A Reappraisal of Resilience in Digital Infrastructure

A Study of Cyber-Physical-Social Systems in Ongoing Crises

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UiA University of Agder

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A Reappraisal of Resilience in Digital Infrastructure: A Study of Cyber-Physical-Social Systems in Ongoing Crises

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Abstrakt

Digitale teknologier er gjennomgående i kjernevirksomheten til organisasjoner som utfører kritiske tjenester (OCS). Dette skjer på bakgrunn av kontinuerlig innovasjon i arbeid og praksis. Ettersom nye programmer og tjenester blir utviklet, skjer det en konvergens av tradisjonelle fysiske infrastrukturer og raskt skiftende moderne digitale teknologier. Disse teknologiene er komplekse og er blitt karakterisert av cyber-physical-social systems (CPSS).

CPSS-er er tett integrerte, koordinerte, sensorbaserte digitale løsninger med både menneskelige og datateknologiske karakteristikker. De er særlig innarbeidet i og tilrettelegger for organisasjoner som utfører kritiske tjenester operasjoner. Et fremtredende eksempel på denne utviklingen finner vi i helsesektoren. Serviceinnovasjon (eks. telemedisin) har vært vanlig i denne sektoren i flere tiår. Det har likevel vært en signifikant økning i de siste årene, en som COVID-19 pandemien har forsterket.

En prioritet for organisasjoner som utfører kritiske tjenester er å imøtekomme operasjonelle forstyrrelser med fortsatt sikker behandling. Dette blir i større grad oppnådd ved å bruke digitale virkemidler slik som CPSS. Helseorganisasjoner som utfører kritiske tjenester sin bruk av CPSS og andre digitale verdier gjennom pandemien har blitt anerkjent som en resiliens respons i litteraturen innen informasjonssystemer (IS). Likevel ser vi at tidlige erfaringer fra pandemien avslører en tydelig sårbarhet overfor uforutsette begrensninger. Faktisk stagnerte helsetjenesten nesten fullstendig.

COVID-19 var (og er fortsatt til en viss grad) en destabiliserende faktor i disse organisasjonene. På den ene siden forårsaket den uforutsette utfordringer og varig instabilitet. På den andre, så har den iverksatt omfattende innovasjon og endring. Det er begrenset med forskning som undersøker en krise fra denne typen dualistisk perspektiv; en krise som samtidig er en katastrofe og en mulighet. Vanskelige forhold iverksetter kortsiktig innovasjon og selektiv utbedring av digitale verdier. Dette trigger igjen en transformativ læring og mulig langsiktig evolusjon i kritiske tjenester organisasjoner som utfører kritiske tjenester.

I denne avhandlingen følger jeg en empirisk case der en CPSS-løsning ble iverksatt av helseorganisasjoner som utfører kritiske tjenester (OCS) sin beredskap rundt pandemien i Agder kommune i Norge. Som en del av beredskapsresponsen i Agder ble eksisterende verktøy for hjemoppfølging av pasienter tilpasset og gjenbrukt for

overvåking av COVID-19-pasienter. Pandemien presenterte særlige begrensninger og raskt-voksende mutasjoner av nye virusvarianter. Dette betød at de helseorganisasjonene som utfører kritiske tjenester kun hadde små avbrekk mellom nye bølger av smitte.

En organisasjon som utfører kritiske tjenester, kan konseptuelt vises gjennom den digitale infrastrukturens (DI) konseptuelle rammeverk. Den progressive bruken av CPSS i disse organisasjonene blir derfor et empirisk tilfelle av en evolusjon innen digital infrastruktur. Evolusjonen innen digital infrastruktur representerer et 'balansespill' der den enkelte infrastrukturen gjennomgår flere runder med destabilisering som tvinger vedvarende endrings- og stabiliseringsprosesser.

Jeg observerer at COVID-19-pandemien har ført med seg slike runder av destabilisering, som har trigget stabiliseringsprosesser innen digitale infrastrukturer. Helseorganisasjonene som utfører kritiske tjenester i Agder fylke som jeg har fulgt gjennom pandemien i min empiriske studie, representerer her den digitale infrastrukturen. Stabiliseringsprosessen har innebåret en forening av digitale verdier, kunnskap, dokumenterbare metoder og rutiner innen digital infrastruktur.

Mitt hovedargument er:

Jeg påstår at (a) den overnevnte stabiliseringsprosessen representerer operasjonalisering av resiliens, og (b) at de fører til endring og evolusjon digital infrastruktur.

Denne doble påstanden støttes av litteratur innen informasjonssystemer, der resiliensteori er i ferd med å oppnå mainstream popularitet. Resiliens portretteres ofte som en ønsket organisatorisk kapasitet i møte med de destabiliserende effektene av ytre sjokk. Jeg skal undersøke moderne litteratur innen digital infrastruktur relatert til sentrale konsepter innen resiliens og evolusjon. Mitt mål er å svare på det følgende nøkkelforskningsspørsmålet:

Hvordan kan organisasjoner som utfører kritiske tjenester innovativt utvikle og bruke CPSS når de responderer til kriser, og for å utvikle seg i retning sikre operasjoner i ustabile forhold?

Jeg ønsker å gi en omvurdering av forståelsen og grunntanken bak resiliens og evolusjon i de relevante digitale infrastrukturene. Dette skal jeg gjøre ved å modellere de pågående infrastrukturelle endringene som pågår mens digitale infrastrukturer gjennomgår runder med destabilisering. For å fange en mer gjennomgående destabilisering som gitt av pandemien, lener jeg meg på unstable equilibrium modell. Denne modellen mener jeg er et optimalt utgangspunkt for å forstå 'balansespillet' som inngår når en digital infrastruktur kontinuerlig destabiliseres, men så stabiliseres ved å uttrykke resiliens. Dette er en forflytning fra den dominerende IS-oppfatningen av punctuated equilibrium.

Min avhandling bidrar på to måter. For det første utarbeider jeg en dynamisk resiliensmodell basert på en empirisk studie. Denne modellen sammenfatter eksisterende kunnskap om digital infrastrukturs resiliens og evolusjon. Den bidrar også med innsikt inn i de stabiliseringsprosessene som operasjonaliserer dynamisk resiliens i en digital infrastruktur mens den gjennomgår runder med destabilisering. For det andre så lukker en dynamisk resiliensmodell et konseptuelt 'gap', et som eksisterer mellom resiliens, generativ endring og evolusjon i digital infrastruktur.

Jeg konkluderer denne avhandlingen med å reflektere rundt min forsknings praktiske implikasjoner. Disse refleksjonene kan bistå beslutningstakere og policy i organisasjoner som utfører kritiske tjenester med praktisk kunnskap rundt sikker bruk av CPSS i kritiske tjenester.

Abstract

Digital technologies are now entrenched in the core operations of organisations providing critical services (OCSs). This is due to ongoing innovations in work and practice. As new applications and services are developed, there is a convergence of traditional physical infrastructures and rapidly changing modern digital technologies. These technologies are complex and have been characterised as cyber-physical-social systems (CPSSs). CPSSs are tightly integrated, coordinated, sensor-based digital solutions with both human and cyber characteristics. They are notably embedded in and facilitate OCS operations.

A salient instance of such a development is identifiable in the health sector. Service innovations (e.g., telemedicine) have been common in this sector for decades. There has, though, been a significant upturn in recent years, one that the COVID-19 pandemic has compounded. A priority for health OCSs is to bridge operational disruptions and secure care continuity. This is being increasingly achieved by leveraging digital assets like CPSSs.

Health OCSs' leveraging of CPSSs and other digital assets during the pandemic has been recognised as a resilient response in the information systems (IS) literature. However, early experiences during the pandemic revealed a stark fragility to unanticipated constraints. Indeed, health services nearly came to a standstill. COVID-19 was (and to some degree still is) a destabilising factor in OCSs.

On the one hand, it posed unforeseen challenges and introduced sustained instability. On the other hand, it ignited widespread innovation and change. Limited research examines a crisis from this kind of dualistic perspective; a crisis is simultaneously a calamity and an opportunity. Unfortunate circumstances influence short-term innovation and digital assets' selective expansion. This, in turn, triggers transformative learning and possible long-term evolution in OCSs.

In this thesis, I follow an empirical case in which a CPSS solution was leveraged in an OCS supporting pandemic response efforts in Agder County, Norway. As part of the crisis response planning in Agder, a pre-existing remote patient monitoring tool was adapted and repurposed for monitoring COVID-19 patients. The pandemic presented unprecedented constraints and fast-paced mutations of new variants. This meant that OCSs only had a brief reprieve between waves of infection.

Conceptually, an OCS can be viewed through the digital infrastructure (DI) conceptual framework. The progressive use of CPSSs in OCSs is, then, an empirical instance of DI evolution. DI evolution represents a 'balancing act,' one in which the relevant infrastructure undergoes both bouts of destabilisation instigating change and processes of stabilisation yielding persistence.

I consider the COVID-19 pandemic to have constituted bouts of destabilisation triggering stabilising processes in the DI. The health OCS in the Agder County that I follow during the pandemic in my empirical case study is the relevant DI. The relevant stabilising processes involved a recombination of digital assets, knowledge, documented techniques, and routines in the DI.

My core argument is as follows:

I argue (a) that the above-mentioned stabilising processes represent the operationalisation of resilience and (b) that they lead to the DI's change and evolution.

This dual claim is supported by the IS literature, where resilience theory has gained mainstream traction. Resilience is often portrayed as a desired organisational capacity when encountering the destabilising effects of exogenous shocks. I will examine contemporary DI literature related to the central concepts of resilience and evolution. My goal is to answer the following key research question:

How do OCSs innovatively develop and use CPSSs when responding to crises and evolving toward secure operations in unstable environments?

I aim to provide a reappraisal of the nature and understanding of resilience and evolution in the relevant DI. I do so by modelling the ongoing infrastructural change that occurs as the DI endures bouts of destabilisation. To capture the sustained destabilisation experienced during the pandemic, I draw on the unstable equilibrium model. This model, I contend, is an optimal lens for understanding the 'balancing act' involved when a DI is continually destabilised but then stabilises by exhibiting resilience. This is a departure from the dominant IS notion of punctuated equilibrium.

My thesis' contribution is two-fold. Firstly, based on an empirical study, I develop a dynamic resilience model. This model reconciles extant knowledge about DI resilience and evolution. It provides insight into the stabilising processes that operationalise dynamic resilience in a DI as it endures bouts of destabilisation.

Secondly, the dynamic resilience model bridges a conceptual 'gap,' one that currently exists between resilience, generative change, and evolution in DIs. I will conclude this thesis by reflecting on my study's practical implications. These reflections can provide OCS policy and decision-makers with practical knowledge about the secure use of CPSSs in OCSs.

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List of Abbreviations

CPSS	Cyber-physical-social system
DI	Digital infrastructure
GP	General practitioner
IS	Information systems
IT	Information technology
OCS	Organisations providing critical services
Q-ID	Qualitative identification
RKG	Regional Coordination Group

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Glossary of Terms

Actor: An individual or team directly involved in making changes and/or being affected by the changes needed to generate a crisis response in an organisation.

Capability: An organisation's capacity to deploy its (tangible or intangible) resources to perform a task or activity that improves performance (i.e., the ability to perform a coordinated set of tasks using organisational resources to achieve a specific end result) (Amit & Schoemaker, 1993).

Crisis: A situation that poses a threat to an actor's essential goals or values. It is commonly characterised by limited decision-making time and numerous unpredictable events or uncertainties linked to the relevant situation. These characteristics make it difficult to forecast outcomes emanating from pertinent decisions and actions (Pursiainen, 2017).

Cyber-Physical-Social Systems: Smart engineered systems characterised by the networking of social, computational, and physical components (Zhou et al., 2019).

Digital Infrastructure: The basic information technologies, organisational structures, and related services and facilities necessary for an enterprise or industry to function (Tilson et al., 2010).

Equilibrium: When an organisation's social components are combined with its technical components in an attempt to create a balanced and synergistic relationship (Erbaugh et al., 2021).

Information technology: Technology involving the development, maintenance, and use of computer systems, software, and networks for processing and distributing data (Merriam-Webster, 2022).

Operational technology: Hardware and software that detects or causes a change through the direct monitoring and/or control of physical devices, processes, and events (Gartner, 2022).

