in the mortality rate compared with the baseline condition. The water-related system components are currently in poor condition indeed, and this causes a water outbreak of four hours on the day of the event, while at the baseline condition the water-related system is not expected to compromise the availability of water. The lack of water compromises the capacity of performing surgeries, which ultimately causes an increase in the mortality rate below 24 hours from admission.

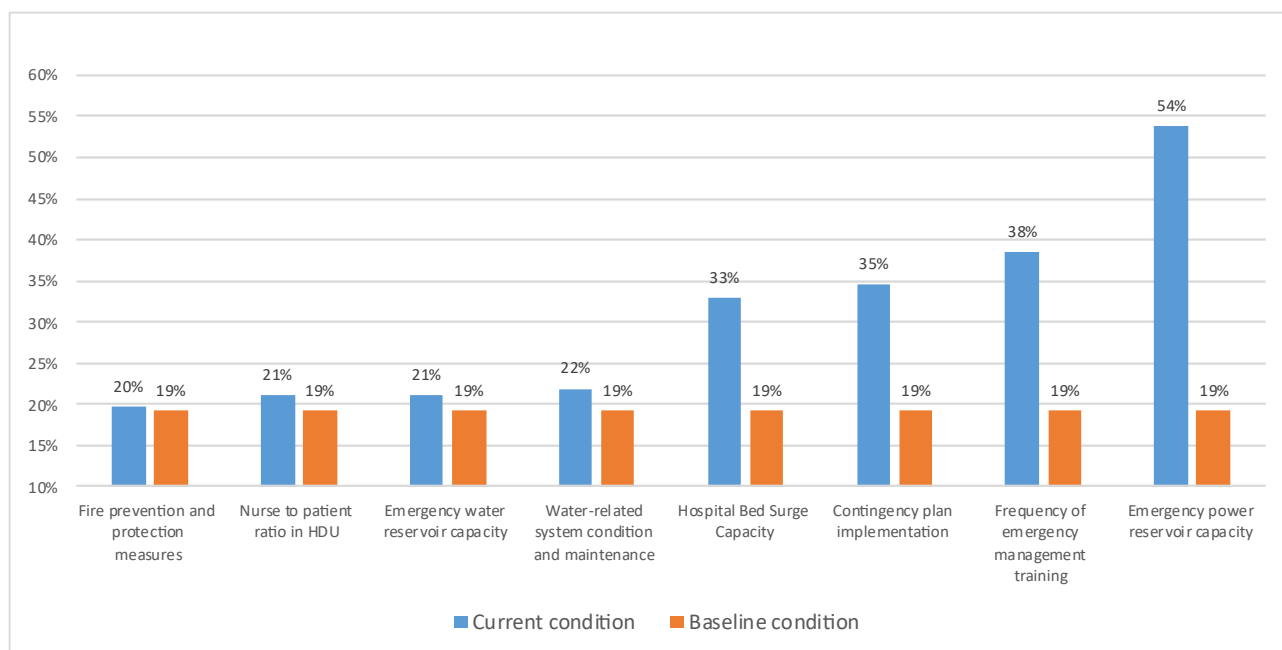


Figure 4. Estimation of the mortality rate below 24hrs from admission

Figure 5 shows the average mortality rate after 24 hours from admission at the baseline condition (5%) and at the current condition (varying according to indicator values). The baseline average mortality rate after 24 hours from admission is supposed to be equal to the average mortality rate recorded during the last month, which refers to non-disruptive circumstances.

Again, the power availability and the frequency of emergency management training are the areas of biggest concern. It is indeed assumed that for each day the power is lost, the mortality rate increases by 40% (in this case, it increases by 120%) and that when emergency training is rarely performed (i.e., more than 2 years ago from the moment of the assessment), the mortality rate can double. This means that investing in power autonomy and emergency training can significantly improve this hospital system's resilience.

A new area of concern is the coordination with the referral system. Indeed, if patients are stabilised at the emergency department, they might need to receive surgery after that. However, if the hospital system capacity cannot meet this demand, patients need to be transferred, otherwise they will not survive. At the baseline condition, the hospital system is supposed to transfer patients who cannot receive surgery to other facilities, while the hospital system under analysis does not have formal mechanisms for coordinating with other facilities, thus the transfer is compromised. In this example, the demand for surgery on the day of the event equals 80, and it is supposed that these surgeries must be performed over 36 hours, but available resources allow to perform 45 surgeries only, thus 35 patients might die due to the unmet demand for surgery. This means that the analysed case study should invest in stronger mechanisms for coordination with the surrounding healthcare system to improve its resilience against a Mass Casualty Incident.

The mortality rate after 24 hours from admission is influenced by the Hospital-Acquired Infections too. At the baseline condition, the surgical site infection incidence rate is supposed to be less than 5% and written reports should be available to document it (surgical site infections are used as a proxy to account for all the potential hospital-acquired infections). At the moment of the assessment, the authors did not have access to written reports but relied on the opinion of a doctor working at the hospital. The analysed hospital system could significantly improve its resilience by monitoring and reducing the surgical site infection incidence rate, as many patients will receive surgery in the

aftermath of a Mass Cass Incident, and with good infection prevention and protection measures many lives can be saved.

Finally, you can see that some areas of concern overlap with those of Figure 4, however their relevance changed. For example, the lack of preventive and protective measures in case of fire has a higher impact on the mortality rate after 24 hours from admission than on the mortality rate below 24 hours from admission due to the high risk of fatal health outcomes associated with smoke inhalation which is supposed to affect 30% of hospitalised patients (as reported in Table 8).

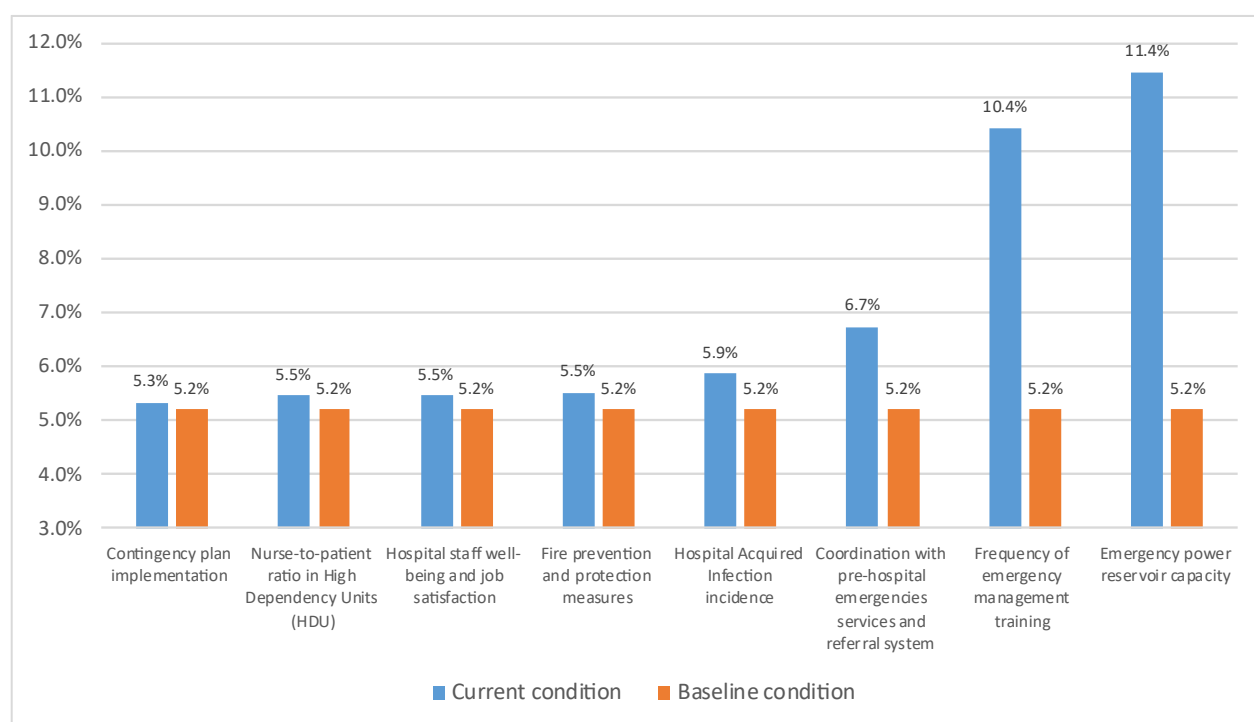


Figure 5. Estimation of the average mortality rate after 24 hrs from admission

Figure 6 shows the average length of stay at the baseline condition (8.2 days) and at the current condition (varying according to indicator values). The baseline length of stay is supposed to be equal to the length of stay recorded during the last month, which refers to non-disruptive circumstances.

The below-baseline emergency power reservoir capacity (0 vs 3 days) significantly affects the length of stay at the RHUH. Indeed, patients are assumed to spend one day more at the hospital each day the power is missing.

Another area of concern is fire prevention and protection. As measures to protect patients (and staff) in case of fire are missing and given that 30% of hospitalised patients are assumed to be affected by smoke inhalation, which leads to an increase in length of stay of 60%, the average length of stay increases by 18% compared to the baseline condition, where patients are supposed not to be affected by the smoke.

