RESEARCH IN PROGRESS

STRENGTHENING RESILIENCE IN A DANISH HEALTH SYSTEM – A LONGITUDINAL STUDY

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This study evaluates the enhancement and preservation of resilience initiatives within the Danish health IT platform, sundhed.dk[1], used for managing COVID-19 test results and vaccine certifications. Employing a longitudinal approach, the research builds on qualitative interviews with IT personnel directly involved in the system's design and implementation. It assesses which measures implemented during the pandemic persisted, which were discarded, and how these strategies adapted over time. Results categorize enduring resilience-enhancing strategies into optimization of organisational structures, refinement of frontend processes, and improvement of backend systems. The research underscores the importance of re-evaluation over time to establish best practices for managing resilience in public sector IT infrastructure handling sensitive citizen data.

Keywords: resilience, health information systems, rapid scaling, sensitive data, longitudinal study

[1] Sundhed.dk is both the name of organisation behind the Danish health platform and the name of the system.

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1 Introduction

The focus on resilience in the development, operation, and maintenance of IT systems has recently gained even greater importance. Society at large depends on the existence of a secure, robust, and resilient digital infrastructure. This is particularly crucial in the context of health crises, climate emergencies, and the current geopolitical climate.

When considering IT systems, resilience - as defined by Liu et al. (2010) - involves the capability of an information system to maintain its function with minimal service degradation in face of unexpected workloads or disturbances that may lead to partial failures. Furthermore, resilience entails the system's ability to swiftly recover to its normal service level once such unexpected situations cease. In essence, resilience encompasses both the sustained functionality amidst adversity and the subsequent seamless return to normal operations following the resolution of unforeseen disruptions.

In a prior study. the scalability of the Danish health platform, responsible for managing test results and vaccine certifications, was examined (Frederiksen et al., 2023). Specifically, it explored how the platform managed to scale from a few to many users within a mere two weeks. The aim of the present study is to follow up and evaluate which of the initiatives, conceived during a crisis, have been sustained, discarded, or potentially expanded upon to strengthening resilience. The research question is: What initiatives were sustained, discarded, or expanded upon by sundhed.dk to strengthening resilience in the Danish IT health platform before, during and after the Covid-19 crisis?

2 Related literature

The unprecedented COVID-19 pandemic has necessitated a rapid and effective response from health systems worldwide. A critical aspect of this response has been the scalability and resilience of health platforms. Resilience in public health systems, particularly during crises such as the COVID-19 pandemic, is a subject of considerable interest. Haldane et al. (2021) provide a comprehensive analysis of health systems' resilience in managing the COVID-19 pandemic, drawing lessons from 28 countries.

The architectural perspective of resilience, as discussed by Liu et al. (2010), provides a foundational understanding of how system designs contribute to resilience. Further, Pan et al. (2023) propose critical sub-attributes of resilience used to evaluate software architecture resilience: reliability, restoration, availability, safety, robustness, and rapidity. The role of business capabilities and organisational structures in resilience is explored by Müller et al. (2013), Duchek (2020), and Annarelli & Nonino (2016). They emphasize the importance of strategic and operational management in building resilient systems. Gardner LeGars et al. (2023) introduce frameworks for Information Technology System Resilience and Organisational Resilience.

The literature underscores the multifaceted nature of resilience in health systems, particularly in the face of global crises like the COVID-19 pandemic. The Danish health system's rapid scaling serves as a case study in resilience, illustrating the importance of architectural, organisational, and information systems perspectives in managing unforeseen challenges.

3 Methodology

The objective of this study was to investigate the measures implemented by sundhed.dk in response to the challenges encountered during the phased reopening of society following the COVID-19 pandemic, with a focus on the strategies employed to enhance or preserve the resilience of the information system responsible for managing test results and immunity certification.

We argue that resilience is not just about immediate responses, but also about the ability to sustain and develop effective initiatives over time. Therefore, the study adopted a longitudinal approach to examine the strategies that sundhed.dk developed and implemented before, during, and after the COVID-19 pandemic.