Organisations providing critical services: Entities that supply crucial societal support and deliver vital services (Aldeer et al., 2018).

Punctuated equilibrium: A theory that conceptualises of systemic change as being relatively suddenly triggered (i.e., an episodic revolution that is both preceded and followed by periods of stability and inertia) (Gould & Eldredge, 1972; Street & Denford, 2012).

Stable equilibrium: The state of relative imperturbation a body or system returns to after being disturbed (Empson & Alvehus, 2020).

System: Either (a) an organised scheme, process, structure, or method or (b) a set of principles or procedures according to which something is done (Oxford English Dictionary).

Telemedicine: Medical service provision using technology and occurring over a physical distance (Fatehi & Wootton, 2012).

Unstable equilibrium: A state describing a dynamic system in perpetual flux. The system moves through periods of destabilisation and stabilisation but never attains stable equilibrium (Empson & Alvehus, 2020).

1. Introduction

1.1. Research Background

Organisations providing critical services (OCSs) can be thought of as entities supplying crucial societal support and delivering vital services, notably healthcare (Aldeer et al., 2018; Dey et al., 2018). OCSs are, thus, responsible for delivering services that are crucial to society's optimal operation. They are exemplified in organisations that administer and provide managerial oversights during healthcare service deliveries to the general population. Early technological innovations in the health sector led to OCSs using computer systems and networks – information technology (IT) – to process and distribute data. There has recently been a shift toward operational technology. We have witnessed notable innovations in initiatives like mHealth and other sensor-based systems. These systems are commonly referred to as cyber-physical-social systems (CPSSs). CPSSs are varied and serve a wide range of functions in medical and social settings (Yilma et al., 2018; Zhou et al., 2019).

Unlike IT, implementing operational technologies (such as CPSSs) revolves around executing, monitoring, and managing physical processes and routines previously allocated to humans. This process occurs through a combination of software (e.g., algorithms and applications) and hardware (e.g., actuators and sensors) . Humans, machines, and control systems work alongside one another in operational technology environments to complete healthcare processes, procedures, and routines. The CPSSs used in health OCSs are, then, part of a rather complex orchestration of heterogeneous elements. This orchestration spans different communication platforms. It incorporates a collective of informational and operational tools and technologies to complete clinical operations. This integrated effect creates dynamic multi-tiered systems, which support fluid operations and allow for greater flexibility in health OCSs.

CPSS use in health OCSs has recently been in the spotlight due to the COVID-19 pandemic. In highly digitalised countries (such as Norway) CPSSs are centralized and integrated into coordinated strategies and pandemic response efforts. In the past, implementing CPSSs in health OCSs involved measured and strategic approaches, often through digital transformation initiatives. However, the pandemic triggered short-term innovations. This has resulted in the expanded use of CPSSs in health service deliveries, albeit at a less calculated pace.

The pandemic broaches a new dimension in IS research discourse (Sein, 2020). It allows us to understand how a digitally enabled resource (CPSSs in health organisations) can counteract the unique constraints created by the pandemic (Boh et al., 2023). It does so by being innovatively repurposed, resiliently adapted (Sakurai & Chughtai, 2020), and recombined (Arthur, 2009).

The resilience concept is typically employed in engineering settings. It has, though, been extended to crisis management and other domains (even the self-help movement). Talk of resilience really took off in the mainstream IS literature after the onset of the pandemic (Boh et al., 2023; Liu et al., 2023). The prevalent use of operational technologies (e.g., CPSS technologies) is often thought of as an act of resilience. This is related to health OCSs' resilience in the face of a crippling crisis, one that both challenged the global 'normal' and fostered rapid innovation and change. That said, our understanding of operationalising the OCS resiliencies that stabilise and secure operations during ongoing crises remains something of a black box (Boh et al., 2023).

I argue that this progressive use of CPSSs in health OCSs is reminiscent of digital infrastructure (DI) evolution. It can, thus, be theoretically understood through a DI conceptual framework. DIs can be thought of as evolving socio-technical arrangements. They are comprised of people, physical infrastructures, processes, and digital technologies (Tilson et al., 2010). DIs are also inherently open and unbounded. They are, though, anchored by stable components, components that foster the continuous addition of new applications, operations, and capabilities . During their evolution, DIs recombine digital assets, established knowledge, routines, and techniques previously used to solve other problems (Ziman & Ziman, 2003).

DI evolution is often described as a 'balancing act.' The relevant infrastructure endures bouts of destabilisation. These incite change but are also countered by stabilisation processes yielding persistence over time (Hanseth & Rodon, 2021). Nonetheless, some important questions remain: "What are these processes of stabilisation?" and "What (if any) role does resilience play in stabilising processes and DI evolutions during crisis-induced bouts of destabilisation?"

In DI resilience research before the pandemic, change and innovative developments implicitly referenced a return to stability (Erbaugh et al., 2021; Harder Fischer & Baskerville, 2018). An assumption of a return to stability still prevails in current conceptualisations of resilience. Liu and colleagues (2023) have expressed an awareness of a continuously 'turbulent environment'. Yet, they also talk of physicians who use telemedical solutions as "bouncing-back." Boh and colleagues (2023) characterise the change experienced through digital resilience in response to the pandemic as "revolutionary" but also speak of a transformation to a "new stable state". This alludes to an episodic view of change.

If these are indeed acts of resilience, then one wonders whether current theories adequately reflect recent experiences and observations. I believe that analysing the outcome or solution without duly considering the true nature of the trigger (or instigative problem) creates an analytical blind spot. If so, then such analyses will only tell half the story. Although I consider resilience to be an accurate lens for understanding or explaining crisis response efforts and positive recovery outcomes, an episodic view of the crisis (or disturbance) appears insufficient . Arguably, the COVID-19 pandemic arrived in 2019 and simply never left. It has afforded OCSs a brief reprieve but continues to mutate into new variants. It, thus, represents a sustained destabilising force. Indeed, we seem to be one variant away from another shutdown. To view a crisis as episodic when it actually never ends is plainly suboptimal. The nuances and complexities involved in the 'balancing act' a DI experiences – the way that it is destabilised only to enact stabilisation processes countering the destabilisation – appear lost on the episodic view.

The episodic view of the COVID-19 crisis is often rooted in the much-discussed punctuated equilibrium model. In this model, a crisis is a brief and disruptive transition, one in which technologies and innovations emerge through the accelerated actions of niche actors (technology vendors, physicians, and the like). All efforts are geared toward attaining a new stable state. The relevant system is then considered to have moved (changed) from one equilibrium to another; it has attained stasis. Nonetheless, the overarching goal remains a return to equilibrium (Lyytinen & Newman, 2008). The problem is that the pandemic was (or is) neither brief nor transitory in nature. It has, instead, proven to be unpredictable, fast-changing, multidimensional, and pervasive. The developments and changes we observe occur in an unstable environment, one that is characterised by short and uncertain periods with minimal predictability. Innovation and change emerge amid frequent and/or sustained destabilisations. This signifies a notable departure from the prevailing stable systems way of thinking (as exemplified in presiding IS perspectives and models like punctuated equilibrium). If so, then we might need to shift toward a newer and less-studied model of change, one that has been called *unstable equilibrium* (Fischer & Baskerville, 2022).

My thesis represents a reappraisal of the nature and conceptualisation of resilience in DI evolutions given unstable equilibrium. In undertaking this reappraisal, I have been motivated by a curiosity about the innovative adoption and increased use of CPSS technologies in OCSs experiencing ongoing crises. My project notably involves drawing from the literature on resilience and DI evolutions. My focus is on the capacity of DIs to absorb interruptions while recombining and transforming digital assets, established knowledge, routines, and techniques. My thesis should, thus, contribute to our understanding of resilience's role in stabilising DIs enduring bouts of destabilisation emanating from a crisis.

I now discuss the research questions that frame my study and how they address my overall research objective.

Research Questions

In the previous section, I discussed the factors motivating my research study and my overall aim and objectives. My goal in this thesis is to make significant practical and theoretical contributions.

Main research question

My main research question (MRQ) is as follows:

> *How do OCSs innovatively develop and use CPSSs when responding to crises and evolve toward secure operations in unstable environments?*

Three sub-research questions (SRQs), in turn, frame my study and assist in answering MRQ.

First SRQ

It was necessary for me to understand the adoption and deepened use of CPSSs in OCSs. I, therefore, posed the following SRQ:

> SRQ1: How are CPSSs adopted, integrated, and repurposed in OCSs during crises?

This is a process-oriented question, one aimed at understanding OCSs' innovative development and the use of CPSSs during a crisis. There have been extensive studies on OCS innovations in 'stable' settings. My interest lies in acquiring knowledge of technology innovation's subtleties and complexities under less stable circumstances. Grasping CPSSs' adoption, integration, and repurposing during a crisis demands an analysis of the relevant real-time structures, processes, and routines. This is imperative if we want to uncover both what exists before and what emerges beyond a disruption.

Second SRQ

There is also a need to explicitly focus on an organisation's capacity to deploy its (tangible or intangible) assets to perform some tasks. . My second SRQ aims to address this issue:

> SRQ2: Which organisational capacities are necessary when utilizing CPSSs to deliver critical services during crises?

This is a follow-up to SRQ1. The goal is to understand how OCS components are operationalised to (a) complete routines and processes during a crisis and (b) leverage a CPSS.

Third SRQ

It would be naïve to think that innovative changes only present added benefits. It is reasonable to assume increased risk and vulnerability due to OCSs implementing CPSSs (Pasandideh et al., 2022). My third SRQ addresses the likelihood of undesirable possibilities:

> SRQ3: Which novel risks and vulnerabilities might the innovative development and use of CPSS expose OCSs to?

From a security perspective, a CPSS's physical, computational, and social components are interrelated and interdependent. SRQ3 prompts reflection on how OCSs using CPSSs evolve toward secure operational conditions.

1.2. Empirical Setting

In the Fall of 2019, the motivation for my PhD work related to curiosity about the convergence of information and operational technologies in OCSs. However, the world changed drastically as the first COVID-19 infections were reported and as the world locked down. These unfortunate developments naturally influenced and shaped my research agenda.

All countries' health services proved inadequate during the first waves of infections. Those that prevailed, leaned quite heavily on digitally enabled solutions. The pandemic posed complex challenges to normal societal functions. Although calamitous, the crisis presented a rare opportunity to study the nature of accelerated innovation in OCSs experiencing prolonged uncertainty . This is especially the case given that health OCSs are traditionally conservative in their approach to innovation projects (Ross et al., 2016).

In February 2020, the Norwegian health sector outlined COVID-19 infection control and prevention measures. In Norway's Agder County, a pre-existing remote patient monitoring tool was adapted and repurposed for monitoring COVID-19 patients. This presented an interesting case. The Agder County remote patient monitoring tool linked hospitals, doctors, and patients. It also provisioned safe, secure, and remote digital health services to COVID-19 patients. Although remote consultations and patient monitoring solutions had been introduced before, the pandemic instigated an accelerated adoption and scaling of use.

The empirical study in my thesis focuses on this remote patient monitoring tool and the OCS responsible for the relevant innovation project (for repurposing the patient monitoring tool to the new COVID-19 context). This study encapsulates how health OCSs stabilise their operations when navigating a crisis and resultant changes.

1.3. Summary of Contributions

My thesis is based on findings from five research papers, and although in the thesis I refer to "my research," the publications have been collaborative. Three have been published through peer-reviewed conference proceedings and two in peer-reviewed journals. All publication outlets fall within the IS research discipline. Table 1-1 details the relevant publications. They are listed in the order in which they contribute to the thesis. In Chapter 6, I will reflect on these papers in three distinct phases: (1) initial response, (2) recovery/resolution, and (3) learning and evolution. Each publication represents an independent contribution to our practical understanding of CPSSs in health OCSs. The complete papers are included in the Appendix.