The hospital system should also ensure staff well-being and job satisfaction, indeed, as at the current condition salaries have lost purchasing power compared to the baseline condition, the staff turnover increases and job satisfaction decreases, leading to lower care quality, which ultimately increases the length of stay by 60% compared to the baseline.

Finally, the hospital system currently has two days of water autonomy (assuming the water reservoir cannot be replenished within three days) instead of three days of autonomy (i.e., the baseline water autonomy). Thus, in Figure 6 you can see the impact of not having water for one day in terms of length of stay (the length of stay increases by one day for each day water is missing).

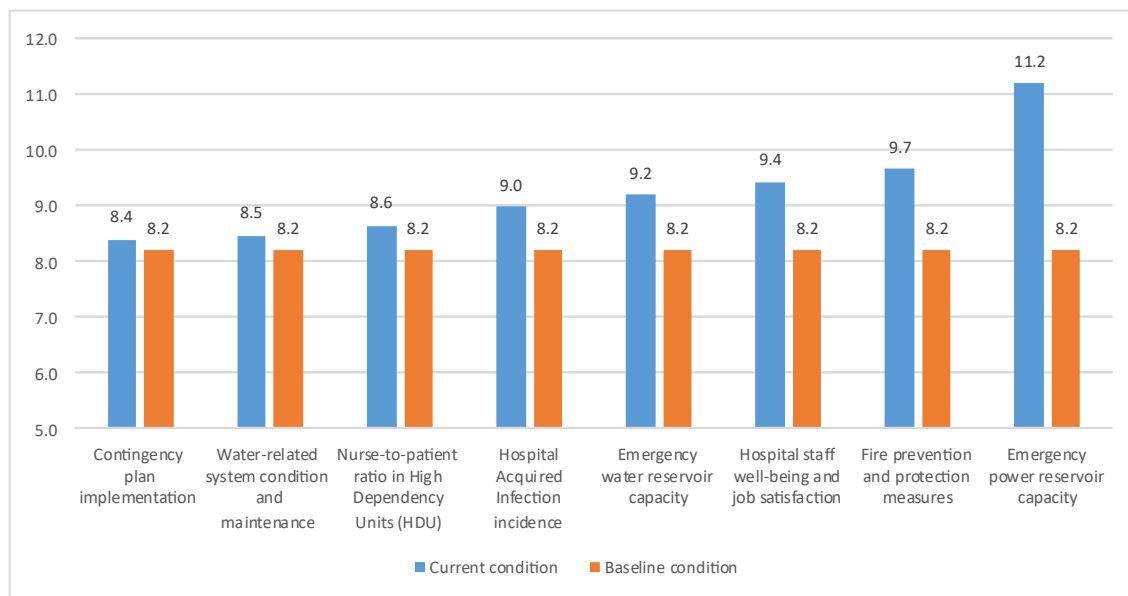


Figure 6. Estimation of the average length of stay

Figure 7 shows the average time spent at the Emergency Department at the baseline condition (6.7 hours) and at the current condition (varying according to indicator values). The average time spent at the Emergency Department at the baseline condition is calculated considering that on the first day (the day of the event) the hospital system is very fast at treating patients (e.g., Red patients need to leave the ED within 1 hour, Yellow patients within two hours) but from the second day it returns to its usual velocity (24 hours spent at the Emergency Department on average).

At the current condition, the time spent at the Emergency Department is mostly affected by the below-baseline nurse staffing level (1:4 vs 1:3), indeed the higher the staffing level the faster the treatment. Please be aware that to the scope of this application, the Emergency Department is intended to as part of the high-dependency units.

You can see that, as the hospital system did not provide emergency management training courses within the last two years, emergency processes are slower than if the same training courses were provided every year. These courses are needed to acquire specific competencies, skills and confidence during emergency times, and they are meant not only to save lives but also to speed up the ED processes.

You can also see the lack of resources needed to implement the contingency plan can increase the time spent at the Emergency Department compared to the baseline condition, where dedicated resources ensure the full implementation of the same plan.

Finally, you can see that low hospital staff well-being and job satisfaction can increase the time spent at the Emergency Department compared to if hospital staff well-being and job satisfaction are high. There are also other two areas of concern, namely the hospital bed surge capacity and the coordination with pre-hospital emergency services and referral system. Missing coordination with other facilities

leads to a decreased number of available beds, and the lower the bed surge capacity the higher the bed occupancy rate, which ultimately affects the time spent at the ED (as per Table 8).

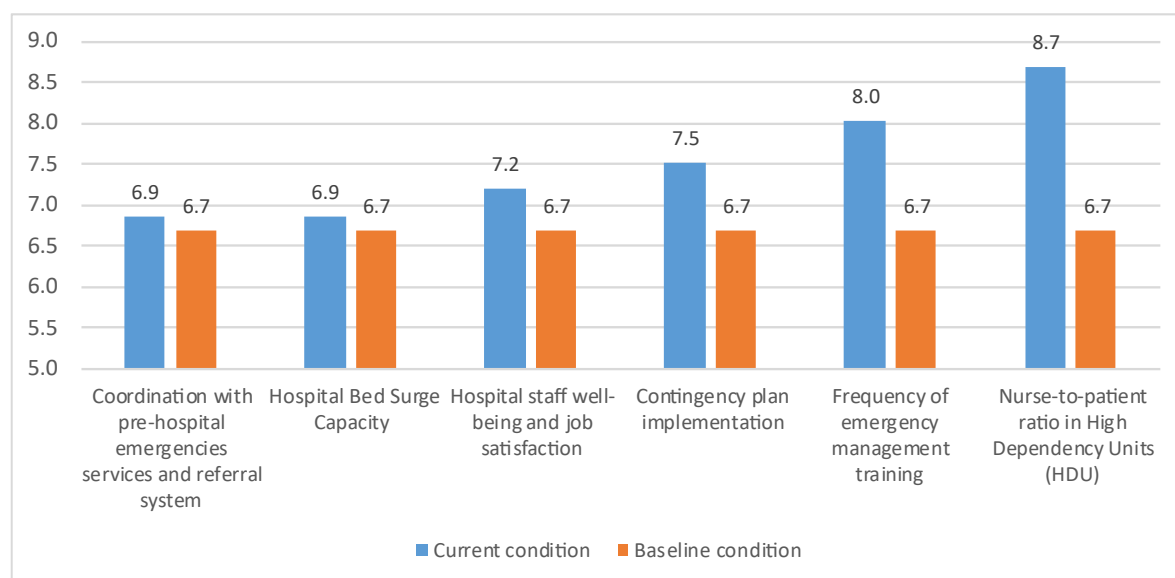


Figure 7. Estimation of the average time spent at the emergency department

Figure 8 shows the surgeries performed over the investigated period at the baseline condition (55) and at the current condition (varying according to indicator values). The surgeries that can be performed at the baseline condition and over the investigated period are calculated assuming that during the first 36 hours 45 surgeries can be performed, and then an additional 10 surgeries are performed over the remaining one day and a half. The first 45 surgeries are calculated considering the number of functional operating theatres, the average operating time, the number of nurses working at the operating block and the number of nurses needed per operating theatre. The additional 10 surgeries are to address a potential demand for emergency surgery from day 2 (as per Table 4). The surgeries the hospital system is supposed to provide (at the baseline condition) are here estimated regardless of additional limiting factors (e.g., sterilisation services) but they only depend on the above-mentioned limiting factors (functional operating theatres, staff availability and average operating time).

Once the baseline number of performed surgeries is estimated, it is possible to compare it with the number of surgeries that can be performed considering other resilience indicator values (i.e., the number of surgeries that below-baseline conditions can lead to).

The provision of surgery is mostly compromised by power availability. A missing emergency power reservoir (i.e., 0 days of power autonomy) reduces the ability to provide surgery compared to the baseline condition, where the power autonomy is expected to last three days.

When a contingency plan exists but dedicated resources are not enough to fully implement the plan, the hospital system's ability to provide surgery is less than if a contingency plan exists and dedicated resources are available to fully implement the plan.

Also, surgical capacity is affected by water availability. As the water-related system components are in poor condition (i.e., water can be missing for 4 hours) the number of performed surgeries is less than what is expected from the same hospital with a water-related system in good condition. Finally, the water reservoir autonomy of two days (at the current condition) instead of three days (at the baseline

condition) makes it impossible to provide surgery on the third day, when the water reservoir is supposed to be exhausted.

From the results discussed so far, you can deduce that the lack of power is consistently affecting the hospital system's resilience, thus interventions aimed at reaching at least three days of power autonomy are of high priority. Regarding the other areas of concern, you have to decide whether or not the service measures have the same relevance in terms of hospital system resilience and make a decision accordingly. Also, the costs of interventions and potential monetary benefits are not estimated here.

