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Resilience in an era of systemic risk: An integrated analysis of critical local and national infrastructure, emergency medicine, and civil defence

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Abstract

The stability and functionality of modern, highly technological societies are profoundly dependent on the uninterrupted availability of critical infrastructure services. The health sector plays a unique role in protecting the highest-priority goal of preserving and saving human lives and health. This analysis uses a systematic investigation, moving from empirically grounded case studies of regional disasters in a winter storm in 2005 and a flood in 2021 in Germany, through operational management models and application-oriented research, to the strategic and legal frameworks at the local to national level. The resilience of health systems and public health cannot be considered in isolation. It is deeply embedded in the resilience of the entire critical infrastructure and, ultimately, in local and national strategies. The results are that institutionalised learning needs to take place following disruptive events, that "single points of failure" and „common-mode failures" need to be identified. The findings point to a demand for engagement with the scenario of civil defence in the context of a collective security crisis, thereby postulating the necessity of an integral, multi-level resilience strategy for emergency medicine and society as a whole.

Take-home message for students Critical infrastructure resilience needs to include individual, local and national aspects of security against dependencies on critical services such as power, information, accessibility, water and food for health facilities to function in a crisis.

Introduction

The stability and functionality of modern, highly technological societies are profoundly dependent on the uninterrupted availability of critical infrastructure services. The supply of energy, the management of water and wastewater, information and communication technology and the healthcare sector constitute the socio-technical backbone of national and societal life. However, the increasing complexity and interdependence of these systems simultaneously heighten their vulnerability to a broad spectrum of disruptive causes, ranging from natural hazards and technical failure to deliberate, malicious attacks within the framework of hybrid threat scenarios.

This analysis is dedicated to a systematic investigation, moving from empirically grounded case studies of regional disasters, through operational management models and application-oriented research, to the strategic and legal frameworks at the local to national level. The culmination of this escalating logic is an engagement with the scenario of civil defence in the context of a collective security crisis, thereby postulating the necessity of an integral, multi-level resilience strategy for emergency medicine and for society as a whole.

1. The empirical foundation: Manifestations of infrastructure crises as an analytical starting point

Any strategic discourse on resilience must be founded upon the analysis of real-world disruptive events. An examination of two archetypal case studies from recent German history impressively demonstrates the tangible consequences of infrastructure failure.

The **Münsterland winter storm of 2005** serves as a paradigm for the consequences of a large-scale, protracted electricity outage triggered by an extreme weather event (Bundesnetzagentur 2006). The analysis of this event extends far beyond the mere fact of the power cut. The reality that individual communities were severed from the electricity supply for up to seven days and that approximately 65,000 inhabitants had to endure several nights without power points to systemic cascading effects. Such an outage directly impacts heating during winter months, the functionality of communication networks and the water supply due to the failure of pumping stations. Critically, the care for individuals dependent on medical support in their homes is severely jeopardised. The fact that a significant portion of the national emergency power capacity of the Federal Agency for Technical Relief (Technisches Hilfswerk, THW) was deployed illustrates the immense strain on civil protection organisations. It indicates the potential limits of their capabilities in the face of even larger or trans-regional events. This event demonstrates the fundamental dependence of nearly all spheres of life on a single critical infrastructure: the electricity supply.

The **Erftstadt flood of 2021**, with a specific focus on the local hospital, shifts the perspective from a purely technical supply failure to a direct physical threat scenario for a central institution of the healthcare system (Wiesehahn and Kaifie 2024). An inundated hospital, reliant on external emergency generators and road accessibility, illustrates a dual vulnerability. On the one hand, the hospital's internal operational capacity is massively compromised, as not only the power supply but also water and wastewater management, medical technol-

ogy and the structure of the building can be affected. On the other hand, the institution becomes isolated from its surroundings. Access routes for emergency services, personnel and supplies may be blocked, rendering the evacuation of patients and the delivery of aid supplies extremely difficult, if not impossible. The 2021 flood disaster thus showed that hospitals do not merely act as system-relevant service providers in a crisis, but can themselves become critically endangered entities in need of external assistance.

Taken together, these case studies establish a fundamental problem: Critical infrastructure, particularly in the healthcare sector, is highly vulnerable to failures in upstream supply systems and direct physical impacts.

2. Operationalising resilience: From theoretical crisis management to application-oriented practice

From this diagnosis of vulnerability arises the necessity for structured solutions aimed directly at actors within the healthcare system, especially hospitals.