A. Table 1-1. Contributing research publications

Initial Response
#1 Magutshwa, S. & Radianti, J. (2022). Is this Digital Resilience? Insights from the Adaptation and Exaptation of a CPSS. *Proceedings of the 55th Hawaii International Conference on System Sciences (HICSS)*. IEEE Computer Society Press.
#2 Magutshwa, S. (2022). Rethinking the Improvisation of Digital Health Technology: A Niche Construction Perspective. *Australasian Journal of Disaster and Trauma Studies, 26, 235–251.*
Recovery and Resolution
#3 Magutshwa, S., Aanestad, M., & Hausvik, GI. (2022) Beyond Crisis Response: Leveraging Sociotechnical Transformability. *Proceedings of the 13th Scandinavian Conference of Information Systems (SCIS), Helsinge, Denmark.*
#4 Magutshwa, S. and Radianti, J (2021) A Qualitative Risk Identification Framework for CPSS. *Proceedings of the 18th International Conference on Information Systems for Crisis Response and Management (ISCRAM).*
Learning and Evolution
#5 Magutshwa S., & Radianti J. (Under review). Digital Resilience in Action: Cultivating Positive Recovery Outcomes. *Pacific Asia Journal of the Association of Information Systems.*

My thesis' contribution is two-fold.

1. Based on an empirical study. I develop a **dynamic resilience model**. This model reconciles extant knowledge on DI resilience and DI evolution. It provides insights into the stabilising processes that operationalise a DI's resilience as it endures bouts of destabilisation. This constitutes my primary contribution; it bridges the conceptual 'gap' that currently exists between DI resilience and DI evolution.
2. My findings also have practical implications discussed in section 8.3. These are considerations made vis-à-vis secure CPSS operations in OCSs. These reflections potentially provide policy and decision-makers with a useful understanding of secure CPSS uses in OCSs.

1.4. Thesis Structure

The remainder of my thesis is structured as follows:

- **Chapter 2:** I review background literature related to healthcare CPSSs. This provides a synthesized understanding of CPSS technologies' fundamental aspects and their use as enabling technologies in health service deliveries.

- **Chapter 3:** I provide an overview of my study's conceptual foundations. I also describe DIs and discuss theories of technological evolution and the topical resilience literature. This provides a conceptual foundation for my study.
- **Chapter 4:** I describe the research design used to address pertinent research questions. I also discuss my work's ontological and epistemological positioning and identify a research strategy and method.
- **Chapter 5:** I describe the empirical context of my study (the Norwegian health system) and provide a detailed case description.
- **Chapter 6:** I provide insight into the five publications included in this thesis. I also reflect on insights from each publication, specifically those I consider to be particularly relevant to this thesis.
- **Chapter 7:** This is a model development chapter in which I describe the steps leading up to my dynamic resilience model.
- **Chapter 8:** I conclude this thesis with a summary of findings and contributions. I also acknowledge some limitations and offer recommendations for future research.

2. Defining ‘CPSS’: State-of-the-Art and Applications

I conducted a literature review of the extant literature to establish a deeper understanding of the relevance and use of CPSSs in OCS processes and operations. In this chapter, I trace the roots of CPSSs in the health sector. I focus exclusively on the use of CPSSs as an enabling technology in healthcare service deliveries.

I now detail my review methodology.

2.1. Review Methodology

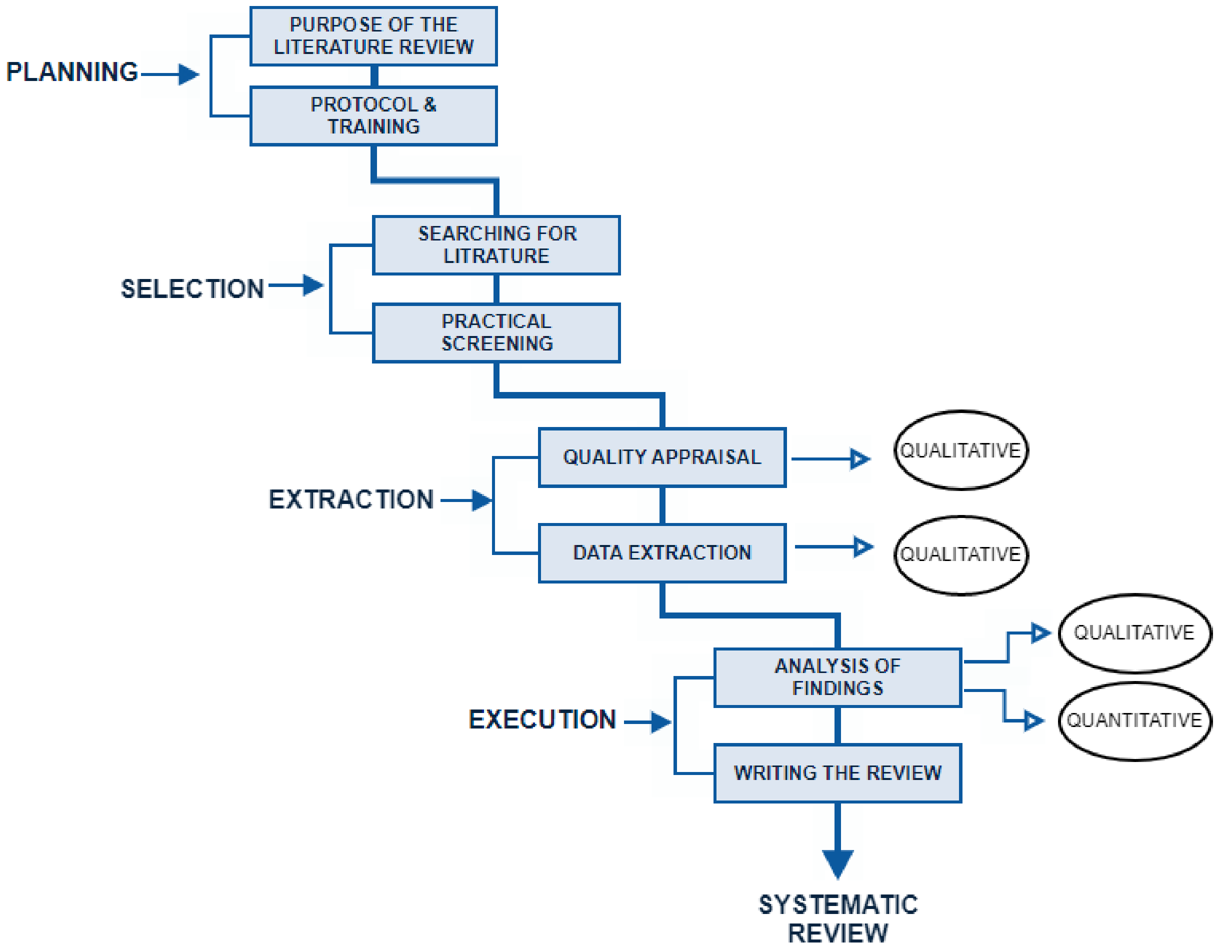

Figure 2-1 Review methodology (adapted from Okoli, 2005)

My method follows Okoli’s (2012) guidelines for IS literature reviews (Figure 2-1. The process flow follows an eight-step, four-phase execution pattern. The recommended approach is supposed to be exhaustive (Okoli, 2012).

A researcher must, first, identify the purpose of the review (Stage 1). The purpose of my review is (a) to understand CPSS technologies’ origins in the topical scientific literature and (b) to determine the 'state of the art' of CPSSs in the healthcare sector. Determining clear review aims leads to a well-defined protocol, which outlines how a review will be conducted (Stage 2). One then engages in a literature search, practical screening, and quality appraisal (Stages 3, 4, and 5). This involves sifting and identifying publications to include in one's study (based on explicit inclusion/ exclusion criteria). To ensure that my review represents the state of the art, I focused on literature spanning the period 2010 –2023. This step involved searching the literature and ascertaining suitability based on predefined selection criteria (Table 2-1).

B. Table 2-1 Literature selection process

Digital library	AIS e-Library; SpringerLink; Wiley; Web of Science; IEEE Xplore; JSTOR; Scopus; Ebsco medline.
Keywords	Critical infrastructure; cyber-physical-system; digital infrastructure; complex adaptive systems; infrastructure interdependencies; essential services; health IoT; telemedicine.
Subject areas	Information systems; cybersecurity; computer science; social science; business management.
Selected and reviewed	46
Language	English.
Inclusion criteria	Article in IS domain; title and abstract screening; article available in full text; article outside IS but relevant in content (studies that investigate the topic or closely related aspects of the focal phenomenon).
Exclusion criteria	Abstract or title not relevant to the study.

My selection began with digital library searches. Using the keywords, I then conducted a search analysis in the digital libraries listed in Table 2-1. The search was based on variations of the following syntax:

"Database search: TI = (Cyber-physical OR complex adaptive ("critical infrastructure" OR "information infrastructure" OR "digital infrastructure" NOT environment)) AND TO = (Manag OR Assess* OR Indicat* OR Metric* OR Character*)."*

Given my primary aim of contributing to the IS domain, I screened hits by initially prioritising top-tier IS journals (basket) and renowned conferences in the IS field (with widened backward snowballing in the case of low yield in top-tier findings). Backward snowballing was conducted through digital libraries by checking and following citations. To factor in cross-disciplinary hits (e.g., eHealth and computer science), I determined a list of keywords and other search criteria (Table 2-1). Table 2-1 summarises my literature selection process. I determined that 46 of the peer-reviewed articles were relevant to the corpus of the review. My search surveyed journals, scholarly articles, and other sources suitably connected to the subject matter.

The last stages in Okoli's literature review method involve data extraction, synthesis of studies, and writing the review (Stages 6, 7, and 8). One also provides a culmination of the review process containing a summary and the literature's collective meaning.

2.2. What are CPSSs?

CPSSs are complex systems that integrate cyber-physical systems with social systems. CPSSs are characterised by (a) their ability to sense, monitor, and interact with the physical world and (b) the incorporation of social and behavioural factors into service design and delivery (Zeng et al., 2020). CPSSs represent a convergence of multiple technological components, physical entities, and human interactions.

The CPSS concept has its roots in the fields of control theory, automation, and real-time systems (Zeng et al., 2020; Zhang et al., 2018). The development of CPSSs was initially motivated by the need to create intelligent and autonomous systems capable of interacting with the physical world and effectively supporting social roles (Zhou et al., 2019). In recent years, a growing body of research has emerged on the design, implementation, and evaluation of CPSSs (Zeng et al., 2020; Zhou et al., 2019). Being a relatively new and evolving field, ongoing research and development continue to shape CPSS conceptualizations and applications. Scholars exploring the challenges and opportunities involved when designing and managing CPSSs typically focus on factors like data privacy, security, ethical considerations, and impacts on decision-making and social behaviour (Moura & Hutchison, 2019).

In the proceeding sections, I will summarize the current state of knowledge in this area, including major trends, challenges, and opportunities for IS research.

2.3. CPSS Research: Emerging Themes and Outcomes

The extant literature typically documents the performance, behaviour, and dynamics associated with CPSS use. Researchers have specifically focused on **developing new technologies** that integrate physical and digital systems. Examples include emergency responses (Liu et al., 2011), smart cities (Cassandras, 2016), and intelligent transport systems (Moura & Hutchison, 2019). **Exploring the social and ethical implications** of CPSS use involves engaging with issues related to privacy, security, and control (Gharib et al., 2017); (Zhang et al., 2018).

While the potential **benefits** are significant, there are also several **challenges associated with implementing CPSS systems**. For instance, the **complexity of integrating physical and digital systems** requires a high degree of technical expertise and coordination. The literature on CPSSs suggests significant potential for innovation and transformation.

The most investigated aspects of CPSS technology pertain to (1) strategy and performance, (2) capabilities, and (3) behaviour and dynamics.

Strategy and performance

CPSSs can improve operational efficiency by automating processes, optimizing resource utilization, and reducing waste. They can also provide real-time data and analytics to support decision-making and facilitate data-driven decisions.

In healthcare, CPSSs are used to support personalized healthcare services by integrating real-time health data from various sources (e.g., wearables and sensors). CPSSs can optimize resource allocation, reduce wait times, and improve the overall efficiency of healthcare delivery. This provides healthcare professionals with a comprehensive understanding of a patient's health status. This, in turn, leads to (a) personalized and effective healthcare services and (b) improved patient outcomes and quality of life (Haque et al., 2014). CPSSs also actively support the monitoring of and responses to potential health risks. This can optimize resource allocations in health services, a sector that often suffers from personnel shortages.

Despite these benefits, integrating social CPSS components into healthcare has been downplayed in literature. This raises concerns related to patient privacy and ethical considerations. These must be carefully addressed to ensure CPSSs' success. There is a need for greater knowledge of how complex digital technologies like CPSSs are embedded in OCS operations and how they are used to tackle critical societal problems.