To investigate the developments before, during, and after the pandemic, the study draws on qualitative interviews with IT architects, operation leads, and developers who participated in developing the system. The selection of interview participants was guided by their level of direct involvement and active engagement in the design, development, and implementation processes. This criterion ensured that the chosen individuals possessed comprehensive and critical insights into the timeline of events, the decision-making rationales, and the strategic responses to the emerging

challenges. By focusing on those with first-hand experience, the study aimed to draw upon a depth of knowledge and expertise that would illuminate the complexities and nuances of the system's evolution and resilience during the pandemic. We decided not to interview the users as the primary aim was to evaluate the system's resilience measures from a technical and organisational standpoint rather than on the user experience or satisfaction. The interviews were conducted with inspiration from the critical incident technique (Chell, 1998; Flanagan, 1954), which aims to reveal the most crucial situations and initiatives that contributed to enhancing or sustaining the system's resilience from the perspectives of the individuals. The longitudinal aspects were empirically studied using a snapshot approach, with data collected at two distinct time points. The initial stage of the interviews targeted a significant two-week timeframe, beginning with the Danish Prime Minister's announcement regarding the partial reopening of the country, and ending with the expected date for the system to be completely operational. The initial four interviews were geared towards understanding the extraordinary measures undertaken during this period of heightened urgency. A subsequent interview took place sixteen months later, with the aim of evaluating the enduring impact of those measures and exploring additional steps taken to further reinforce the system's resilience and thus examine which best practices emerged from this extraordinary effort. We analysed the data, aligning it with the themes and initiatives delineated by Frederiksen et al. (2023). Our goal was to elucidate the progression and maturation of these initiatives since the preceding series of interviews. In tandem with this analysis, we adopted an inductive approach to uncover emergent and prospective initiatives, those which have been set into motion or proposed subsequently.

4 Preliminary results

Upon analysis, the initiatives identified for enhancing resilience can be categorised into three primary domains: optimising the organisation, refining the frontend processes, and improving the backend systems. These three thematic areas are presented below. We refrain from fully unfold the details of the before phase as this is already addressed by the preceding study (Frederiksen et al., 2023). Rather, our focus lies in the following phases, examining alterations and continuities of the initiatives applied.

4.1 Optimising the organisation

Before the two-week period, sundhed.dk faced a comprehensive process for making changes, requiring approval from multiple internal stakeholders and management layers. This bureaucratic system slowed decision-making significantly. The operation lead provides a clear picture of the situation: "*Before, if we should have made such changes, we had to inform and get approval from various internal stakeholders. As a minimum, we had to ask the change advisory board and an architect. And the management should nod and agree that it is a good idea and approve the costs*". However, a pivotal initiative during the two weeks streamlined operations by breaking down barriers between departments. An empowered task force gained authority to interact directly with top management, reducing approval times from days to hours as commented by the operation lead: "*So, if we had a good idea before noon, we could implement it the same afternoon*". This change allowed for rapid implementation of ideas, bolstering the organisation's adaptability and resilience. Although the task force disbanded afterward, the organisation retained insights gained from the experience. It initially embraced DevOps principles with operations and development working together in that same department, but later changed to merely integrate a representative from operations into development meetings to maintain collaborative gains. Discussions continue for a broader adoption of DevOps, reflecting sundhed.dk's commitment to building on positive changes made during the transformative period.

During the task force, documentation was scarce. After the task force documentation has improved as stated by the IT Architect: "*We have become much better at writing documentation*". Sundhed.dk is currently looking into automating part of the documentation by using tools like Swagger/OpenAPI. The goal is to ease onboarding of new employees, limit knowledge loss and thus improving organisational resilience.

4.2 Refining the frontend processes

As traffic to sundhed.dk's digital services began to swell, the organisation faced a series of network and infrastructure challenges. The team proactively expanded their incoming and outgoing bandwidth and strengthened their existing setup with additional hardware. The firewall-interface policy was reconfigured to support the influx of users. However, a noticeable imbalance in traffic volume became apparent.

The operation lead clarifies: "*An incoming request is not very large, but an outgoing request is*" highlighting the disproportionate size of data being processed in each direction. The task force swiftly responded to these imbalances by integrating a content delivery network (CDN), thereby optimizing the delivery of static, less sensitive content to users while ensuring that secured services managed the more sensitive data. This strategic allocation of resources proved effective, as the operation lead reveals, "*The same afternoon, we had access to 40 Mbit CDN*" underscoring the task force's ability to rapidly enhance network capacity. In tandem with these efforts, the team introduced a queue on the front page. This tool was critical for strengthening system robustness and guaranteeing reliability during times of peak load. The IT architect describes the mechanism's utility: "*We can limit the number of users we let in*", a measure to prevent system overloads.

Presently, the CDN continues to be utilized for serving static content to some degree, with the IT architect noting, "*We have that to some extent*". While the queuing system implemented during the peak period is no longer active, its architecture allows for it to be swiftly reactivated should the need arise. Sundhed.dk has also embraced server-side rendering using web components, a move that not only facilitates the distribution of more assets via the CDN but also accelerates the development process. The IT architect reflects on this technological evolution with satisfaction: "*We should arrive at a scenario where we could develop our solutions significantly faster. That's the experience we've had so far with the web component concept. And our experience so far is one solution. Things move faster*". This adaptability and speed mark a new era for sundhed.dk's digital service infrastructure, one marked by increased efficiency and readiness for future demands.