A central theoretical model of crisis management visualises the objective of any resilience effort: minimising damage over time. In academic terms, this involves reducing the area of the so-called ”resilience triangle,” which is defined by the degradation in service quality, the duration of the disruption and the time required for full recovery (Linkov et al. 2014). Without adequate preparation, a longer reaction time, a more pronounced collapse in service quality and a delayed return to normal operations are the consequences, which, in the worst case, can lead to evacuations and harm to patients. Optimal preparation, by contrast, shortens the reaction time, mitigates the initial shock through sufficient primary measures and facilitates a faster, more stable emergency operation.

This theoretical ambition must be translated into practice through transdisciplinary research approaches. Initiatives such as the **NOWATER project (Emergency Planning for Water Supply and Disposal)** are exemplary. They unite academia, federal authorities and healthcare practitioners to develop technical and organisational solutions to failures in fundamental utility services.

The concrete outputs of such projects, for example, in the form of guidelines for emergency supply, represent the crucial step of knowledge translation. Rather than remaining abstract research findings, they must be developed into practical handbooks, including a strategic overall concept, a detailed organisational manual and a framework for conducting exercises (Bodur et al. 2024; Geiger et al. 2023; Joel et al. 2024). This triad enables hospitals to address the issue systematically — from strategic anchoring within clinical leadership, through organisational implementation by the crisis management team, to the practical verification of plans via drills.

Planning for potential events is ideally operationalised through a modular, ’building-block’ system. This approach acknowledges that infrastructure failures can have diverse causes (fire, power, water, IT, medical gases, etc.). Instead of creating a monolithic plan, specific checklists are developed for each scenario, which increases flexibility and applicability in an actual emergency. Whilst research projects can provide templates and models, the responsibility for adaptation and implementation lies with the respective institution.

For acute crisis management, a standardised 10-point plan is essential as a Standard Operating Procedure (SOP). Such a model structures the process from the initial detection of the event and alert, through to final documentation and the ”lessons learned” phase (Geiger et al. 2023). Of particular note is the differentiation of leadership

structures into an Operational Command for the immediate initial phase and a Strategic Coordinating Command for the overall management of the event. This reflects established principles of incident management and ensures that both tactical on-site execution and strategic planning and resource coordination are covered.

3. The strategic and legal framework: Scaling to the national level

After illuminating the operational level of crisis management, the analytical horizon must be expanded to the systemic, legal and societal dimensions.

The application of Geographic Information Systems (GIS) to analyse the accessibility of critical infrastructure in crisis situations is a decisive tool for strategic planning. Modelling the shortest, viable routes from emergency response stations to hospitals, accounting for time delays caused by flooding, is an example of advanced risk analysis. It demonstrates that resilience of a hospital is inextricably linked to the resilience of the surrounding transport infrastructure (Tzavella et al. 2018).

These systemic risks find their corollary in the legal sphere. The planned ”Critical Infrastructure Umbrella Act” (German: KRITIS Dachgesetz) marks a paradigm shift from a voluntary to a legally mandated engagement with resilience. The central pillars of the act — the nationwide identification of critical facilities, the establishment of disruption monitoring, the execution of risk analyses by both operators and the state and the definition of minimum standards for resilience measures — create a binding regulatory framework. The expansion of Critical National Infrastructure (CNI) sectors to include areas such as municipal waste management and space infrastructure signals a deepening and evolving understanding of systemic criticality.

Furthermore, ongoing digitalisation is expanding vulnerability. The distinction between ”predominantly physical” and ”predominantly digital” domains clarifies the extended scope of protection required. Alongside the physical individual, the ”digital avatar” and online social groups emerge as vulnerable entities (Fekete and Rhyner 2020). The dependence on infrastructure broadens from traditional physical supplies (water, food, power) to digital provisions (data, connectivity). This transformation creates new, complex dependencies and widens the attack surface for disruptions.

Finally, societal risk perception must be considered. There is an ambivalence in technological progress: whilst technology solves complex problems, a perceived mastery of risk can lead to behavioural changes that trivialise danger. This reflection on human risk perception serves as a bridge to addressing the ultimate man-made risk: military conflict.

4. The extreme scenario: Civil Defence in the context of hybrid threats

The most demanding stress test of the resilience of critical infrastructure and emergency medicine is the civil defence scenario.

”Civil Defence” is a distinct concept that differs fundamentally from disaster response in peacetime. Constitutionally, civil protection in a state of defence is a federal responsibility, whereas disaster management is a

matter for the constituent states (Länder). Civil defence aims to ensure the functioning of the state and society in the event of war. Its core tasks are the maintenance of state and governmental functions, civil protection (the safeguarding of life and health), the supply of the population and the support of the armed forces.