Capabilities

Scholars analysing CPSSs derive the idea of capabilities from the organisational resource perspective. This relates to an organisation's capacity to deploy its (tangible or intangible) resources (which may be included in a CPSS-based solution). The goal is to perform some task or activity that improves performance and achieves a specific end result (Amit & Schoemaker, 1993; Cassandras, 2016). Some of the main CPSS capabilities discussed in the literature are as follows:

- CPSSs can **monitor and control physical processes in real time**. They sense and collect data from physical systems using sensors and bring about changes in the physical world through actuators. This capability makes CPSSs responsive to changes in their environment (Liu et al., 2011).
- CPSSs are functional in **data processing and analytics**. They can collect and analyse large amounts of data from various sources, including sensors, machines, and other systems. Informed decision-making is, thus, actively enabled by data-driven insights . This makes CPSSs suitable for use in **predictive modelling and decision-making.**
- CPSS predictive modelling techniques can be implemented in forecasting events based on historical data. This capability facilitates the anticipation and prevention of potential future problems. Cyber-physical systems can operate autonomously without human intervention (Frazzon et al., 2013; Gharib et al., 2017). Such **autonomous operations** are crucial in environments where human presence is limited or dangerous (e.g., during the COVID-19 pandemic).

Behaviour and dynamics

CPSS behavioural dynamics refer to the social and psychological processes that affect users' behaviour, including their motivation, communication, and decision-making processes (Su et al., 2017). A key CPSS behavioural dynamic is the impact of trust on user behaviour. In this context, trust refers to the user's perception of the system's reliability and security. Users who trust the system are more likely to use it effectively and comply with its recommendations. Users who do not trust the system might be reluctant to use it or might misuse it, which can naturally compromise the system's efficiency. Trust is a crucial behavioural dynamic in healthcare. Patients and healthcare professionals must trust CPSSs to provide accurate and reliable data and maintain patient privacy and confidentiality. Building and maintaining trust is, therefore, essential to ensuring CPSSs' success (Pasandideh et al., 2022).

Another pertinent behavioural dynamic relates to the impact of social norms on user behaviour. Social norms are the unwritten behavioural rules governing social interactions. When it comes to CPSSs, social norms can influence user behaviour (e.g., users' willingness to share data and/or comply with the system's recommendations) (Wang et al., 2019). Understanding social norms and aligning them with CPSSs can, thus, increase user engagement and adoption. In healthcare, social norms are heavily influenced by ethical and legal considerations. These include the need to obtain informed consent and comply with data protection regulations.

Users are also more likely to adopt and use a CPSS if they perceive it as useful and easy to use. Designing CPSSs that are intuitive, user-friendly, and provide clear user benefits can, then, increase adoption and use. In healthcare, patients and clinicians must perceive a CPSS as useful in supporting decision-making and improving health outcomes. CPSSs must, therefore, be designed in such a way that a wide range of users (with varying levels of technical proficiency) find them easy to use .

Despite the above, CPSS can also have unintended consequences on user behaviour, specifically when it comes to *complacency*, *overreliance*, and *underutilization*.

- Complacency occurs when users become too reliant on the system and fail to exercise critical thinking or judgment.
- Overreliance occurs when users place too much trust in the system and fail to consider alternative options or scenarios.
- Underutilization occurs when users do not use the system to its full potential, thereby missing opportunities for optimization and improvement.

Ensuring that users receive appropriate training and guidance on CPSS use can mitigate these unintended consequences.

2.4. Instances of CPSSs in eHealth

The use of CPSSs in healthcare has grown significantly in recent years. A variety of interchangeable terms are used to reference the use of such technologies in research and practice. These include ‘telehealth’, ‘eHealth’, ‘mHealth’, and ‘telemedicine’ (Aldeer et al., 2018). There are various overlapping definitions of these terms (Martin et al., 2008). That said, ‘telemedicine’ appears to be the most cited and commonly used (Fatehi & Wootton, 2012). To prevent conceptual confusion, I will only refer to “telemedicine” in this thesis. This is not to disqualify the other terms, but only an attempt to condensation to what is most relevant and useful.

Globally, telemedicine was valued at approximately $50 billion in 2019. It is forecasted to grow to approximately $460 billion by 2030 (Stewart, 2021). Roughly, telemedicine represents collective efforts applied in the varying use of a combination of sensors, actuators, and other communication technologies to deliver health services. This description also nicely captures the essence of a CPSS. The World Health Organisation defines ‘telemedicine’ as follows:

> [T]he provision of health care services, where distance is a critical factor, by all health care professionals using information and communication technologies for the exchange of valid information for diagnosis, treatment and prevention of disease and injuries, research and evaluation, and for the continuing education of health care providers, all in the interests of advancing the health of individuals and their communities (WHO, 2020).

This definition reflects how telemedicine can take many forms (e.g., teleconsultation and tele-education).

Several factors have influenced the increased use of telemedicine. These include (a) increased costs of conventional healthcare delivery, (b) healthcare personnel shortages, and (c) the COVID-19 pandemic (Hong et al., 2020; Liu et al., 2023). A significant advantage of telemedical solutions is their ability to increase access to healthcare services (Chen et al., 2021). Patients in remote or underserved areas can access healthcare services without travelling long distances. Telemedicine has also proven to be an effective way of reaching vulnerable populations (e.g., elderly, or immunocompromised patients). Another benefit is telemedicine’s ability to reduce healthcare costs. Healthcare providers can reduce costs by using telemedicine to manage chronic diseases. This reduces the need for hospitalisations and emergency room visits.

Despite the overt benefits of telemedical solutions, there are still several challenges. Some patients might not have access to the necessary technology (e.g., a reliable internet connection or device). Privacy and security concerns are also an issue because patient data must be protected during remote consultations (Checco, 2022). These factors complicate telemedical operations.

2.4.1. Telemedicine in COVID-19 Response Protocols

Since the outbreak of the COVID-19 pandemic, social distancing measures and travel restrictions have made it difficult for patients to receive medical care in traditional settings (Fagherazzi et al., 2020). This has led to an increase in demand for remote telemedical solutions and subsequent radical technological innovations (Durugbo et al., 2021).

Several notable telemedical solutions emerged during the pandemic. These include virtual care platforms, remote monitoring tools, and online prescription services (Fagherazzi et al., 2020). Patients have received consultations, diagnoses, and treatments from home without the risk of being exposed to the virus (Liu et al., 2023; WHO, 2020). The relevant solutions have greatly modernised service delivery models and trigger broad-based health organisation improvements.

The organisation of innovation processes during this period is of interest (Johnsen et al., 2021; Kleinknecht, 2016; Benson, 1977). Established health sector innovations apply incremental and well-calculated approaches, approaches that do not favour randomness and uncertainty or the possibility of failure (Russo and Ciancarini, 2016). These circumstances are identifiable in most telemedicine studies in the IS discipline. However, the need to conform to established approaches is both questioned and marginally reduced during a crisis. This instigates the introduction of short-term innovations and revised techniques and routines (Orlikowski and Scott, 2021; Filippetti and Archibugi, 2011; Archibugi et al., 2013).

The innovative use of telemedical solutions during the COVID-19 crisis represents a knowledge-generating organisational process. The pandemic has created novel experimentation and boundary-pushing in the health technology space, an area traditionally known for its strict regulations and slow technology adoption practices (Oborn et al., 2021; Pöhler et al., 2021). Even if the potential lessons and novel insights are acknowledged, few studies have focused on the nature of the crisis and how it influences the developmental directions of pre-existing OCS telemedical solutions (Camlek, 2020). The literature does not seem to adequately consider crisis events that create opportunities for OCS growth.

2.5. Summary of Research Gaps

CPSSs like telemedicine have been used in the health sector for decades. They have, though, recently been popularised by an unprecedented global pandemic. The COVID-19 pandemic prompted short-term innovative solutions providing medical care while maintaining social distancing measures.

Numerous studies have explored the design and implementation of telemedical solutions under stable conditions. However, recent developments and experiences highlight new research gaps warranting further investigation. Some of these developments and experiences are as follows:

- Accelerated, innovative development: The urgency of the pandemic created a need for rapid telemedical solution developments. This often-meant shortened development cycles for quick deployment and more flexibility than regular innovation projects.
- Prioritisation of essential features: Under normal conditions, innovation initiatives and the development of a new product or service focus on desirable features and functionalities. During the pandemic, the focus was on developing essential features facilitating healthcare providers' and patients' immediate needs.
- Evolving user behaviour: The pandemic induced a shift in user behaviour toward greater acceptance and adoption of telemedical practices. Patients and healthcare providers quickly adapted to virtual care, which, in turn, influenced the design and features of telemedical innovations.
- Regulatory flexibility: Governments and regulatory bodies around the world responded to the pandemic by introducing various temporary measures. These were designed to facilitate the rapid deployment of telemedical solutions. Such changes allowed for increased regulatory flexibility, making it easier for innovators to navigate legal and compliance hurdles.

- Long-term efficacy: Most research has focused on short-term outcomes during the pandemic. Investigating CPSSs' long-term efficacy (beyond the crisis period) is essential if we want to determine continued relevancies, benefits, and challenges on the post-pandemic healthcare landscape.
- Technical infrastructure and security: CPSS-based solutions rely on digital platforms and communication tools. This raises concerns about data security, privacy, and technical infrastructure robustness.

2.6. Chapter Summary

In this chapter, I explored the origins of CPSSs and their progressive use in the health sector during the COVID-19 pandemic. My review assessed CPSSs' effectiveness, noting several benefits but also relevant technological challenges. I discussed the adoption and implementation of various CPSS-based modalities, notably telemedicine. I specifically highlighted telemedicine's role in ensuring continued patient care and improving accessibility. I also underscored the need for ongoing research and policy development. This need motivates my thesis agenda.

In the next chapter, I discuss my thesis' conceptual background.

3. Conceptual Foundations

In this chapter, I provide a theoretical and conceptual framework for my thesis. I will discuss my research's theoretical premise and explain the key concepts, theories, and models my thesis is grounded in.

As discussed in the previous chapter, to understand the role of a CPSS, it is necessary to consider it an element of a larger system. In viewing CPSSs as components of a larger OCS, I emphasise the underlying technological, physical, and social combinations an OCS leverages when implementing a CPSS. I find this perspective helpful in, at least, two ways:

1. Identifying the key components and best practice for developing and deploying CPSSs within OCSs.
2. Exploring the potential benefits and challenges of integrating heterogeneous components into a traditional IS.