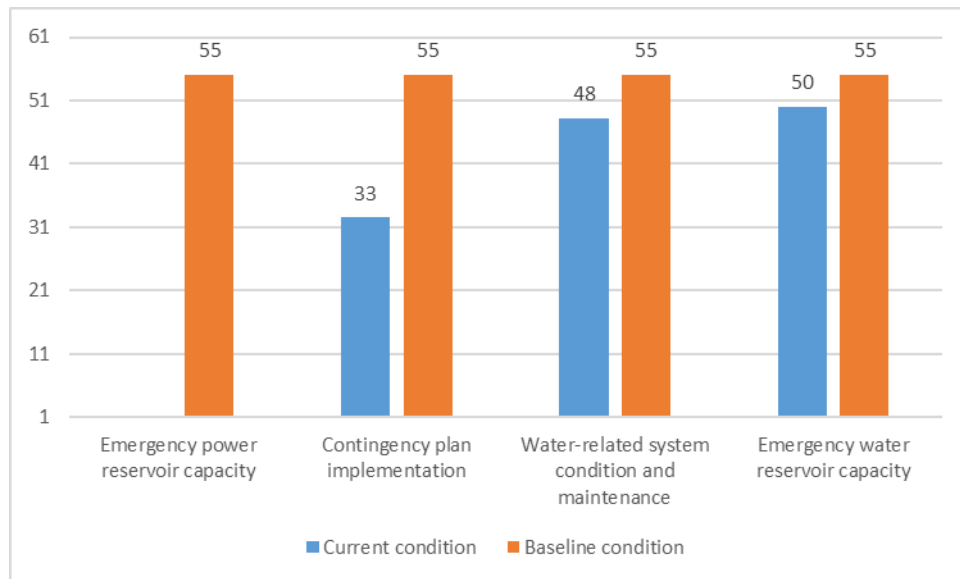


Figure 8. Estimation of surgeries performed over the investigated period

7 Discussion

7.1 Values

The results previously presented show that the presented framework for the overall hospital resilience has practical implications for hospital managers and contributes to knowledge advancement, for example:

- Hospital service managers and humanitarian organisations can use the framework to understand how well a hospital works under specified disruptive events. The results clearly point out the potential weaknesses which can jeopardise the provision of service and allow to determine where to intervene first (see Section 6.5).
- The framework provides a structured way for estimation, keeping the computational time low. The framework does not require excessive detail, but it considers the essential requirements for determination of the resilience of a hospital system. The development of the case study shows that the resilience indicators are relatively easy to use and make the evaluation process fast, once the relevant informants are identified (the authors assessed the current condition of the RHUH in two days).
- The estimation is mostly based on expert opinion and is strengthened by the strategic collaboration between medical staff, administration, and technical expertise.
- The framework is flexible enough to be adapted to any hospital. Both resilience indicators and service measures can change while keeping the structured way for resilience estimation.
- The framework can be used to monitor hospital resilience (by means of service measures) and hospital performances (by means of indicators) over time. Also, the more the data collected the more valid the estimation.

7.2 Limitations

The work presented in this document has the following limitations:

- This document summarises the most commonly emerging resilience themes keeping in mind a multi-risk approach, avoiding specific hazard-related indicators. The user can further detail the assessment according to the specific analysed event. For example, the location of essential supplies and critical areas are of interest in case of flood or earthquake, technological performances are of interest in case of an epidemic, etc. The number of indicators to be used for estimation can be modified too and it will depend on the level of modelling desired, and the hazard considered.
- The research team tried to strike a balance between the level of detail of the results (and of the input data) and the speed of analysis. The estimation does not provide an accurate prediction of services provided, yet once the critical points are identified, you can rely on dynamic models to analyse them further (e.g., using the Work Package 3 delivery).
- The estimation requires a collaborative environment between both parties, ICRC delegates and hospital staff. Whereas this would not be available, the estimation can be compromised. It is important also to plan for a relatively small group of experts which can take the responsibility of using the tool, including defining the service measures and estimating resilience.
- Before using the framework, the assumptions behind the estimation need to be checked. Table 8 reports the assumptions used for the RHUH, which can serve as an example for the next application.

8 Conclusions

Hospital systems play a crucial role by offering emergency and acute care, thereby saving lives and mitigating the impact of potentially disruptive events on communities. Examples of disruptive events are earthquakes, floods, explosions, and bombing. Recognizing the significance of the hospital system role during these events, it is imperative for hospital service managers and supervisory organizations to gauge hospital system resilience.

This document presents an indicator-based framework to assess the overall hospital system resilience. Developed in collaboration with the ICRC, the framework offers a structured and high-level overview, empowering strategic decision-makers to comprehensively understand and improve a hospital system's ability to deliver services in the aftermath of a disruptive event.

The framework implies the hospital system description, service measures definition, resilience estimation by means of indicators. Each methodological step has been described in the text and a case study is presented to prove the applicability of the framework.

The framework has been developed to provide a structured way for resilience estimation while keeping a high level of customisation. The authors have developed one case study which can facilitate the application of the framework in the future. However, it is important to mention that the next testing application will require the revision of the indicators and of the assumption behind the model. For this reason, a possible advancement would be applying the framework to other facilities. Future work will also include the use of the framework with other types and severity of potentially disruptive events. Finally, a user-friendly interface has been developed to facilitate the adoption of such a framework.

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Annex 1. Examples of tools for assessing hospital resilience, safety, and emergency preparedness

Table 9. Examples of tools for hospital resilience, safety, and preparedness assessment

Citation	Aim of the tool	Description of the tool
World Health Organization (2006) Field manual for capacity assessment of health facilities in responding to emergencies. Geneva: WHO.	Evaluating the preparedness of health facilities for dealing with disasters.	The tool is a questionnaire including three main parts aimed to provide an overview of the current capabilities, to assess structural, non-structural and functional vulnerability, to assess preparedness for specific emergencies, namely industrial emergencies, infectious disease outbreak, biological, chemical, and radiologic emergencies.
World Health Organization (2011) Hospital emergency response checklist. Copenhagen: WHO Regional Office for Europe.	Supporting hospital managers and emergency planners to respond effectively to disasters of all types.	The tool is a checklist of recommended actions (due to review, in progress, completed) about nine components: command and control, communication, safety and security, triage, surge capacity, continuity of essential services, human resources, logistics and supply management, post-disaster recovery.
World Health Organization (2012) Toolkit for assessing health-system capacity for crisis management. Geneva: WHO.	Assessing the capacities of health systems to respond to various threats and identify gaps.	The toolkit comprises the user manual and the assessment form. The assessment form is a checklist structured into six blocks: leadership and governance, health workforce, medical products, vaccines and technology, health information, health financing, service delivery. Answers (yes, no, partly) lead to colour coded fundings (red, yellow, green).
World Health Organization Pan American Health Organization (2015) Hospital Safety Index. Guide for Evaluators. Washington, D.C.: WHO, PAHO.	Assessing hospital vulnerabilities and safety.	The tool is a checklist divided into four modules: hazards, structural safety, non-structural safety, emergency and disaster management. The calculation of the index is based on the weighting of the respective modules.
ICRC – HClD (2016) Security Survey for Health Care Facilities.	Identifying the level of preparedness for a health-care facility to continue operating during or post conflict related security events.	The assessment covers three modules: the hazards confronted by the facility, the current management procedures in place and the state of the physical infrastructure. The results aim at quantifying preparedness and vulnerability to specific hazards by looking at the scoring of the indicators.
World Health Organization (2019) Health Emergency and Disaster Risk Management Framework. Geneva: WHO.	Providing a summary of policy considerations to reduce risks and consequences of emergencies and disasters and build resilient health systems.	The framework provides for a list of functions that collectively reduce the health risk and consequences of hazards. The functions are grouped in ten components: policies and legislation, planning and coordination, human resources, financial resources, information and knowledge management, risk communication, health infrastructure and logistic, health and related services, community health, evaluation.
World Health Organisation (2020) Rapid hospital readiness checklist. Geneva: WHO. This is part of: <i>Suite of health service capacity assessments in the context of the COVID-19 pandemic</i> developed by World Health Organization (2020)	Rapidly determining current capacities and gaps in service necessary to respond to COVID-19 pandemic.	The Checklist highlights 12 key components that are essential to managing COVID-19 in a hospital setting: leadership and incident management system, coordination and communication, surveillance, risk communication and community engagement, administration and finance, human resources, surge capacity, continuity of essential support services, patient management, mental health, rapid identification, infection prevention and control. The results are expressed in terms of percentage of fulfilment of a list of indicators.
European Centre for Disease Prevention and Control (2021) Infection prevention and control and preparedness for COVID-19 in healthcare settings. Stockholm: ECDC.	Providing guidance on preparedness and infection prevention and control during the COVID-19 pandemic in healthcare settings.	The document contains a list of measures regarding occupational safety and health in several settings including acute care settings. There are administrative, clinical, and environmental hygiene measures.

Annex 2. Connection between the deliverables

The connection between the deliverables is depicted in Figure 9. To conceptualise the hospital system the authors considered the checklist for a rapid resilience assessment proposed by WP1, which comprises: Space, Stock and supply, Staff, Strategic structure and governance, Services, Society. The rapid resilience assessment is to be used to describe the status quo of a facility while the overall hospital resilience assessment tool is focused on in-hospital characteristics impacting service provision when a disruptive event occurs, with no consideration of the surrounding environment. WP2 proposed a subset of indicators to be used to measure hospital system resilience. The indicators were modified and grouped to avoid repetitions and to ensure that the subset of indicators were the most relevant ones in terms of resilience. For this reason, the “Strategic structure and governance” and “Services” parts have been merged into one part called “System” and the “Society” component has not been considered. The resilience indicators are used by WP3 to inform supplies, demand, and data quality, which are needed to perform dynamic resilience assessment on specific departments of the hospital system.