The modern threat no longer stems primarily from conventional, declared war, but from a hybrid threat landscape. This operates below the threshold of classic warfare and aims to destabilise society from within. The instruments include disinformation campaigns, espionage, cyber-attacks, acts of sabotage and propaganda, all designed to undermine trust in democracy. Plausible threat projections can illustrate a gradual process of escalation: from a ”frozen conflict” through massive troop movements and large-scale military exercises, to concrete acts of sabotage against civilian infrastructure and the beginning of a major military deployment.

In such a scenario, a nation like Germany would assume the geostrategic key role of a central ”logistical hub” in Europe. As a primary transit country, it would not only have to ensure the deployment and supply of tens of thousands of allied soldiers (”Host Nation Support”), but also manage the multi-directional flows that a conflict entails: refugee streams, the transport of the wounded and, potentially, prisoners of war. The design of logistical infrastructure, such as Convoy Support Centres (CSCs), is essential to fulfilling this role (Budendorfer-Licht et al. 2025).

This places immense demands on the protection of critical infrastructure, which must now be hardened not just against failures, but against deliberate attacks by an intelligent adversary. An analysis of the critical infrastructure sectors of energy, IT and transport reveals a discrepancy between the current state and the desired capabilities. Future required competencies include proactive measures such as Open-Source Intelligence for early threat detection, a real-time interdisciplinary common operating picture and robust business continuity concepts. The command and communication structures must ensure seamless cooperation between federal, state and local levels, as well as between civil and military actors.

5. Reflections on missing links of a national strategy – adding the local and individual components

The national perspective is key because health is a **cross-cutting** topic that too often stops at administrative borders. It requires an overarching effort to address large-scale crises and disasters. Especially federal systems, but also well-intentioned county-level autonomies and the respective individual solutions of health organisations make sense for everyday emergency cases. But they come to their limits in longer-term, cross-regional disasters, often also with a dimension of overwhelming human perception, imagination and experience.

However, while national resilience efforts are certainly important, they need to be complemented by improvements in **resilience at the local and individual levels** within health organisations and professionals. The contribution therefore also showed examples of how hospitals, as one example of health facilities, can massively reduce their failure risk and cascading pathways in a crisis when introducing some simple measures. A simple measure could be a redundant energy supply, which already often exists. But a simple yet major improvement would be to ensure it is not placed as a common-cause failure in the basement,

where it would be flooded, for example. And avoiding single-cause failures, such as alarm chains dependent on one person who might be on holiday or not on station, should also be checked and supplemented with additional fallbacks, including people who will be immediately and automatically informed when the first person in line is not connecting to the phone.

Critical national infrastructure resilience must therefore be complemented by critical local infrastructure resilience. And a warning must be expressed about the usage of resilience in this context. Especially in our health and medical context, resilience is often used in relation to the psychological and motivational aspects of individual beings. It is therefore important to also stress this level, which might be termed critical individual resilience. Individuals must be encouraged, educated and enabled to stand up, speak out and inform when something happens. Especially in hospital contexts, traditional roles of the chief physician still create hierarchical, top-down, patrimonial command chains in which individuals are not heard when they do not have the same status. This idea of resilience includes enabling laypeople, such as bystanders or lower-ranking medical personnel, to express observations when they notice negative symptoms in a patient, for example. This principle should also be applied in everyday patient observation, including during crises. Especially in acute and major disasters, clear, hierarchical command chains often serve their purpose and work better when procedures are strict and clear. However, even there, individual resilience should be reconsidered to complement the picture. This means that command-and-control procedures, as suggested in our hospital guideline above, should still be the primary way to address a crisis such as a blackout, flood or military attack. However, then it must immediately also be accepted and from the start, integrated that there will always be bystanders and volunteers. And these lay persons are often largely underestimated in their capacity and knowledge by those in the established command chains. Cases such as the floods in Germany and others have often produced volunteers who are the first on site and have high-level skills, whether as risk managers in everyday life in their jobs or as technical experts, IT experts, social care experts or others. Future systems must therefore combine critical national resilience with critical local and individual resilience. A more mature integration of top-down and bottom-up forms of integration of people with diverse status, competencies and motivations must be achieved.