3.1. DI Foundations

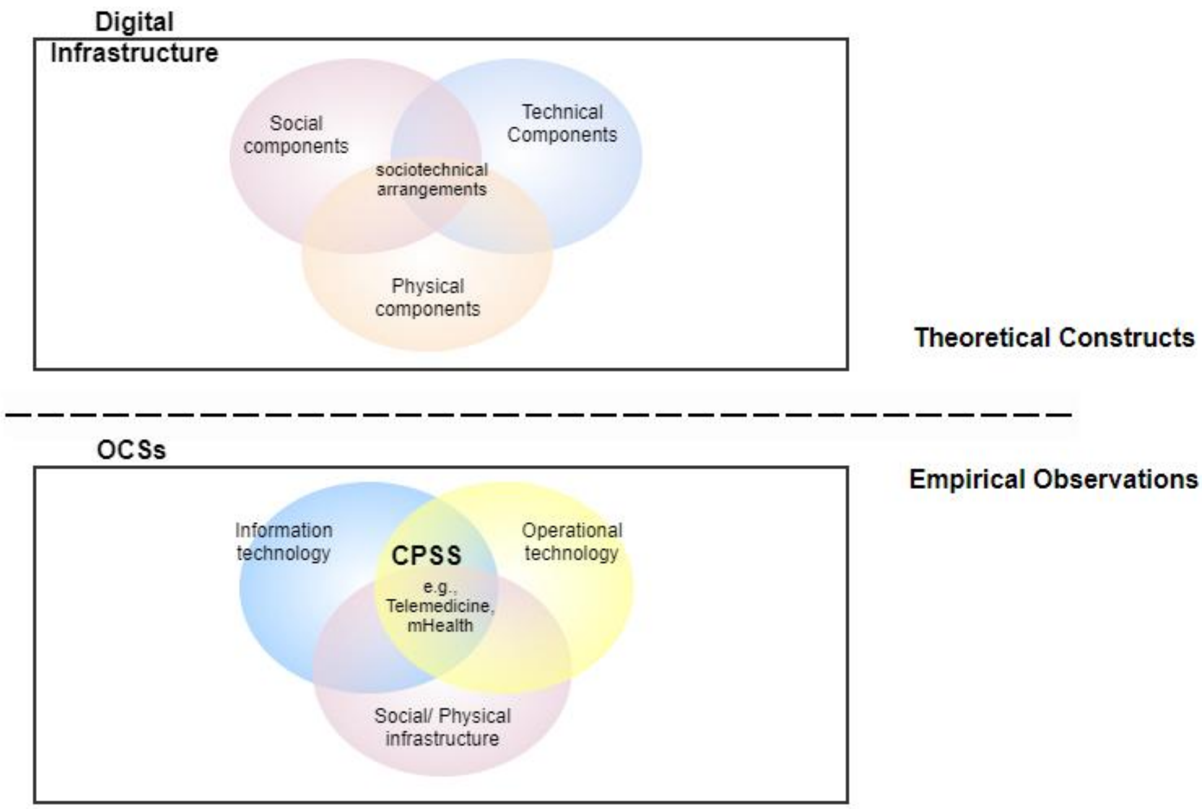

Figure 3-1 Overview of central theoretical and empirical constructs

DIs are fundamentally rooted in the IS domain and represent highly socio-technical assemblages (Bostrom & Heinen, 1977; Sarker et al., 2019). These assemblages comprise of vast array of social actors and technical and physical infrastructures . I have framed the OCS empirical constructs (discussed in the previous chapter) in Figure 3-1. There, we can see that a CPSS is a combination of IT, OT, social, and physical systems. The relevant empirical observations can be wholly framed within the theoretical constructs of the DI framework. Figure 3-1 is a synthesis of the IS terms and reference disciplines I consider relevant to establishing a mutual understanding of central theoretical and empirical constructs in the thesis.

DIs can be viewed as unique socio-technical arrangements comprising a collective of social, physical, and technical components contributing to an IS's differential functioning (Tilson et al., 2010). This involves integrating ISs, sensors, databases, and communication networks to both enable data flows and support decision-making processes and coordination. DIs are characterised by this convergence of various components (digital and otherwise) serving varied operational functions. The DI framework, thus, emphasises the interconnected nature and diversity of infrastructure components.

Empirically, OCSs are also an arrangement of systems and technologies comprising social/physical systems, information, and operation technologies. CPSSs are systems orchestrated within OCSs and are leveraged in the execution of a routine. This often yields intricate connections of IT, OT, social and physical systems, and social structures.

The IS field has made significant progress in studying empirical examples of what can be called CPSSs (such as telemedical solutions and mHealth). However, these are often framed as resources or isolated innovations serving a specific purpose, one that emanates from planned or deliberate changes. There has been little consideration for how decisions to implement CPSSs can (a) trigger wide and unplanned organisational shifts and (b) influence future OCS directions, thereby potentially creating interdependencies and new vulnerabilities.

Applying the DI conceptual framework to the OCS context, allows me to secure a unique vantage point. It allows me to (a) understand whether CPSSs generate change in OCSs, (b) how this occurs (when it does), and (c) the nature of such change. According to (Lyytinen & Newman, 2008), IS change covers "the generation, implementation, and adoption of new elements in an organisation's social and technical subsystems”. The study of CPSSs in OCSs can, thus, yield salient theoretical developments in the IS field. It can also inform policy formulations, specifically those that promote secure and efficient CPSS operations in OCSs.

3.2. Technological Evolution in DI

There are striking similarities between biological evolution and technological evolution. The IS literature is rich in biological metaphors and references to evolutionary models of technological change. Biological evolution concepts – like mutation, selection, adaptation, metamorphosis, and survival of the fittest – are widely used in the IS field when studying technological change (Basalla, 1988; Gill & Hevner, 2013; Street & Denford, 2012). A common notion in technology evolution models is that an artefact is invented by building on knowledge associated with previous artefacts or documented techniques and routines (Basalla, 1988). This implies that (a) new artefacts do not suddenly appear and (b) technological evolution involves the recombination of infrastructure, knowledge, and techniques previously used to solve different problems (Arthur, 2009; Basalla, 1988).

DIs exhibit the emergence of new properties and traits through the combination of different elements. Applying evolutionary theory principles allows us to view a changing DI as an evolving entity subject to selection pressures and competition. Evolutionary processes like adaptation and selection are observed in DIs as they respond to user needs and their operational environment.

Evolutionary processes are triggered by environmental changes and then shape a DI’s development and transformation over time. In this sense, a DI’s components must be resilient and acclimatised to the operational environment if it is going to thrive. The evolutionary process thereby ensures that the DI ‘survives’ (grows) and evolves over time. Technological evolution explains how DIs evolve via both the cumulative innovations of extant technologies and the adoption of new knowledge, techniques, and routines (Arthur, 2009). Feedback loops and iterative processes also play an important role. DI evolution can then be considered a longitudinal, iterative selection process where innovations or infrastructural elements are pursued or discontinued. Here, successful infrastructural elements replicate and spread, while less successful elements are refined or gradually eliminated (Koutsikouri et al., 2017).

DI evolution is considered to be “a gradual process by which digitally enabled infrastructure changes into a more complex form” (Henfridsson & Bygstad, 2013; Koutsikouri et al., 2017). It has also been described as “the extension of the scope of an infrastructure as an enhanced capacity to effectively serve emerging possibilities and changing purposes” . Hanseth and Rodon (2021) characterise DI evolution as a process of change and persistence, one involving

> a continuous process of destabilisation that opens up the infrastructure for change, followed by processes of stabilisation that give persistence to the infrastructure.

This suggests that, as with other technologies, DI evolution involves unanticipated functions being derived from a recombination of DI capacities (knowledge, routines, techniques, etc.) to meet unforeseen circumstances.

We can say that changes in a DIs’ environment initialise the ***pressured selection*** of useful functions, the intentional ***adaptation*** of established routines, and the short-term innovation of pertinent techniques. This kind of change contributes to innovation accumulations and increased ***variety*** in the DI. It is, though, not deliberately designed for ***retention*** or for contributing to long-term outcomes (viz. the DI’s overall evolutionary direction).

It is also worth mentioning ***generativity*** in the study of DI evolution. Zittrain (2009) defines ‘generativity’ as “a technology’s overall capacity to produce unprompted change driven by large, unvaried, and uncoordinated audiences” (Zittrain, 2009). (Thomas & Tee, 2022) have more recently spoken of “a sociotechnical system where social and technical elements interact to facilitate combinatorial innovation”.

Generative mechanisms play a central role in generativity. According to (Henfridsson & Bygstad, 2013), generative mechanisms are “causal structures that generate observable events”. These are essentially the processes that define what constitutes a DI. Henfridsson and Bygstad’s findings suggest that innovation, adoption, and scaling are the identifiable mechanisms of DI evolution. DI evolution cannot be accredited to a single mechanism. Positive outcomes can be traced to a configuration of two or three different mechanisms.

I do not consider the technological evolution and generative change perspectives to be in conflict. Understanding DI changes from both perspectives emphasises the critical role of contextual forces emanating from the operational environment. A combination of stabilising processes or generative mechanisms appears necessary. In this thesis, I am focusing on the technological evolution perspective. Nonetheless, the proximity of the technological evolution perspective and the generative change perspective means that my research findings can also contribute to our understanding of generative change in DI.

The notion of stability is central to the technology evolution perspective. I will, therefore, focus on it in the proceeding sections.

3.3. Assumptions of DI Stability and Equilibrium

Assumptions of stability form the foundation for understanding and analysing DI functioning (Hanseth & Rodon, 2021). This occurs in, at least, four ways:

1. Technical stability assumes that the underlying technical components operate reliably.
2. System stability assumes a well-defined structure and stable interconnections within the infrastructure.
3. Interoperability assumes stable and well-defined interfaces for effective communications between components (Bygstad & Øvrelid, 2020).
4. Organisational stability assumes stable governance structures and coordination mechanisms among the infrastructure's entities.

Stability is also implied in situations where a complex system is vulnerable to external influences. An example is the introduction of a new technology (a disruption) or a sudden change in the operational environment (Erbaugh et al., 2021).

The assumption of stability is consistent with the punctuated equilibrium model (introduced in Section 1.1). Punctuated equilibrium refers to a pattern of change over extended periods of time. The focus is on the dynamics of change, characterised as short periods of rapid and disruptive change followed by prolonged stability (Gould, 2009; Lyytinen & Newman, 2008). This dominant narrative operates on the premise that any disruption or destabilising force that a DI experience is a momentary interruption; the DI will soon return to stability.

The notion of stability suggests something that is firmly established and not likely to change. If an entity has changed after a disturbance, then it is no longer considered to be stable. This is because it did not return to its initial state (Fischer & Baskerville, 2022). We can, nonetheless, think of such an entity as being at equilibrium (if equilibrium is a state where opposing forces [disturbances or influences] are balanced). This important distinction requires us to recognise that an entity can be at equilibrium yet remain unstable. The entity is, then, at *unstable equilibrium* due to ongoing change; it is only 'really' stable when no further changes occur.

Unstable equilibrium describes a dynamic entity, one that (a) only experiences momentary stability, (b) remains in perpetual flux, and (c) moves through periods of stabilisation and destabilisation while never attaining stable equilibrium (Fischer & Baskerville, 2022). This definition recalls Hanseth & Rodon's (2021) characterisation of DI evolution (from the previous section) as

> a continuous process of destabilisation that opens up the infrastructure for change, followed by processes of stabilisation that give persistence to the infrastructure.

To reach equilibrium, entities in unstable equilibrium are required to enact stabilising measures to secure temporary stability and balance opposing forces (Fischer & Baskerville, 2022; Harder Fischer & Baskerville, 2018). Such stabilisation processes are nicely reminiscent of resilience; they help the relevant entity adapt to changes while maintaining balance (Hanseth & Rodon, 2021). This involves short-term innovations and revising established routines and techniques. We can, then, think of unstable equilibrium as a driver of adaptation, variation, and resilience. As Holling (1973) notes, resilience is often achieved through a combination of stability and instability when systems adapt and reorganise in response to change.

In the next section, I discuss resilience's relevance to entities in unstable equilibrium states.

3.4. Securing Temporary Stability Through Resilience

In crisis management, resilience is a capability comprising a suite of adaptive capacities. The crux of the idea is that disturbances or disruptions should be viewed as opportunities for recombining certain structures and available capacities (Norris et al., 2008; Pursiainen, 2017). The objective in disaster management is to operationalise necessary capabilities to cope with disturbances. This is seldom thought of as a return to equilibrium but rather as continuous change fostering reduced susceptibility to future disturbances (Pursiainen, 2017).

In engineering, resilience is framed as a capacity that is unique to dynamic systems. These systems adapt to disturbances posing a threat to their core functions, designs, and advancements . Some of the recent literature emphasises redundancy, intelligent sensing, ubiquity, access, and experimentation. These are considered to be some of the key technological attributes necessary for building digital resilience in the face of major shocks (Boh et al., 2023; Boh, 2020) There is a specific emphasis on illustrating how shock absorption acts as a predecessor to transformation (see the framework in Figure 3-2). This proactively secures preparatory measures for the next major shock.

There have been calls for a deeper understanding of how people, processes, and cultures contribute to an entities' resilience to major shocks and how resilience influences future decision-making (Liu et al., 2023).