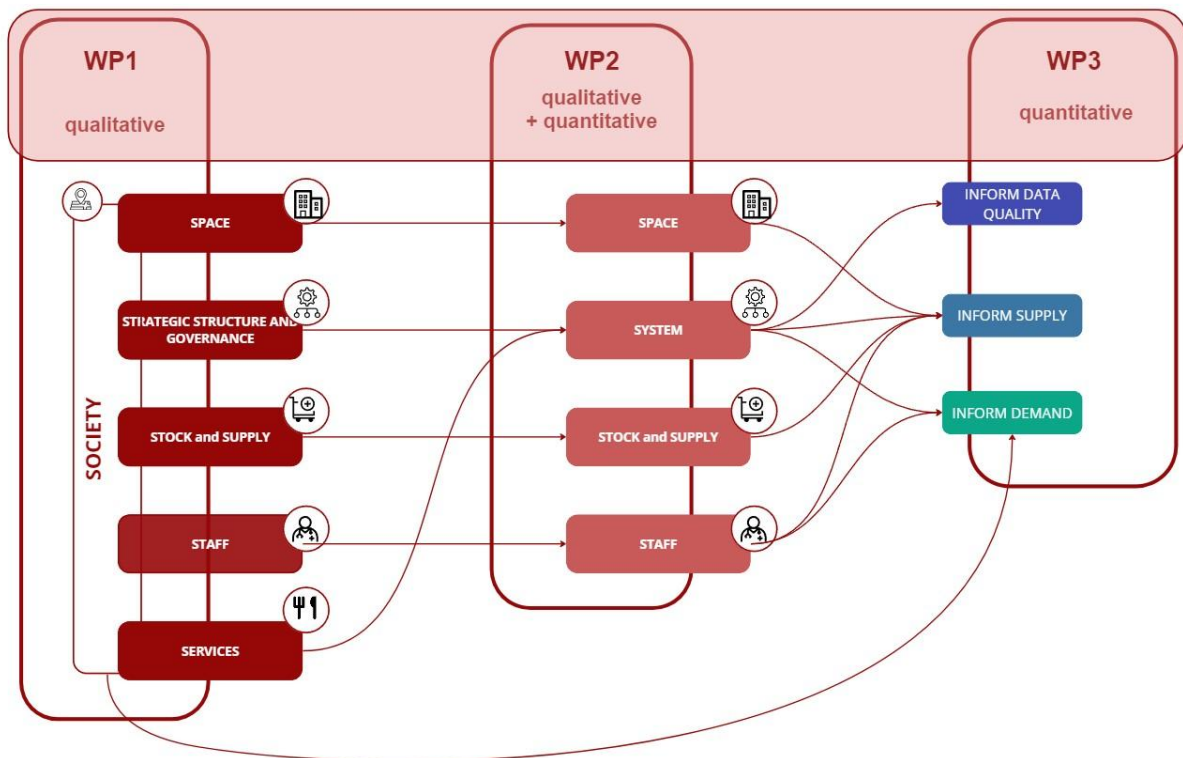


Figure 9. Connection between the deliverables

Annex 3. Questionnaire on resilience indicators

A questionnaire was used to reach an agreement on the resilience indicators. The questionnaire was sent out in the form of an Excel file with an introduction part with instructions, followed by data collection sheets. Collected data included opinions on the relevancy of the topic, the feasibility of the way to measure, suitability of the indicator values meaning (i.e., values the indicator can assume), and additional comments for potential new topics of assessment. Figure 4 reports an extract of the introduction section. The questionnaire was filled out by 18 experts distributed as follows: 10 respondents from Water and Habitat unit; 2 respondents from Health Care in Danger unit; 6 respondents from Health unit. The main results show that:

- There was a strong agreement on the relevancy of the identified topics for assessment, however some changes were made to disaggregate some indicators or to insert new topics of assessment (e.g., water quality, blood stock etc.)
- New ways of measurement and new values have been proposed by the experts. When an agreement was not reached, the authors collected additional opinions by means of one-to-one interviews with key informants (e.g., on how to measure the coordination with external facilities, how to measure the water quality, values for indicating the level of preparedness of contingency plans etc.). It is worth noting that this activity was tailored for the Rafik Hariri University Hospital, so adaptations might be needed when applying the tool to other facilities.

Instructions for compiling the questionnaire.

Each indicator comes with a description, way to measure, the values the indicator can assume and the related meaning. **For each indicator you express your level of agreement using a 5-points Likert scale using a drop-down menu in the RELEVANCY OF THE TOPIC, FEASIBILITY OF THE WAY TO MEASURE, SUITABILITY OF THE MEANING columns.** In case you disagree or you are not sure, you are asked to **justify your answer** and provide for an alternative by typing in the **COMMENT box**. You can leave general comments and **suggest introducing additional indicators** by using the **ADDITIONAL COMMENTS box** at the end of each section (related to each part of the hospital system). You find an illustrative picture below.

TYPE IN THE BOX TO STATE YOUR CURRENT ROLE AT THE ICRC.

USE THE DROP-DOWN MENU TO EXPRESS YOUR OPINION.

Part	N	Indicator name	Description	Ways to measure	Indicator value	Meaning	RELEVANCY OF THE TOPIC	FEASIBILITY OF THE WAY TO MEASURE	SUITABILITY OF THE MEANING
Staff	1.1	Nurse availability in non-critical care units	It evaluates the number of nurses per patient in non-critical care units.	Average daily staff nurse census / average daily patient census (referred to non-critical care units over the investigated period).	0	1:10 or more	AGREE	DISAGREE	
					1	1:8	In case you disagree, please elaborate why and provide for alternatives using the box below.		
					2	1:6	Comments: MEASURING THE NURSE TO BED RATIO IS EASIER, IT CAN BE MEASURED BY...		
					3	1:4			
					4	1:3 or less			

USE THIS BOX TO SUGGEST IMPROVEMENTS TO THE ANALYSED PART.

ADDITIONAL COMMENTS:

IF YOU DISAGREE LEAVE A COMMENT TO ELABORATE WHY.

Figure 10. Extract of the introduction to the questionnaire

Annex 4. Resilience indicators

Table 10. Staff indicators

N	Indicator name	Description	Ways to measure	Indicator value	Meaning
1.1.1	Nurse-to-patient ratio in non-High Dependency Units	It evaluates the number of nurses per patient in non-high dependency units.	Average monthly staff nurse census / average monthly patient census. Refer to last month.	0	1:12 or more
				1	1:10 – 1:12
				3	1:8 – 1:10
				4	1:8 or less
1.1.2	Nurse-to-patient ratio in High Dependency Units	It evaluates the number of nurses per patient in high dependency units.	Average monthly nurse census / average monthly patient census. Refer to last month.	0	1:5 or more
				1	1:4 - 1:5
				3	1:3 - 1:4
				4	1:3 or less
1.2	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. The indicator refers to both clinical and non-clinical staff.	Qualitative evaluation based on document review, walkover survey and interviews. Refer to the last 12 months.	0	Salary is not regularly paid AND it has low purchasing power.
				2	Salary is not regularly paid OR it has low purchasing power.
				4	Salary is regularly paid AND it has good purchasing power.
1.3	Frequency of emergency management training	It evaluates if the staff is frequently trained for mass casualty incident management. The indicator considers both clinical and non-clinical personnel. Whereas applicable, training can be referred to contingency plan components (e.g., specific patient management; crowd management; ensuring basic resources). Triage course and Advanced Trauma Life Support course are taken here as an example.	Qualitative evaluation based on document review and interviews. Refer to the last 24 months.	0	Training is not provided
				2	Training is provided at least once every two years
				4	Training is provided at least once per year