4.3 Improving the backend systems

Sundhed.dk faced challenges with their security measures, which significantly slowed down the application performance. As the IT architect explains, some security services were not equipped for many users at the same time: "*And the problem is that some of the security services we have running, they cannot serve many concurrent users*". The issue was compounded by excessive encryption for each user, which the IT architect describes as "*completely overkill in this context. It really sucks up performance*". To address the concerns raised, the team during the peak project period focused on optimizing data transfers between services. This involved reevaluating the need for encryption,

particularly for data sensitive to security breaches, such as man-in-the-middle attacks. The IT architect notes the necessity of encryption for inter-service communication: "*There's a service that needs to call another service. It needs to transport some data that's personally sensitive, so therefore we have to encrypt it*". The combination of access control and encryption was crucial for ensuring the security of these transfers: "*There's an access control element, and at the same time, it's encrypted*" (The IT architect). To further enhance performance, the task force considered switching off message encryption and relying solely on HTTPS, a less resource-intensive option, but as indicated by the IT architect they ended up with message encryption: "*Turn off HTTPS and run with message encryption*". Following the peak period, the task force's work resulted in work to re-introduce HTTPS on the backend and eliminate resource-intensive elliptic encryption. This step, alongside a more holistic view of the scalability challenges, particularly concerning external dependencies like health data and NemID[1] login mechanisms, marked an evolution in sundhed.dk's approach. The IT architect highlights the necessity for external components to scale in tandem: "*It's not just sundhed.dk... there are some external factors that need to scale with us*".

The implementation of short timeouts for synchronous calls was an interim solution to ensure service restoration in case of failures. The task force planned and later implemented a circuit-breaker pattern to manage these issues, although its complexity led to a reduction in its use. A shift to lazy loading for a less-frequently used service led to faster response times, a change that has been maintained post task force, as the IT architect confirms, "*It's in operation unchanged*".

The IT architect explains that prior to the task force, an exploration into replacing old servers took place. During the peak, services were consolidated onto virtual machines, which allowed for local calls, removal of service discovery service and thus reducing communication overhead and enabling horizontal scaling with the addition of hardware and a load balancer. The IT architect details this scalable solution: "*So, the web service and gateway (service) were put on the same server... If we need to support 1000 simultaneous users, we simply make 10 of those machines*". Post-task force, the practice of virtualisation was continued, and service discovery was reintroduced.

[1] Personal key to digital services in Denmark

Work is in progress to split a monolithic application into smaller, independent, and scalable microservices, enhancing reliability and failover capabilities. The microservices chassis pattern and service template pattern are being utilized to speed up development and ensure consistency across services. The IT architect expresses optimism for the new direction: "*We implement chassis. The goal is faster development. The experiences from the first solution are good*".

Overall, the changes done by the task force has been refined to ensure resilience of sundhed.dk going forward.

5 Conclusion and further research

Our initial investigation revealed several strategies that enhanced the resilience of Sundhed.dk. However, as this subsequent study indicates, not every seemingly promising concept withstands the scrutiny of time.

The circuit-breaker pattern was ultimately discarded, as it led to an overly complex architecture without effectively addressing the core issue. Nevertheless, this architectural pattern remains robust and should be considered for future implementations.

A selection of initiatives has proven enduring: The use of a Content Delivery Network (CDN) for the static components of the frontend has been successful. The backend remains virtualised, yet there is ongoing effort to streamline the architecture, progressively moving towards a microservices approach.

A service discovery mechanism, removed in the task force, has now been reintegrated, enhancing the architectural design with minimal additional burden. Furthermore, the utilisation of web components, lazy loading of proxy components, and the microservices chassis pattern are considered to be advantageous.

In the realm of security, the transition from dual to singular encryption was made early in the process. We anticipate adopting web standards for encryption as they are deemed sufficiently secure.

The organisation has undergone several changes. Under favourable conditions, the re-establishment of a DevOps team is recognised as potentially beneficial. Further work is going on at sundhed.dk to improve documentation to prevent knowledge loss.

Through our study, we have identified the specific initiatives that were sustained, discarded, or expanded upon by sundhed.dk in strengthening resilience within the Danish IT health platform across the phases before, during, and after the COVID-19 crisis.

The insights gained may serve as a foundation for subsequent research in public entities that manage highly sensitive citizen data and thus have stringent privacy requirements.

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