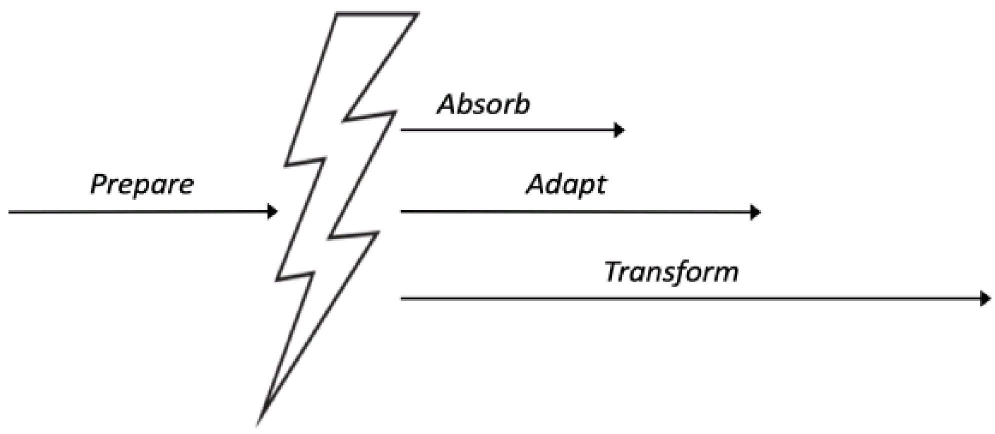

Figure 3-2 Temporality of resilience capabilities (Boh et al., 2023)

Resilience is a complex construct. It is necessary to specify whether one is treating it as a process, a capacity, or an outcome in any given research stream. Boh and colleagues (2023) have noted a pressing question in the IS field: "[H]ow are new technologies informing the science of resilience and what are the most effective ways to enhance resilience?”. Nemeth and colleagues’ (2011) conceptualise of resilience as an “ability of systems to mount a robust response to unforeseen, unpredicted, and unexpected demands and to resume or even continue normal operations”. Sakurai and Thapa (2016) argue that the ongoing restructuring of organisational functions necessitated by disaster does not constitute “returning to an equilibrium”. Instead, an organisation creates an ecosystem to facilitate the attainment of resilience capacities and evolutionary progress (Sakurai & Thapa, 2017).

Also noteworthy is Sakurai’s (2021) resilience framework (Figure 3-3). This conceptualisation factors in phases of resilience and continuous evolutionary processes following stressors or shocks to a system. As depicted in Figure 3-3, there are three distinct phases in the enactment of resilience: (1) initial response, (2) recovery/resolution, and (3) evolution. Much research has focused on the first two phases, but there seems to be less concern with the final phase - where a crisis triggering continuous evolution is operationalised (Pursiainen, 2017).

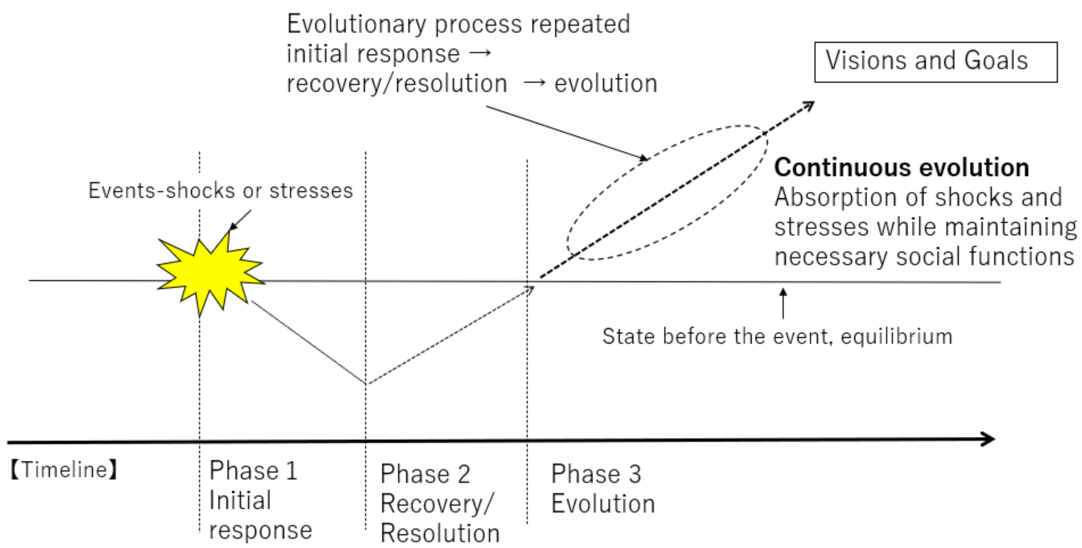

Figure 3-3 Resilience and evolutionary processes (Sakurai, 2021)

I consider this framing of resilience alongside evolutionary processes to be both progressive and applicable to DIs. Following a stressor or shock, a DI is less oriented toward returning to a prior known state. It is, instead, dynamic, on an upward trajectory, and in a state of continuous evolution. This can involve modifications to an entities’ structures, processes, or functions. This can, in turn, contribute to those entities’ long-term evolution (McCarthy et al., 2017).

The above alludes to an infrastructure's *evolutionary fitness*. In the event of disruption, the infrastructure emerges as more valuable (adaptable or exaptable[1]) than it would have been if used for its originally intended purpose (Gill & Hevner, 2013). That said, Figure 3-3 is a linear depiction of resilience, and things seldom play out in such a 'straightforward' manner. There seem to be embedded subprocesses and hidden capacities that can lead to positive outcomes. Moreover, while the notion of evolution emanating from resilient capacities is discussed in the literature, there has been little mention of the role resilience plays in the evolution of organisations and digital entities.

3.5. Chapter Summary

In this chapter, I presented my thesis' conceptual background. I explained how we can understand the fundamental theories, models, and concepts underpinning my research. I also establish a theoretical foundation by delineating DIs, unstable equilibrium, and resilience. This provides a conceptual roadmap for grasping the interplay between these different elements in my study. I also justified my selection of the pertinent theoretical framework and suggested a logical connection between these frameworks and my research objectives.

I will outline my research methodology in the next chapter. I explain my research design, data collection methods, and data analysis techniques. I also express the rationale for my chosen methodology.

[1] In the DI context, exaptation relates to revised service delivery models and deepened use of secondary technological features (Magutshwa & Radianti, 2022; see also Gould, 1991).

4. Research Design

In this chapter, I cover the methodological approach I took in addressing the research questions from Section 1.1. As a process, research design involves outlining practical data generation and analysis methods (Creswell & Poth, 2016). My discussion is split into three sections detailing (1) philosophical grounding, (2) strategy of inquiry, and (3) research method. I conclude the chapter with a discussion of my chosen research approach's limitations. I also reflect on some apropos ethical considerations.

4.1. Brief Background of Research Philosophy in IS

Knowledge assertions are founded in philosophical underpinning. These underpinnings facilitate the formulation of research problems and frame solutions, explanations, and understandings. A philosophical underpinning represents a fusion of *ontological* and *epistemological* stances.

- Ontology is 'a theory of being' (of what is).
- Epistemology relates to how one accesses knowledge (Myers & Avison, 2002).

There is an interdependency between these two concepts, one that makes discerning a distinction challenging.

Multiple approaches can be applied in the scientific domain when building an IS theory. A researcher must, nonetheless, be clear and consistent when it comes to the philosophical stance grounding her work.

Realism and *constructivism* are common philosophical bases in IS work, and they often exemplify opposing worldviews (Figure 4-1).

- Scholars following a realist ontology tend to be inherently objectivist. They perceive a single truth and seek to ascertain it. They often focus on objects, forces, and social structures that exist in the world independently of human beings (Mingers, 2004).
- Constructivists tend to believe in a socially constructed truth, one in which social phenomena and meanings are largely shaped and influenced by social actors (Walsham, 2006).

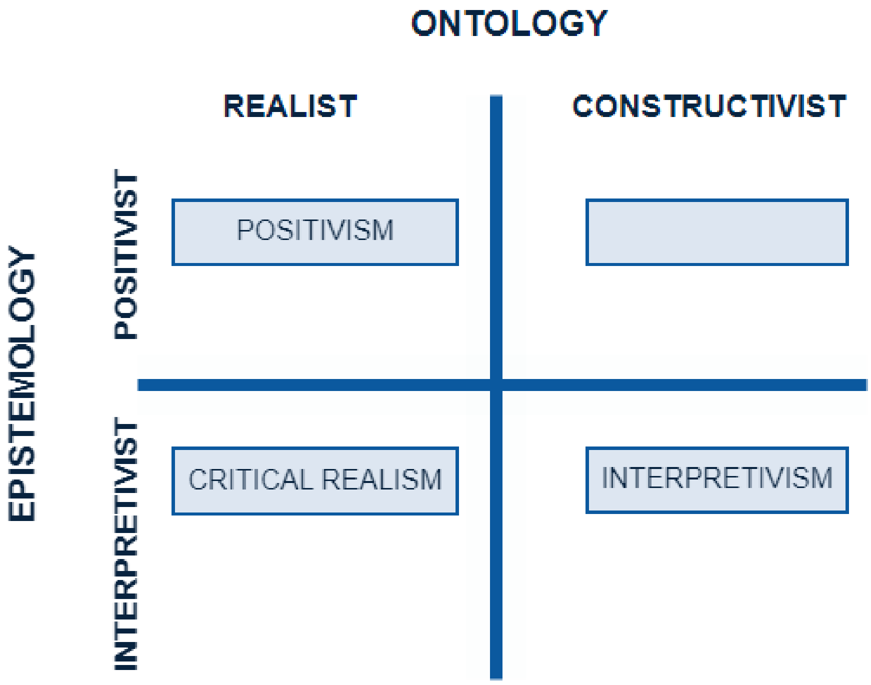

Figure 4-1 Research paradigms (Creswell & Poth, 2016)

Although these are the dominant traditions, there is an emerging middle ground. We can think of this as a sort of 'multiple truths' perspective, one that can be identified with critical realism (which, among other things, seeks to identify underlying causal mechanisms) (Mingers, 2004).

Pragmatism cannot be accurately mapped onto the matrix in Figure 4-1, but it is represented in Saunders and colleagues' (2016) research onion (Figure 4-2). Pragmatists are mostly concerned with how we generate *useful* (or valuable) knowledge rather than with (abstract and/or final) 'true' knowledge per se.

In pragmatism, truths evolve and change with the emergence of new information. Pragmatists go beyond a straightforward cognitive interest in understanding phenomena and the rigidity of identifying cause and effect. Instead, they aim to extract practical consequences in whatever knowledge domain (Goldkuhl, 2012; James, 2020).

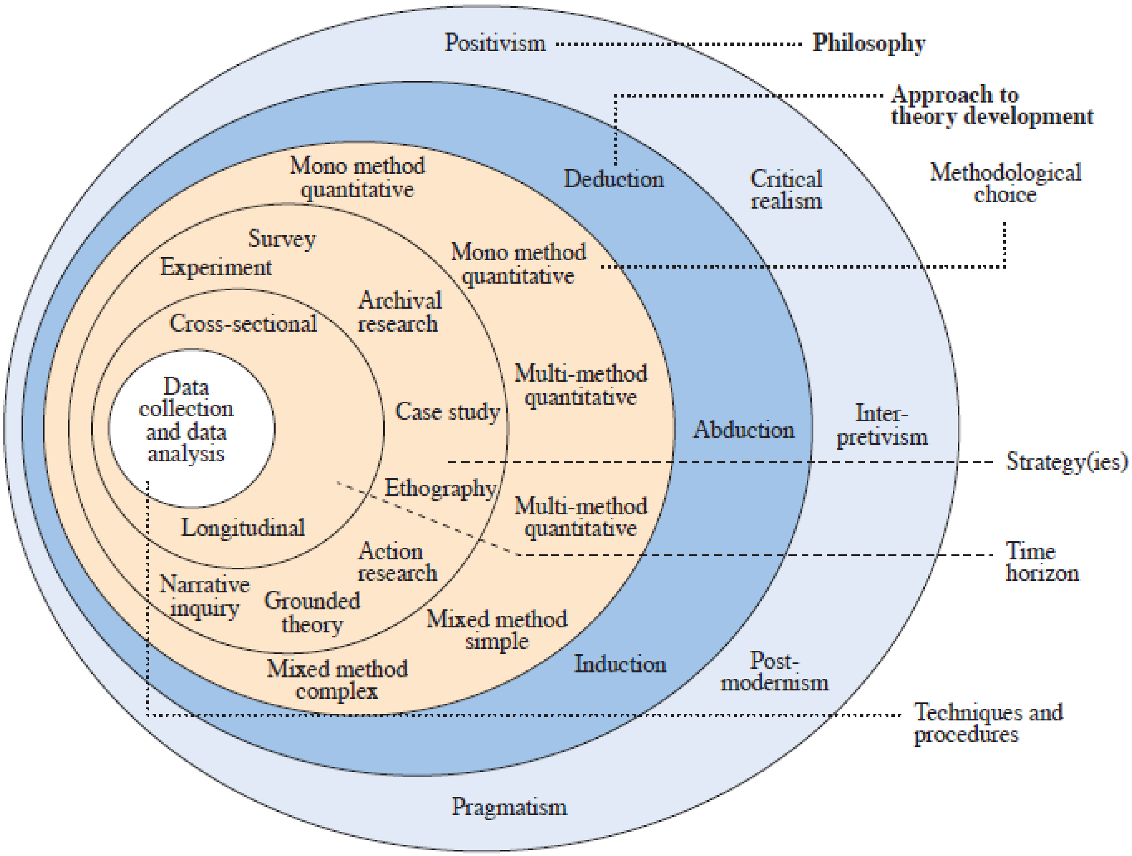

Figure 4-2 Research onion (Saunders et al., 2016)

I will explain my philosophical views in the following subsections, specifically my ontological and epistemological positionings. I also outline the strategy of inquiry and the research method implemented in my work. These concepts are key to understanding both (a) my perspective on the phenomena under study and (b) implications related to the research outcomes and contributions discussed in this thesis.