Table 11. Stock and supplies indicators

N	Indicator name	Description	Ways to measure	Indicator value	Meaning
2.1.1	Emergency power reservoir capacity	It evaluates the number of days of power autonomy assuming that the main power supply system is out of service. If the back-up system relies on generators, then you have to assume that you cannot buy additional fuel for 72hrs. If an emergency power supply system exists and it is functional, you can assess the duration of the back-up generation assuming to supply priority lines only (e.g., to supply essential services and units). Reduce the indicator value if generators are subject to corrective maintenance only.	Capacity of back-up power generation system expressed in days. Refer to last month.	1	Emergency power reservoir is absent, or capacity is not assessed, or emergency reservoir capacity lasts less than 1 day
				2	Emergency power reservoir lasts one day (2 days without power)
				3	Emergency power reservoir lasts two days (1 day without power)
				4	Emergency power reservoir lasts 3 days or more
2.1.2	Tertiary power supply availability	This indicator is relevant in case of a power outage of less than 2hrs (with or without back-up power generation system). It evaluates the presence of a third supply usually in the form of a UPS and battery system for specific life supporting equipment and critical areas (e.g., ventilators and monitors, imaging equipment, O2 concentrators, surgical equipment, refrigerators etc.).	Technical evaluation based on document review, walk over survey, interviews with the Engineering department. Refer to last month.	1	Absence of UPS and local batteries.
				4	Presence of UPS and local batteries.
2.2.1	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. Water reservoir is referred to domestic and medical uses only (no drinking water, nor fire safety related tank). You have to assume that you cannot refill water reservoir for 72 hours. Whereas applicable, you can assess the duration of the water reservoir assuming to limit water to critical services and to suspend non-essential services (e.g., cancelling elective procedures, closing outpatient clinics, using disposable sterile supplies, suspending environmental cleaning etc.). Reduce the indicator value if the emergency water reservoirs (and, if applicable, related supply systems) undergo corrective maintenance only.	Capacity of back-up water reservoir expressed in days of autonomy. Refer to last month.	1	Water reservoir is absent or capacity is not assessed or water reservoir capacity lasts less than 1 day
				2	Water reservoir lasts one day (2 days without water)
				3	Water reservoir lasts two days (1 day without water)
				4	Water reservoir lasts three days or more
2.2.2	Water quality	It evaluates the frequency of water quality checking, the existence of a reporting system and a plan for water quality checking. It is assumed that positive results (i.e., water not safe) is followed by a risk reduction action. Water sampling against <i>Pseudomonas aeruginosa</i> is here taken as an example.	Technical evaluation based on document review, interviews with the Quality and the Engineering departments.	1	Water quality is not assessed OR Reports and plans are not available OR Tests are performed less than once per year.
				2	Water quality is assessed at least once per year AND reports and plans are available.
				4	Water quality is assessed at least each six months AND reports and plans are available.

Table 11. Supplies indicators (continued)

N	Indicator name	Description	Ways to measure	Indicator value	Meaning
2.3	Oxygen stock capacity	It evaluates the duration expressed in days of oxygen stock assuming that you cannot replenish your stock for three days.	Capacity of oxygen stock in terms of days. Refer to last month.	1	Stock capacity is not assessed - no stock
				2	Stock lasts 1 day (2 days without oxygen)
				3	Stock lasts 2 days (1 day without oxygen)
				4	Stock lasts 3 days or more
2.4	Blood stock shortage	It evaluates the number of blood stock-out days. The assessment is based on Packed Red Blood Cell stock as it is a proxy for the entire stock.	Blood stock-out days.	1	Stock out of 3 days or more
				2	Stock out of 2 days
				3	Stock out of 1 day
				4	No shortage
2.5	Essential drug products and medical items shortage	It evaluates the number of days over a month with shortage of essential drugs, medical items. Lack of antibiotics is here taken as an example for estimating the Length of Stay, while anaesthetic and IV fluids are considered for estimating Mortality and Surgeries performed.	Oxygen stock-out days	1	Stock out of 3 days or more
				2	Stock out of 2 days
				3	Stock out of 1 day
				4	No shortage

Table 12. Space indicators

N	Indicator name	Description	Ways to measure	Indicator value	Meaning
3.1.1	Architectural and structural maintenance and condition	It evaluates the condition of structural and architectural elements of the building. If only corrective maintenance is performed decrease the indicator value.	Technical evaluation based on building inspections (at a given time).	1	System components are in very poor condition (e.g., they can cause closure of hospital units/areas; disruption of essential service; relocation of patients).
				2	System components are in poor condition. Their condition slightly compromise hospital functionality and activities.
				4	System components are in fair condition. Their condition does not compromise hospital functionality and activities.
3.1.2	Power related system maintenance and condition	It evaluates the condition of electrical system including power generation systems and power-related systems. If only corrective maintenance is performed, then decrease the indicator value.	Technical evaluation based on building inspections (at a given time).	1	System components are in very poor condition (e.g., they are frequently out of service and this can cause closure of hospital units/areas; disruption of essential service; relocation of patients).
				2	System components are in poor condition (they are rarely out of service and this slightly compromises hospital functionality and activities).
				4	System components are in fair condition. Their condition does not compromise hospital functionality and activities.
3.1.3	Water-related system maintenance and condition	It evaluates the condition of water-related systems, including water treatment plant and reservoir, plumbing system and other water-related systems. If only corrective maintenance is performed then decrease the indicator value.	Technical evaluation based on building inspections (at a given time).	1	System components are in very poor condition (e.g., they are frequently out of service and this can cause closure of hospital units/areas; disruption of essential service; relocation of patients).
				2	System components are in poor condition (they are sometimes out of service and this slightly compromises hospital functionality and activities).
				4	System components are in fair condition. Their condition does not compromise hospital functionality and activities.

Table 12. Space indicators (continued)

N	Indicator name	Description	Ways to measure	Indicator value	Meaning
3.2.1	Bed Occupancy Rate	It evaluates the average bed occupancy of hospital units.	Average daily census/ opened beds per day in HDU areas. Refer to the last month.	1	more than 90% or BOR not assessed
				2	80%-90%
				4	80% or less
3.2.2	Hospital Bed Surge Capacity	It evaluates the hospital capacity of increasing the number of OPENED BEDS. Bed surge capacity for a mass casualty incident should be happening within a few hours from the first arrival at the ED, in order to avoid the consequences of not being able to address the sudden increase in demand. Bed surge capacity includes operational measures (e.g., discharge of patients or reverse triage) or infrastructural adaptation (e.g., by placing additional beds in already used patient rooms or by equipping additional space as empty rooms, lobby, corridors, parking etc.). NB: Opened beds are those staffed and equipped.	Number of additional opened beds/ total number of opened beds.	1	Less than 15% or bed surge capacity not assessed
				2	15 - 30%
				4	More than 30%
3.3	Fire safety measures adoption	It evaluates if safety in case of fire is provided by means of the following: 1) fire detecting system and fire fighting system (e.g., smoke sensors, fire compartments, extinguishers, presence of water reservoir for fire etc.); 2) presence of fire response team in the hospital ; 3) evacuation plan available and implemented (e.g., emergency exits and routes are indicated, evacuation routes are free of obstacles; presence of emergency light system etc.); 4) fire training and education sessions . Safety measures must be adopted at least in the following areas: patients rooms and treatment areas (e.g., intensive care, operating theatre) AND areas at high risk of fire (e.g., kitchen and storage of inflammable items).	Technical evaluation based on building inspections, surveys, and documents review. If planned maintenance on fire safety system is not performed OR evacuation plans are outdated OR the frequency of fire training and education sessions is more than 2 years OR safety measures are not adopted in the listed areas, then decrease the indicator value.	1	Safety in case of fire is severely insufficient/ not provided.
				2	Safety in case of fire is insufficient.
				4	Safety in case of fire is sufficient.

Table 13. System indicators

N	Indicator name	Description	Ways to measure	Indicator value	Meaning
4.1	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. The evaluation includes mitigation and preparedness measures as well as response and recovery strategies (e.g., command committee definition, identification of critical services and related needs, identification of roles and responsibilities, listing and stocking critical items for emergency kits, human resources surge plan, emergency protocols etc.).	Technical evaluation based on document reviews, surveys, and interviews (at a given time).	1	No contingency plan developed, nor emergency stock available
				2	Contingency plan developed but dedicated resources do not ensure the implementation of the plan (e.g., some of the essential drug products and medical devices are missing) or no regular plan updates (not reviewed or maintained).
				4	Contingency plan developed, dedicated resources ensure the implementation of the plan and regular reviews are carried out.
4.2	Information Management System implementation	It evaluates if an Information Management System (IMS) is implemented to keep track of resources availability and patient data. Resources include personnel, beds, stocks and supplies. Patient's medical record file should contain all the relevant information to identify the patient, to support the diagnosis, to justify the treatment, and to document the course and results of treatment. IMS can be digital or paper-based.	Technical evaluation based on document reviews, surveys, and interviews (at a given time).	1	No IMS available
				2	IMS is adopted in every department/unit OR data is missing, duplicated and inconsistent.
				4	IMS is adopted, data is consistent, it is possible to keep track of available resources.
4.3	Hospital Acquired Infection incidence rate	It evaluates the incidence of Hospital Acquired Infections (HAIs) among hospitalised patients. Surgical Site Infections have been used for this assessment.	Quantitative evaluation based on document review. Refer to the last 3 months.	1	Infections are not monitored or reports are not available
				2	The hospital has informal mechanisms in place to coordinate with other facilities and services.
				4	The hospital has formal mechanisms in place to coordinate with other facilities and services.
4.4	Coordination with pre-hospital emergency service and referral system	It evaluates if the hospital is able to collaborate with external healthcare providers and with pre-hospital emergency care providers. This is related to the opportunity of transferring patients as well as controlling the emergency arrivals.	Qualitative evaluation based on document reviews and interviews (at a given time).	1	The hospital has no mechanism in place to coordinate with other facilities and services.
				2	The hospital has informal mechanisms in place to coordinate with other facilities and services.
				4	The hospital has formal mechanisms in place to coordinate with other facilities and services.