The health sector is not so different from most other sectors. It, however, has a unique role in protecting the highest-priority goal of preserving and saving human lives and health. And it is composed of staff and professionals with very specific duties, education and expertise. It is therefore a special challenge for the health field to overcome siloed, special expertise thinking and practice. In everyday situations, most patients who undergo medical treatment already know this, and when communicating with medical personnel, they often find it difficult to find doctors with a holistic view. This is probably due to the high specialisation in medical care. But especially when it comes to crises at a larger scale than dealing with single patients and everyday routine, but dealing with unknown situations in a major disaster, such as a major earthquake, forest fire, or any other situation that has not been experienced, it needs much more open-mindedness, cross-sectoral and overall holistic views on the situation. This means that health professionals must receive more training in cross-sectoral communication skills and awareness that goes beyond usual duties and comfort zones.

Training would be one way to approach this, and they should not be as dull as many work safety or fire drills often are. But scenarios of a three-day blackout or evacuation during inaccessible road conditions should be practiced at least once a year.

Such exercises can reveal a lot of existing knowledge and awareness amongst people we might assume think only in very specialized ways. But in reality, also medical staff often are engaged in many daily activities in other situations, and therefore principally have the same skill set as any other sector to also manage large-scale and unexpected crises and to develop resilience. The health sector is also much broader than just medical staff and personnel, and it includes a wide range of management, organisational, psychological, supply chain and other skills and resources. It can therefore also support other sectors affected by its special expertise and experience in considering the impact on human health related to important services that need to remain running, such as those connected to critical infrastructure and overall national, local and individual resilience.

6. Lessons for a local and national resiliency

The analysis synthesises fundamental lessons from past catastrophes that hold universal validity for future planning.

1. **The principle of institutionalised learning:** The systematic analysis of official reports following disruptive events is the foundation of an iterative improvement process. Resilience is not a static **state but a dynamic learning cycle.**
2. **The principle of decoupling dependencies:** The physical concentration of critical lifelines at geographical ”bottlenecks,” such as bridges, creates ”single points of failure.” The identification and, wherever possible, the mitigation of such critical dependencies through redundancy creation is a core principle of technical resilience.
3. **The principle of avoiding ”Common-Mode Failures”:** The Fukushima nuclear disaster of 2011 serves as a stark reminder. A single event (the tsunami) caused the failure of both the primary system and the supposedly redundant backup system. A backup is worthless if it is exposed to the same threat as the system it is intended to protect. This principle is universally applicable across all domains of emergency planning.

In summary, the resilience of health systems and public health cannot be considered in isolation. It is deeply embedded in the resilience of the entire critical infrastructure and, ultimately, in local and national strategies. The trajectory from a local power outage to the analysis of hybrid warfare demonstrates the necessity of an integrated, multi-domain and multi-level approach. A proactive, knowledge-based and realistic engagement with the risks of the 21st century is no longer an option but a strategic necessity in an increasingly fragile and uncertain world.

Five strategic demands for local and national resilience

Based on the foregoing analysis, the following five strategic demands are formulated to enhance local and national resilience in the face of systemic risks:

1. **Mandate integrated, cross-sectoral resilience planning:** policy must

move beyond siloed approaches. It shall be mandated that resilience strategies for healthcare, energy, transport and digital infrastructures be jointly developed and tested, creating an integrated resilience framework that formally links national civil protection with local disaster management planning.

2. **Implement a strategy for mitigating critical dependencies:** A systematic audit must be undertaken to identify single points of failure and common-mode vulnerabilities across all infrastructure sectors. Local municipalities and counties must identify their critical infrastructure dependencies. But this must also be conducted at the national level, across all administrative areas and CI sectors, and also regarding their international cross-border interdependencies. This audit must be followed by a funded, long-term strategy to build redundancy, diversify supply chains and physically harden the most critical nodes.
3. **Invest in proactive hybrid threat intelligence for civil protection:** National and regional civil protection agencies must be equipped with and trained to use advanced capabilities for early threat detection in the hybrid domain. This includes robust investment in Open-Source Intelligence, social media analytics and cyber-defence intelligence, as well as the formal integration of this intelligence into civil crisis management and warning systems.
4. **Establish a mandatory cycle of stress tests:** A regular, legally mandated cycle of large-scale, multi-agency resilience exercises must be established. These exercises must move beyond conventional scenarios to stress-test the entire system against complex, cascading failures, including hybrid attacks and the simultaneous failure of primary and redundant systems.
5. **Secure long-term, ring-fenced funding for Critical National Infrastructure resilience:** Enhancing critical infrastructure resilience must be treated as a matter of long-term national security, not short-term discretionary spending. Governments must establish dedicated, multi-year, ring-fenced funding mechanisms to support the implementation of the above demands, ensuring that the development of a resilient nation is a sustained, strategic priority.

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