4.1.1. Ontological and Epistemological Research Positioning

My study is founded on a pragmatist premise. Pragmatists generally subscribe to a pluralist ontology and a constructivist epistemology (Moore, 1966). For, pragmatists, there are multiple realities; there are diverse modes of being that are knowable in a variety of ways (Dewey, 1938; Turner, 2020).

During research, pragmatists rationalise data while aiming to solve a problem (rather than simply attempting to understand or ascertain ‘the truth’). The pragmatic paradigm emphasises change and an interplay between knowledge and action (Bryant, 2009; James, 2020). Pragmatism is considered suitable for studies aiming to (a) generate constructed (rather than objective) knowledge, (b) make contributions that go beyond merely observing and documenting facts, and (c) highlight the value of practical possibilities (Goldkuhl, 2012).

The pragmatic paradigm is appropriate when studying CPSSs that are innovatively developed to solve practical problems in critical contexts. This is because the pragmatic process emphasises real-world interventions. The reality of a CPSS cannot simply be perceived as either socially constructed or solely objectified. The design and development of such enabling technologies are often contextualised. They must inevitably satisfy situated user requirement specifications (i.e., utility) and abide by contextualised development standards and regulations. A multimodal view of reality harnesses a combination of objective and subjective views. This facilitates an appreciation of the dynamics and the iterative approach involved when developing and deploying CPSSs.

Some IS research work implicitly applies a pragmatist approach (even if this is rarely explicitly expressed) (Ågerfalk, 2010; Goldkuhl, 2012; Sein & Rossi, 2019). IS research's socio-technical orientation provides a rich opportunity for contributing to CPSS discourse while avoiding difficulties encountered when reducing complex social, computational, and physical phenomena to a single paradigmatic stream.

I have identified pragmatism as my research paradigm by discussing my thesis' ontological and epistemological foundations. I now focus on my research method.

4.1.2. Strategies of Inquiry

An optimal strategy of inquiry is derived by thoroughly reflecting on some practical problem. Generally, adopting a CPSS within an OCS begins with a social problem or the need to complete organisational processes and operations. CPSSs are widely integrated into the operations of and embedded in the OCS. My study context is the innovative development and use of CPSSs as enabling technologies in OCSs. To contribute to extant knowledge on the relevant phenomenon, I apply a research method that both (a) provides multiple views and (b) offers an opportunity to understand the relationships constituting innovative CPSS development and use.

(Dewey, 1938) framed the notion of pragmatic inquiry as a "systematization of human beings' natural efforts to improve their situation". The motivation for pragmatic inquiry is fuelled by an interest in a specific part of reality, one that has the potential to yield constructive knowledge leading to a controlled change in that reality. Moreover, pragmatist inquiry does not only consider what is but also the (as yet) unseen world. My research questions are formulated in a way that reflects this method.

We can think of the process of knowledge creation as being guided by Goldkuhl's (2012) cyclical model of human action (Figure 4-3). In the model, knowledge creation begins with a pre-assessment to understand the preconditions for action. I assumed a constructivist approach during the early phases of my study to acquire an in-depth understanding of the relevant study elements. This included the human and non-human aspects of the health OCS. The constructivist paradigm in the early phases allowed for optimal exploration of the empirical context and pre-assessments.

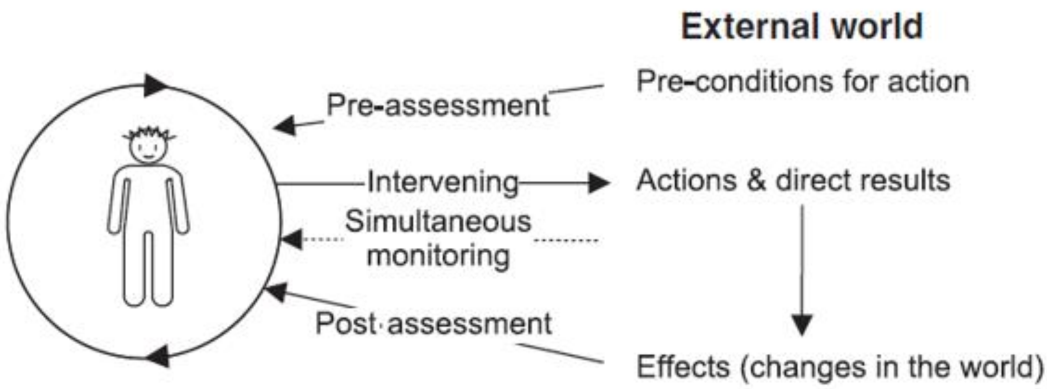

Figure 4-3 Goldkuhl's cyclical model of human action

According to (Creswell & Poth, 2016), the pragmatist paradigm is suitable for mixing "paradigms, assumptions, approaches, and methods for data collection and analysis". This is consistent with so-called 'functional pragmatism.' Functional pragmatism incorporates the notion of 'knowledge for action' and naturally focuses on what works. Pragmatism does not maintain a dogmatic stance when it comes to data generation methods. Instead, it favours a pluralist attitude, one that blends research methods according to situated research purposes and empirical circumstances (Maarouf, 2019).

Given the above, an abductive research method integrating prospective, prescriptive, and normative knowledge aspects appears appropriate. A qualitative research design possesses the depth and range to generate adequate data when addressing these questions.

4.2. Research Method

The essence of my research questions is quite practical and therefore demands a simultaneously explorative and investigative research method (Creswell & Poth, 2016; Myers & Newman, 2007). I chose an abductive approach, one that combines explorative case studies with literature analyses. A case study approach nicely fits attempts to capture information on explanatory 'how,' 'what,' and 'why' questions. It also provides insights into how an intervention is implemented and received in practical terms. It can also offer insights into pertinent knowledge gaps and/or why one implementation strategy is preferable to another. During the case study process, one also explores the relationship between theory and the empirical world (Dubois & Gadde, 2002). This helps develop and refine one's theory.

4.2.1. An Exploratory Case Study

The research approach I adopted is exploratory. It is based on a single case study, semi-structured interviews, and documented organisational activities (analyses through reports, meeting minutes, and observations). My analysis reflects on the organisational changes made in response to an ongoing health crisis. The empirical setting is Norway's Agder County. Specifically, I followed the county's innovative design and implementation of a CPSS solution when responding to the COVID-19 pandemic.

The study participants all had some relation to the digital follow-up tool (Section 1.2) but from a range of organisational positions. All were encouraged to give detailed descriptions of their experiences in their own terminology. To ensure a managerial perspective and holistic organisational view, I conducted 22 interviews with 14 participants, totalling 24 hours. The range of interviews spanned three years and included seven top managers and seven other key employees involved in the digital follow-up tool's development and implementation processes. I used organisational documents (e.g., reports) to verify and elaborate on details provided during the interviews.

I compared the reliability of recollections about technical and operational details across the interviews and then against internal documents and reports. My analysis and interpretation of the empirical data were also supported by discussions with both other researchers working on the research project and the participants themselves in subsequent interview rounds.

I now describe the data generation process and the phases in which it was conducted.

4.2.2. Data Generation

As seen in Figure 4-5, there were three distinct phases involved in the work targeting my research questions. I selected collective and instrumental design elements. I did so using (formal and informal) qualitative data-gathering techniques (e.g., interviews and organisational records and media archives analyses).

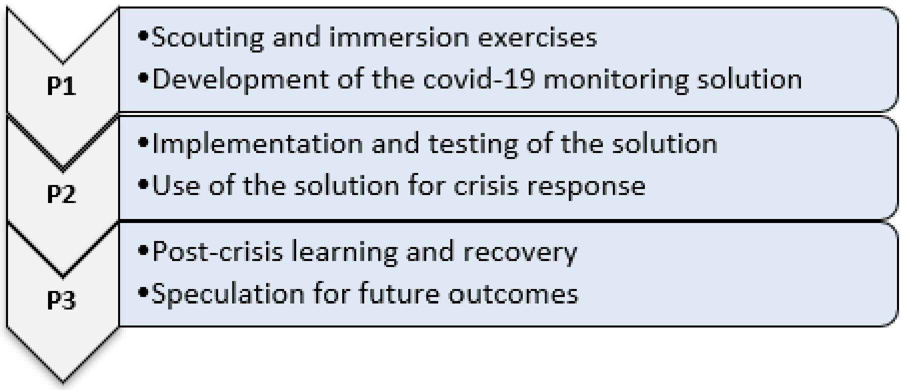

Figure 4-4 Data generation phases (P1–P3)

I had three rounds of data gathering, conducted over a three-year period (2020–2022). This led to the final research outcome.

The use of varied data sources is known to contribute to case study validations (Fisher et al., 2018). Figure 4-5 provides an overview of the various data generation phases: P1 (June 2020–November 2020), P2 (January 2021–March 2021), and P3 (January 2022–March 2022).

The first phase of data gathering was conducted soon after the first wave of COVID-19 infections in Norway. It was framed as an immersion exercise. I spent time understanding and learning about the CPSS technology and the processes involved in its design, development, and operations. The technical details about the system were provided through live demonstrations and system documentations. Agder County has maintained a long-standing collaboration with the University of Agder. I, therefore, had access to lots of data linked to the legacy systems and early versions of the solution.

My main aim at this stage was to document and derive a process theory related to how adoption of the CPSS happens. I identified the key stakeholders: technology vendors, project team members, municipalities, and the like. I then classified them as knowledgeable agents. Ethical considerations were also made. The Norwegian Centre for Research Data approved my data processing procedure. This ensured that there was informed consent and that I complied with regulatory requirements related to information security and data privacy.

Participants were provided with an information letter outlining the intent of the study. They also gave the requisite written consent. Tables 4-1, 4-2, and 4-3 show the distinct phases of my data-gathering activities and how each phase was documented. Different participants were brought in at differing stages of the activities (as outlined in the overview tables).

C. Table 4-1 Overview of P1: Data gathering activities and documentation

	Form	**Participants**	**Documentation**
P1	Initiator meetings with the technology vendors. Live technology demonstration (June 2020).	Head of digital and enterprise services. Digital solution lead.	- Audio recorded discussions and transcriptions. - Personal notes and screenshots. - System documentation provided.
	Documentation collection and collation (June 2020).	County project team.	- Early project objectives and impressions. - Requirement specification documents.
	Semi-structured interviews – 1.25 hours (July 2020).	Head of digital and enterprise services. Digital solution lead.	- Vendor-suggested solutions and approaches. - Procedure and tech developer activities. - Decision-making and collaboration detailing. - Audio recorded and transcribed.
	Semi-structured interviews – 4 hours (November 2020).	Head of research and medical doctor (county).	- Early project achievements and impressions.

		National project manager.	- Crisis management repertoire documents.

Process unpacking facilitated the formulation and fine-tuning of the questions for follow-up interviews during later rounds of data gathering. Understanding how the OCS delivered their services provided insight into how adoption of the CPSS emerged. It also emphasised the importance of reflecting participants' understandings of their environment (a concept the case studies are rooted in). This enabled an in-depth single case study with multiple rounds of data gathering, which cumulatively contributed to my investigation.