Annex 5. Instructions on how to use the overall hospital resilience assessment tool

Use case description

The ICRC has started a conversation with a hospital system requiring support, and there is interest in improving the hospital system's resilience against a mass casualty incident.

The ICRC asks hospital system managers to demonstrate how well they are likely to perform with respect to a mass casualty incident and clarify the areas where they are likely to have the largest improvement in resilience if they can modify the system. To do this they take this tool.

Input

You insert:

- Hospital data (e.g., current operational condition);
- Disruptive event data (e.g., number of patients seeking hospital care and related illness condition).

Output

You get the areas of intervention based on their potential gain in hospital system resilience.

Limitations

The tool was developed for a mass casualty incident scenario. The analysis of other disruptive events requires modifications of input and output worksheets and of the assumptions made to estimate the resilience.

Getting started

The tool is implemented as a workbook in Microsoft Excel.

Please be aware that you must make the file a trusted document and enable macros before using the tool. To do that, you should:

- Right-click on the file, go to the file's properties, under General unblock the security protection for files coming from other computers,
- Open the file with Excel, select the File tab and choose Options. Select Trust Center, and then choose Trust Center Settings. In the Trust Center, select Macro Settings. Enable all macros.

The tool contains the introduction sheet, the dashboard and background sheets.

Introduction sheet

Take a moment for the **introduction** sheet to understand the approach used to estimate the overall hospital resilience.

It is assumed that the better a hospital can provide service when a potentially disruptive event occurs the more resilient it is considered to be.

Measures of hospital service are used to quantify hospital resilience, namely:

- Average mortality rate below 24 hours from admission;
- Average mortality rate after 24 hours from admission;
- Average time spent at the Emergency Department;
- Average length of stay;

- Total performed surgeries.

You are about to compare what your hospital system can provide today (in terms of mortality rate, performed surgeries, etc.) if a mass casualty incident occurs against what it is supposed to provide (which is here referred to as the service provided at the baseline condition).

For example, you would like to say that if you are running a hospital where a contingency plan exists and dedicated resources are enough to ensure the implementation of the plan, you are better prepared to face a mass casualty incident than if you are running a hospital with no contingency plan. Indeed, the mean mortality rate (for example) is expected to increase due to the missing contingency plan compared to the mean mortality rate expected when a contingency plan exists (Figure 11).

With regard to Figure 11, the less the red area the greater the hospital system resilience.

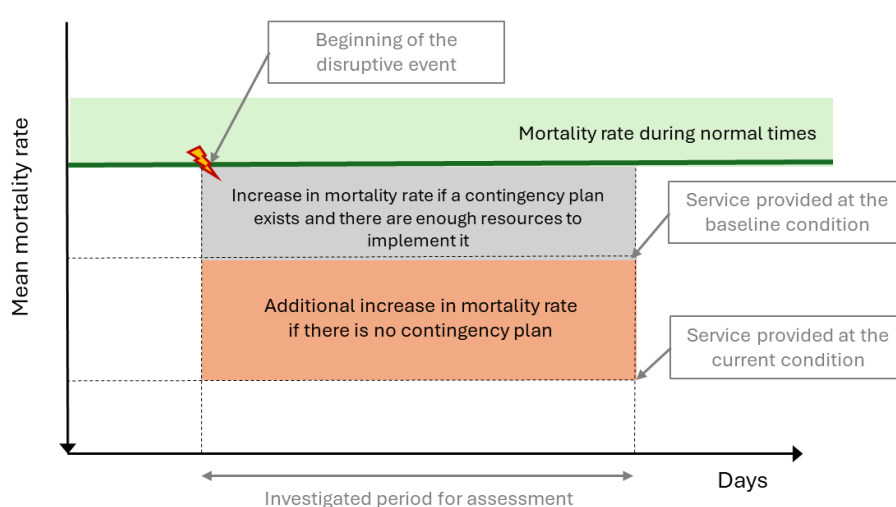


Figure 11. Current condition and baseline condition comparison

The dashboard

The **dashboard** is aimed at summarising input and output data in an easy-to-digest form.

You can use it to get a quick overview of how well your hospital system is likely to withstand a mass casualty incident.

Input data is to be inserted in the green-coloured cells.

You first fill in the Hospital data Table. You can refer to the last monthly nurses report available at your hospital to fill the cells related to the current service measures (without disruptive event). In case there is no available report, you need to ask hospital staff (specifically doctors and nurses) about the service measures, you can refer to the last month situation.

You can retrieve the number of hospital beds which are expected to be opened and staffed during a mass casualty incident from a contingency plan, whereas existing. Otherwise from the last monthly nurses report you should be able to retrieve the current number of opened and staffed beds at the hospital. Then you need to adjust it to a mass casualty incident scenario. You can start asking the head of the emergency department about the bed surge capacity in case of a mass casualty incident. In case no information is available about the bed surge capacity, you have to assume that the number of hospital beds remains the same, thus you can use the last monthly nurses report to fill the table. Please

check consistency between the data you insert in this table and the data you insert in cells C19:C25 in the “Hospital data” worksheet.

On the right side of the worksheet, you can see the Current Condition Assessment table. Use the short list of indicators to describe the current operational condition of the hospital.

In the last monthly nurses report you can find the information about the current staffing level and the bed occupancy rate. It should be easy to assess the hospital bed surge capacity with the information you collected to fill the Hospital beds table. Also, if no information is available about the hospital bed surge capacity in case of a mass casualty incident, the indicator assumes the worst value (i.e., “bed surge capacity not assessed”)

Ask the head of the engineering department about the emergency power and emergency water reservoir capacity.

The stock manager will be able to tell you the oxygen stock capacity, while you can ask the pharmacy (and the head of nurses) about the essential drug products and essential medical devices shortage.

Finally, you set the disruptive event of interest, defined in terms of the total number of patients arriving at the Emergency Department, their distribution (i.e., red, yellow, green, blue and black patients) and the number of patients requiring surgery.

You are now ready to get an overview of how well the hospital system performs under the defined disruptive event.

The outputs are shown in the form of spider and column charts. You can use the charts to compare the service measure values at the baseline and at the current condition. In other words, you can identify the areas of biggest concern (i.e., the indicators which increase the red area in Figure 11), which are, at the same time, the areas where you should intervene to ensure that the interventions will have the largest possible impact in terms of resilience.

In the dashboard, you can:

- Select the service measure to display;
- Filter the indicators to display;
- Reset data to default values (valid for resilience indicators and patient distribution);
- Save the chart as a picture.

Figure 12 shows the Dashboard overview.

If a new scenario is to be analysed (e.g., new current conditions, increased number of patients, etc.), the refresh button generates the results according to the new inputs.

Finally, the buttons placed below the output chart allow you to:

- Change the baseline condition;
- Access protected worksheets.

If you want to better customise the resilience assessment, by providing additional hospital data (e.g., using additional resilience indicators) or by changing the assumptions used to estimate the service measures values, you need to access the background sheets.

Each of the input tables in the Dashboard is linked to the corresponding background worksheet. You can access these worksheets by clicking on the tables' header rows. More details on the background sheets are provided in the following sections.

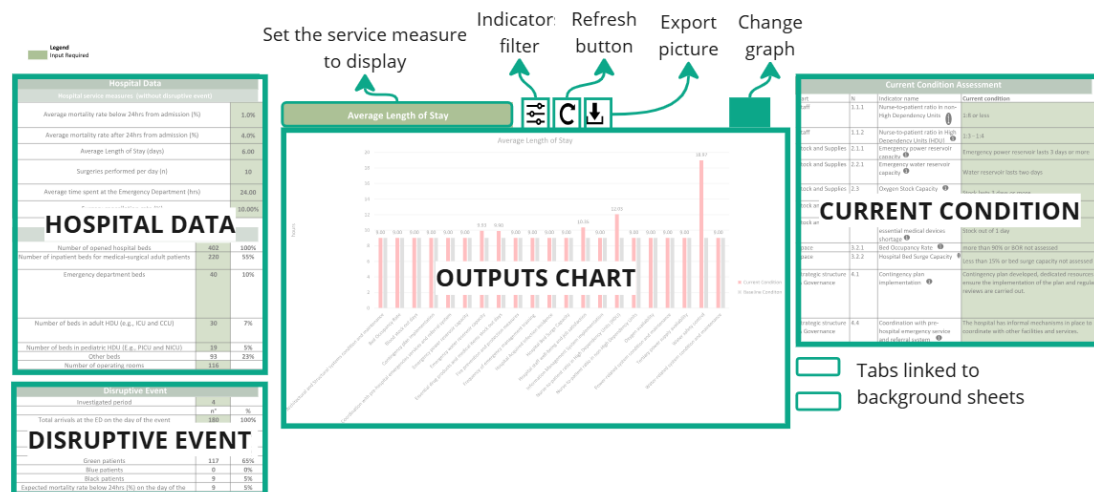


Figure 12. Dashboard overview

Hospital data

The **hospital data** worksheet contains inputs on the hospital, such as:

- Identification of the hospital (Table 14). Here you can insert information to identify the hospital facility and keep track of the assessment process. It is worth noticing that this information is not used for resilience assessment, thus it can be left blank;
- Hospital characteristics (Table 15). Here you must set the number of opened and staffed beds during normal circumstances and the number of currently functional operating theatres (you can refer to the last month). This data is used to take into account patients already hospitalised before the disruptive event happened. For example, in high-dependency units, there are patients requiring oxygen therapy hospitalised before the simulated disruptive event.
- Hospital characteristics (Table 15). You have already inserted this information on the Dashboard.
- Current measures of service (Table 16). You have already inserted this information on the Dashboard.
- Additional required information (Table 17). Here you set additional information used to estimate the hospital resilience (you can refer to the last month). This information refers to average values of:
 - o patients requiring oxygen therapy (e.g., those hospitalised in high dependency units);
 - o patients requiring blood transfusion;
 - o patients requiring antibiotic treatment;
 - o daily arrivals at the Emergency Department;
 - o daily emergency surgeries;
 - o daily hospital admission;
 - o bed occupancy rate. The overall bed occupancy rate is calculated considering the number of beds in high-dependency and non-high-dependency units.

Data is to be inserted in the yellow-coloured cells.

Table 14. Identification of the hospital

Identification of the hospital		
Item	Value	Note
Country	Lebanon	This information are not used for calculation, the cells can be left blank if not of interest.
City	Beirut	
Facility name	RHUH	
Hospital level	University hospital	
Respondent or key informant's name	R. M.	
Respondent of key informant's position	ETHZ	
Date (DD/MM/YYYY)	29/07/2024	

Table 15. Hospital characteristics

Hospital characteristics			
Opened and staffed beds without a disruptive event			
Item	Value		Note
Total number of hospital beds	Type here	XXX	You can refer to the last month
Number of inpatient beds for medical-surgical adult patients	Type here	XXX	
Emergency department beds	Type here	XXX	
Number of beds in adult High Dependency Unit (e.g., Intensive Care Unit)	Type here	XXX	
Number of beds in pediatric High Dependency Unit (e.g., Pediatric and Neonatal Intensive Care Unit)	Type here	XXX	
Other beds	XXX	XXX	
Number of functional operating rooms	Type here		
Opened and staffed beds during a disruptive event			
Item	Value		Note
Total number of hospital beds	XXX	XXX	YOU HAVE ALREADY FILLED THIS TABLE ON THE DASHBOARD
Number of inpatient beds for medical-surgical adult patients	Type here	XXX	
Emergency department beds	Type here	XXX	
Number of beds in adult High Dependency Unit (e.g., Intensive Care Unit)	Type here	XXX	
Number of beds in pediatric High Dependency Unit (e.g., Pediatric and Neonatal Intensive Care Unit)	Type here	XXX	
Other beds	Type here	XXX	
Number of functional operating rooms	Type here		

Table 16. Current service measures

Current measures of service		
Item	Value	Note
Average mortality rate below 24hrs from admission (%)	Type here	YOU HAVE ALREADY FILLED THIS TABLE ON THE DASHBOARD
Average mortality rate after 24hrs from admission (%)	Type here	
Average Length of Stay (days)	Type here	
Surgeries performed per day (n)	Type here	
Average time spent at the Emergency Department (hrs)	Type here	
Surgery cancellation rate (%)	Type here	

Table 17. Additional required information

Additional required information (referred to non-event related patients)		
Item	Value	Note
Average n° patients requiring oxygen therapy (%)	Type here	Clarification: These are patients requiring oxygen therapy (e.g., ventilation). If these patients do not receive oxygen they die. They do not comprise surgical patients who require oxygen for receiving surgery. You can refer to last month.
Average n° patients requiring blood transfusion (%)	Type here	Clarification: These are patients requiring transfusion (otherwise they die). You can refer to last month.
Average n° patients requiring antibiotics (%)	Type here	Clarification: The length of stay of these patients increases if antibiotics are missing. You can refer to last month.
Average n° of arrivals at the Emergency Department per day (n)	Type here	You can refer to the last month.
Emergency surgeries performed per day (n)	Type here	
Average daily hospital admissions (emergency and elective) (n)	Type here	
Bed Occupancy Rate of High Dependency Units (%)	Type here	
Bed Occupancy Rate of non-High Dependency Units (%)	Type here	
Overall bed occupancy rate (%)	XXX	

Disruptive event

The **disruptive event** worksheet contains a description of the potentially disruptive event of interest. You have already set this information on the Dashboard. This section provides for clarification regarding the data to be used.

You first define the investigated period for assessment, i.e., the number of days, including the day of the event, you want to use to estimate the resilience of the hospital. At least three days are to be used.

You define the total number of patients arriving at the Emergency Department on the day of the event and their distribution in terms of triage colours (i.e., red, yellow, green, blue and black).

Green patients report minor injuries and they do not affect the service measures. Indeed, it is supposed that they are not admitted to the Emergency Department, they are not hospitalised and they do not require surgery.

Yellow and red patients report major injuries, they are admitted to the Emergency Department, they are hospitalised and most of them require surgery.

Red patients in very critical conditions can be triaged as blue when they receive palliative care only.

Black patients are dead when they arrive at the Emergency Department.

Black and blue patients are assumed to increase the mortality rate within 24 hours from admission.

You can explore different scenarios for the same type of disruptive event of interest, for example by increasing the number of critically ill patients or by reducing the demand for surgery.

Finally, you define the number of patients requiring surgery.

Data is to be inserted in the yellow-coloured cells.

A Mass Casualty Incident triggered by a blast is used as default. For another type of disruptive event, you could need to rework the sheets (e.g., defining new patient types and making new assumptions).

Baseline service measures estimation

The **baseline service measures** worksheet is to estimate the service that should be provided at the baseline condition, i.e., what the hospital is supposed to provide or what you would like it to provide under the disruptive circumstances defined before.

Table 18 reports illustrative values of service measures under the disruptive circumstances defined before.

Table 18. Expected measures of service under disruptive event

Expected measures of service under disruptive event		
Item	Value	Note
Average mortality rate below 24hrs (%)	19%	Calculated as the weighted average (over the admissions)
Average mortality rate after 24hrs (%)	5%	Hypothesis: as before the event
Average Length of Stay (days)	9	Hypothesis: as before the event
Average time spent at the Emergency Department (hrs)	7	Calculated as the weighted average (over the admissions). It is assumed that on the first day the hospital speeds up the treatment processes at the Emergency Department, but from the second day it goes back to the "normal" treatment velocity.
Surgeries performed over the investigated period (n)	66	This takes into account the event-induced surgeries and additional emergency surgeries. After 1 week from the event, you perform elective surgeries too.
Average surgery cancellation rate over the investigated period (%)	80%	This is based on the assumption that you cancel the elective surgical volume for one week.

The average mortality rate below 24 hours from admission is calculated as the weighted average over the admissions. It considers the expected mortality rate on the day of the event and the mortality rate defined in Table 16.

It is worth noticing that the number of admissions is the sum of the event-related volume, expected on the day of the event, and the average number of daily arrivals at the Emergency Department expected from day two (defined in Table 17).

The average mortality rate after 24 hours from admission and the length of stay are to be set according to expert opinion. By default, they assume the current values (defined in Table 16).

The average time spent at the Emergency Department is calculated as the weighted average over the admissions. In particular, red and yellow patients are supposed to spend one and two hours respectively at the Emergency Department. Patients coming from day two are supposed to spend the average time set in Table 16.

Regarding the surgical volume, it is assumed that for one week the hospital performs emergency surgeries only, then it restores the elective volume. Emergency surgeries comprise event-induced surgeries (defined in the Disruptive event worksheet) and daily emergency surgery from day two, according to Table 17.

The average surgery cancellation rate over the investigated period is equal to the number of cancelled surgeries over the number of performed surgeries. It is not necessarily equal to 100% as the number of cancelled surgeries depends on what has been defined in Table 16 (i.e., surgeries performed per day), while the number of performed surgeries depends on the demand for emergency surgery (defined in Table 17 and Disruptive event worksheet).

Baseline condition assessment

The **baseline condition assessment** worksheet is to define the baseline condition of the hospital.

You use a set of 21 indicators to describe the baseline operational condition of the hospital.

The indicators list contains indicators' names, descriptions, ways to measure, and meanings of values, as reported in Table 19.

A default baseline condition is set, assuming all indicators at their best value (e.g., nurse-to-patient ratio in non-high dependency units equals 1:8 or less).

You can change the baseline values using the drop-down menu in the yellow-coloured column if you have the password to unlock the worksheet.

Table 19. extract of the incators to be used to set the baseline conditon

Part	N	Indicator name	Description	Ways to measure	Indicator value	Meaning	Baseline condition
Staff	1.1.1	Nurse-to-patient ratio in non-high dependency units	It evaluates the number of nurses per patient in non-high dependency units	Average monthly staff nurse census / average monthly patient census. Refer to last month.	0	1:12 or more	1:8 or less
					1	1:10 - 1:12	
					3	1:8 - 1:10	
					4	1:8 or less	
Stock and Supplies	2.2.2	Water quality	It evaluates the frequency of water quality checking, the existence of a reporting system and a plan for water quality checking. It is assumed that a positive result (i.e, water not safe) is followed by a risk reduction action. Water sampling against <i>Pseudomonas aeruginosa</i> is here taken as an example.	Technical evaluation based on document review, interviews with the Quality and the Engineering departments.	1	Water quality is not assessed OR Reports and plans are not available OR Tests are performed less than once per year.	Water quality is assessed at least each six months AND reports and plans are available.
					2	Water quality is assessed at least once per year AND reports and plans are available.	
					4	Water quality is assessed at least every six months AND reports and plans are available.	

Current condition assessment

The **current condition assessment** worksheet is to define the current operating condition of the hospital.

You use a set of 21 indicators to describe the current operational condition of the hospital.

The indicators list contains indicators' names, descriptions, ways to measure, and meanings of values, as reported in Table 20.

You can change the indicators' value using the drop-down menu in the yellow-coloured column.

Table 20. Extract of the indicators to be used to set the current condition

Part	N	Indicator name	Description	Ways to measure	Indicator value	Meaning	Current condition
Staff	1.1.1	Nurse-to-patient ratio in non-high dependency units	It evaluates the number of nurses per patient in non-high dependency units	Average monthly staff nurse census / average monthly patient census. Refer to last month.	0	1:12 or more	1:8 – 1:10
					1	1:10 - 1:12	
					3	1:8 - 1:10	
					4	1:8 or less	
Stock and Supplies	2.2.2	Water quality	It evaluates the frequency of water quality checking, the existence of a reporting system and a plan for water quality checking. It is assumed that a positive result (i.e, water not safe) is followed by a risk reduction action. Water sampling against Pseudomonas aeruginosa is here taken as an example.	Technical evaluation based on document review, interviews with the Quality and the Engineering departments.	1	Water quality is not assessed OR Reports and plans are not available OR Tests are performed less than once per year.	Water quality is not assessed OR Reports and plans are not available OR Tests are performed less than once per year.
					2	Water quality is assessed at least once per year AND reports and plans are available.	
					4	Water quality is assessed at least every six months AND reports and plans are available.	

Results

The **results** worksheet contains the estimated service measures at the baseline and at the current condition.

This information is reported on the dashboard, but you might find it beneficial to access this worksheet if you want to get the results in the form of tables too.

In the Tables, you can easily identify the indicators which can affect the ability to provide service the most, i.e., the resilience of the hospital. These are outlined in a different colour.

Table 21 reports an example of the estimated length of stay and mortality rate after 24 hours from admission.

The results worksheet is for visualization only.

Do not change the Tables manually nor type in the cells.

Table 21. Example of the results tables

ESTIMATION OF THE AVERAGE LENGTH OF STAY				
Part	Indicator number	Indicator name	Current Condition	Baseline
Supply	2.2.2	Water safety control	19.95	9.00
Staff	1.1.1	Nurse-to-patient ratio in non-high dependency units	14.40	9.00
Space	3.1.2	Power-related system condition and maintenance	9.00	9.00
ESTIMATION OF THE AVERAGE MORTALITY RATE AFTER 24 HOURS FROM ADMISSION				
Part	Indicator number	Indicator name	Current Condition	Baseline
Supply	2.2.2	Water safety control	5.24%	5%
Staff	1.1.1	Nurse-to-patient ratio in non-high dependency units	6.0%	5%
Space	3.1.2	Power-related system condition and maintenance	5%	5%

How to interpret the result

From Table 20 and Table 21 you can deduce that the absence of water quality controls and a nurse-to-patient ratio equal to 1:10 can increase the average length of stay compared to the baseline condition, where water quality controls are performed at least once every six months and reports are available and the nurse-to-patient ratio in non-high dependency units equals 1:8 or less. In this case, water quality control appears to be more critical than staffing levels (19.95 vs 14.40 days of hospitalisation). On the contrary, the same nurse-to-patient ratio causes a higher increase in the mortality rate than the water quality control.

The indicators are both relevant in terms of hospital resilience against the analysed disruptive event, as they both affect the hospital service measures.

The results are meant to facilitate the discussion between the hospital administration and the International Committee of the Red Cross on where to intervene to enhance hospital resilience.

The ultimate decision on where to intervene first is up to the user. It is worth noticing that the costs of intervention are not considered in this assessment.

The results are based on the assumptions explained in the next section.

Protected rows-consequences

The **protected rows -consequences** worksheet allows you to access and change the assumptions used to estimate how the resilience indicators affect the service measure values.

This worksheet defines the consequences in terms of service measure changes of below-baseline indicator values. For example, literature findings suggest that for each additional patient per nurse, there is a +10% increase in the mortality rate. Thus, when the nurse-to-patient ratio in non-high dependency units equals 1:10 instead of 1:8, the mortality rate increases by 20% (both below and after 24 hours from admission).

Table 22 reports the consequences of below-baseline nurse-to-patient ratio in non-high dependency units.

Table 22. Consequences of below-baseline nurse-to-patient ratio in non-high dependency units

Item	Value	Note	Source
Increase in mortality rate below 24hrs from admission (%)	20%	For each 2 additional patients per nurse, there is a +20% increase in mortality	Literature. 10.1001/jama.288.16.1987; https://doi.org/10.3390/ijerph192315566
Increase in mortality rate after 24hrs from admission (%)	20%		
Increase in length of stay (%)	60%	For each 2 additional patients per nurse, there is a +60% increase in the Length of Stay	Literature. 10.1097/MLR.0b013e3181468ca3; https://doi.org/10.3390/ijerph192315566
Increase in time spent at the Emergency Department (%)	30%	For each 2 additional patients per nurse, there is a +30% increase in time spent at the Emergency Department	Literature. 10.1111/j.1553-2712.2010.00727.x
Surgeries not performed (n)	0.00	Unknown	

Table 23 reports the consequences of not having an emergency power reservoir, which is to say, not having power for three days in a row including the day of the event.

It is assumed that red and yellow patients die within 24 hours from admission as they cannot receive life-saving treatment. Also, patients requiring emergency surgeries who arrive on the second and third day die within 24 hours from admission for the same reason.

Regarding the mortality rate after 24 hours from admission, it is assumed that each day of power loss causes an increase in mortality of 40%.

The length of stay is increased by each day of power loss.

Finally, surgeries cannot be performed when power is missing.

You can deduce that the impact of a power outbreak on the average mortality rate below 24 hours from admission and on the performed surgeries is not linear, indeed, it is more relevant on the day of the event than on the following two days. Conversely, the impact of a power outbreak on the mortality rate after 24 hours from admission and on the average length of stay is linear.

Table 23. Consequences of three days without power - N.B. : this is the consequence of not having power on the day of the disruptive event and the next two days

Item	Value	Note	Source
Patients dying below 24hrs from admission (n)	93	Each day without power leads to the death of patients requiring emergency lifesaving treatment (here they include both red, yellow patients and emergency surgeries arriving on the days after the disruptive event).	Expert opinion
Increase in mortality rate after 24hrs from admission (%)	120%	Each day without power causes an increase in mortality of 40%.	Literature. http://dx.doi.org/10.1080/17441692.2016.121703
Increase in length of stay (day)	3	The length of stay is increased by each day the power is lost.	Expert opinion
Increase in time spent at the ED (%)	0.00%	Unknown	
Surgeries not performed (n)	38	Surgeries cannot be performed.	Expert opinion

There is a table for each indicator. The tables contain the item to be investigated (i.e., the service measures), the values of the consequences (i.e., the changes in service measure values), notes used for clarification and sources of information.

The consequences of below-baseline indicators values have been retrieved from scientific papers, grey literature and expert opinion. You are recommended to check them and decide whether to use them as they are or adjust them as you like.

In this worksheet there are other three tables of interest, namely:

- required Emergency Department bed surge capacity;
- required hospital bed surge capacity;
- surgical capacity.

In the Table “Required Emergency Department bed surge capacity” you have to define the number of hours most patients are expected to reach the Emergency Department on the day of event. The default value is 4 hours. This time interval is fundamental to understanding if the Emergency Department can cope with the admission demand. For simplicity, the admission capacity depends on the bed turnover only.

In the Table “Required hospital bed surge capacity” you need to define:

- patients who can be transferred or early-discharged. It is assumed that nobody can be transferred to other facilities but 10% of non-critical patients can be early-discharged;
- admission demand for high dependency units. It is assumed that red patients require admission to high dependency units;
- admission demand for non-high dependency units. It is assumed that yellow patients and those hospitalized at the Emergency Department before the occurrence of the disruptive event require admission to non-high dependency units.

In the Table “Surgical capacity” you need to define:

- time for completing surgeries on event victims. The default value is 36 hours from admission;
- average operating time. The default value is 4 hours, and it comprises operative time, cleaning time and potential out-of-service time;
- nurses working in operating theatres per day. It is assumed that 2 nurses are needed in each operating room.

This a protected worksheet and a password is needed to change the values reported in the yellow-coloured columns. The current password is: 1234.

Protected rows – formulas

The **protected rows–formulas** worksheet is used for calculation only.

It appears hidden by default, however you can unhide it.

This a protected worksheet and you are not supposed to edit these cells.