D. Table 4-2 Overview of P2: Data gathering activities and documentation

	Form	**Participants**	**Documentation**
P2	Semi-structured interview – 1 hour (January 2021).	eHealth research innovation manager.	Audio recorded discussions and transcriptions. - First two infection wave experiences.
	Semi-structured interview – 1 hour (January 2021).	eHealth unit advisor.	Audio recorded discussions and transcriptions. - First two infection wave experiences.
	Semi-structured interviews – 4 hours (January 2021).	Design project lead, security project lead, and distribution project lead.	Audio recorded discussions and transcriptions. - First two infection wave experiences.
	Semi-structured interview – 1 hour (January 2021).	General practitioner.	Audio recorded discussions and transcriptions. - First two infection wave experiences.
	Semi-structured interview – 1 hour (January 2021).	Hospital nurse.	Audio recorded discussions and transcriptions. - First two infection wave experiences.
	Document analysis.	County project reports.	Personal notes and summaries of feedback from reports.

			User experience survey.

My design is somewhat lengthy. Yet, each phase cumulatively moved the study toward answering each stipulated question. This staggered execution of the case further contributed to ease of comprehensibility vis-à-vis theoretical and practical contributions from the topical literature. A rigorous approach also allowed for the possibility of alternative explanations.

My initial data-gathering activities subsequently led to a theoretical sampling process. Theoretical sampling is a helpful approach in iterative analytic processes, where data is collected in cycles. The 11 'leading interviews' (Phases 1 and 2) best fit the focal phenomenon definition criteria. I used intermittent coding and analyses to decide which questions to ask in follow-up interviews and develop the theory as it emerged .

In my study's final phase, I followed a theory-driven approach. This targeted SQR3 (Section 1.1) and reconciled my findings with MRQ (Section 1.1).

E. Table 4-3 Overview of P3: Data gathering activities and documentation

	Form	Participants	Documentation
P3	Semi-structured interview – 1 hour (January 2022). - Follow-up interview.	eHealth research innovation manager.	Audio recorded discussions and transcriptions. - Future outlook and overall reflections.
	Semi-structured interview – 1 hour (February 2022).	eHealth advisor.	Audio recorded discussions and transcriptions. - Future outlook and overall reflections.
	Semi-structured interviews – 3 hours (March 2022). - Follow-up interview.	Three project leads (design, security, and distribution).	Audio recorded discussions and transcriptions. - Future outlook and overall reflections.
	Semi-structured interview – 1 hour (January 2021).	Municipal leadership.	Audio recorded discussions and transcribed. - Future outlook and overall reflections.

	Semi-structured interview – 1 hour (March 2022).	Municipal leadership.	Audio recorded discussions and transcriptions. - Future outlook and overall reflections.
	Semi-structured interview – 1 hour (February 2022). - Follow-up interview.	Head of research and medical doctor (county).	Audio recorded discussions and transcriptions. - Future outlook and overall reflections.
	Semi-structured interview – 1 hour (February 2022).	Municipality leadership.	Audio recorded discussions and transcriptions. - Future outlook and overall reflections.
	Semi-structured interview – 1 hour (August 2022). - Follow-up interview.	National project manager.	Audio recorded discussions and transcriptions. - Future outlook and overall reflections.

At this stage, I was reflecting on constructive knowledge from earlier phases and questioning how it can underpin new prospects and lead to new practical insights. The relevant empirical case provides insight into how legacy systems facilitate solution generations in unanticipated future scenarios. There are, though, no immediate indicators of what the future holds for the CPSS technology that is necessary when performing the prescriptive and prospective analyses required to answer SRQ3. In Phase 3, I spent a significant amount of time during interviews asking participants to give their informed speculations on what lay ahead.

I now outline the preliminary and formal analysis phases emanating from data-gathering activities in Phases 1 to 3.

4.2.3. Data Analysis

The interview transcripts were analysed in NVivo. The data interpretation, reporting process, sense-making, and development do not represent a linear process. Instead, they comprised multiple iterations in pursuit of a deepened engagement with the focal phenomena, the emerging data, and its interpretation. In pursuing methodological rigour and transparency, my approach to data analysis and theory development (Figure 4-6) was inspired by the Gioia method as described in the following text (Gioia et al., 2013).

My results were analysed with a focus on the technology, functions, and organisational routines that the participants described. This occurred in an iterative process throughout Phases 1–3. During Phase 1, I prioritised sequencing the steps and processes followed during the preliminary stages of the project. The first-order concepts are mainly direct excerpts from the Phase 1 interviews (completed in July 2020 and updated to reflect follow-up interviews in later phases).

I identified the empirical case's key activities and routines and then used them to inform future interview questions. In Round 1, for instance, I asked participants the following question: "Can you tell me the story of how the situation unfolded in your workplace in the period beginning February 21st when Norway reported its first COVID-19 case?" The questions at this stage were open-ended and intended to capture the participants' full experiences with no theoretical basis. A first-order concept derived from an answer to this question would be "realisation of a direct threat to health service."

I then mapped the first-order concepts to second-order themes in the literature. This involved a process of sense-making and deepening understanding, a process that I repeated several times during the interview phases. I then used it to refine the interview questions. As a follow-up to the previous question, for instance, I asked the following question in the second round: "Did your early experiences and the changes you made you feel more prepared for the second wave of infections?"

I divided the analytical processes and routines across my five papers into three distinct phases: (1) initial response, (2) recovery/resolution, and (3) learning and evolution. The aim at this stage was to aggregate the concepts discussed in my publications and derive a collective meaning. A snapshot of the analytical data structure can be found in Figure 4-6.

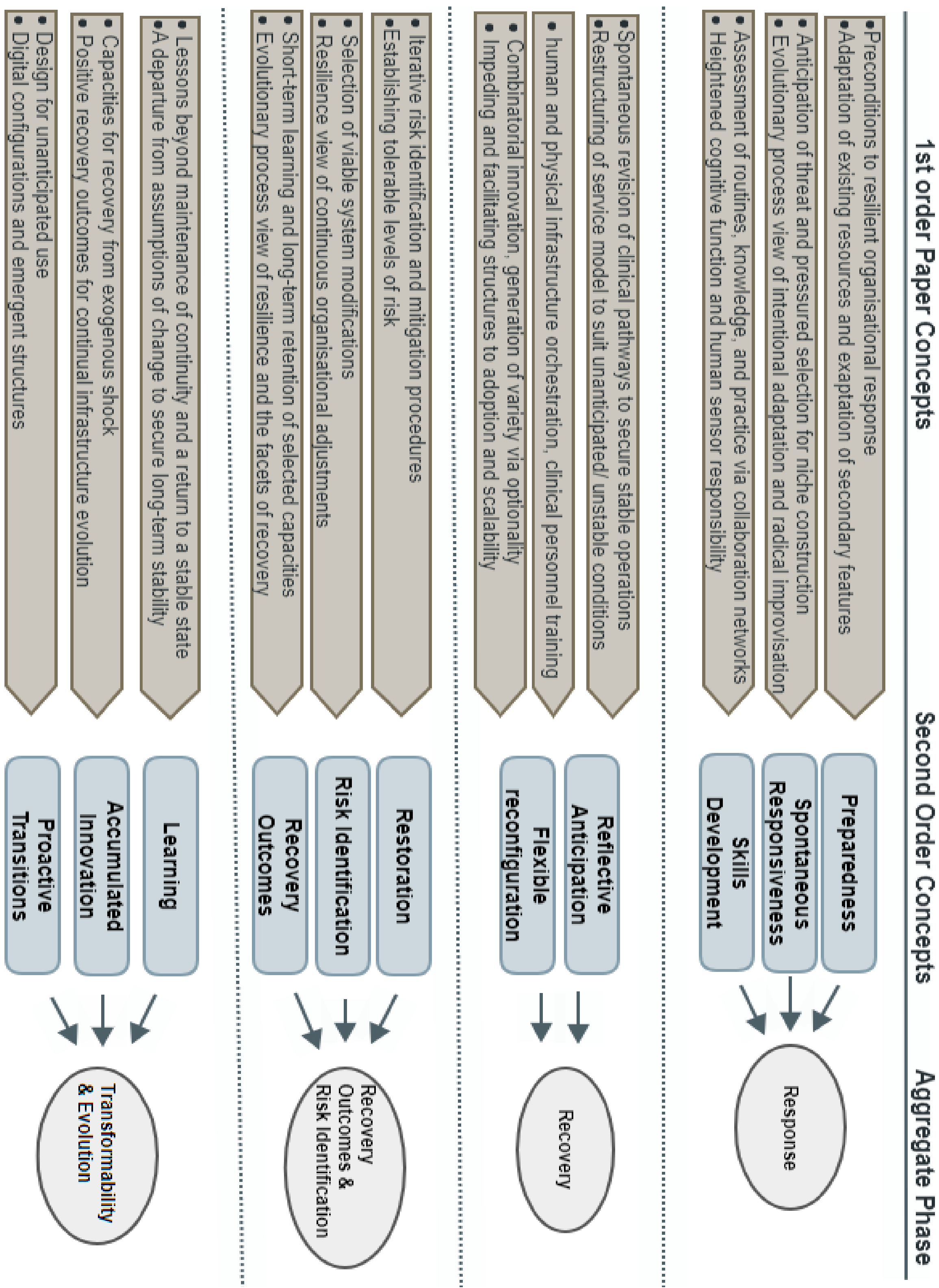

Figure 4-5 Data structure depicting a snapshot of publication concepts analysis for consolidation to thesis contribution (adapted from Gioia, 2013)

I mapped the second-order themes according to an analytical framework. This generated four aggregate theoretical concepts: (1) response, (2) recovery, (3) recovery outcomes and risk identification, and (4) transformability and evolution. I will discuss the results of this analysis in Chapter 6 (where I discuss those empirical and conceptual insights from my publications that are relevant to this thesis).

4.2.4. Validity Issues

Validity relates to an assessment of the accuracy of research outcomes and findings from the researcher's, reader's, or informant's perspective. A researcher should be conscious of validity issues related to her data collection and analysis because both are instrumental when formulating a result. A validity strategy must also be devised and adhered to, one that services the chosen method and the credibility of results (Myers & Newman, 2007). Although my chosen method (the semi-structured interview) can be a powerful instrument, there are well-documented pitfalls involved in its use. Structured interviews are often viewed suspiciously. They can also be plagued by a lack of trust and concerns about the level of organisational entry and researcher bias (Myers & Newman, 2007). I have been cognizant of this throughout the study period and have taken pre-emptive measures against known pitfalls.

My study is framed by the underlying principle of the so-called hermeneutic circle. This framed my data-gathering, analysis, and reporting processes (Klein & Myers, 1999). The hermeneutic circle guides oscillations between individual interpretations reflected in contributing research publications (Table 1-1) toward the holistic view presented in this thesis. This approach is often employed during interpretive studies. In earlier sections of this chapter, I discussed my use of constructivism as a supporting paradigm during the early phases of my PhD. One can, then, think of my adoption of the hermeneutic circle as an act of due diligence. When selecting participants, I was careful to give fair representation to all levels in the OCS. My supervisor had engaged in prior research collaborations with the relevant participants, and she facilitated the initial contact. Much time was allocated to introducing myself at the beginning of interviews. This was to minimize participants' discomfort and establish some level of trust.

The Gioia methodology relates to an applied method of analysis, it allows for a longitudinal and iterative approach (hermeneutic). It also accommodates sense-making through data gathering and analysis by using suitable theoretical frameworks (Gioia et al., 2013). I attempted to exercise flexibility and improvisation as new research avenues and agendas emerged during the data-gathering stage. I shared my research publications' abstracts with participants who expressed interest in them. I also integrated all feedback into the findings. My co-authors and supervisors are familiar with the relevant empirical setting (Norway's Agder County). They participated in the analysis and also interrogated my interpretation of the interview data (Creswell & Poth, 2016). The Gioia method is also designed to foster research transparency. It provides clear documentation of the step from empirical data to theory.[2]

Table 4-4 summarises the validity issues addressed in my study. At this point, it is important to address the 'paradigm shift' that occurred in my philosophical stance over the course of my study. I applied interpretive approaches in the early phases. Constructivism is a supporting paradigm in this case. It facilitates the abductive process in the early phases of a research journey and was instrumental during my theory-development process. That said, I ultimately reconciled these early processes with my pragmatist philosophy.

F. Table 4-4 Klein & Myers' (1999) summary of validity issues

Guiding Principle	**Application in study**
The principle of the hermeneutic circle.	I conducted multiple iterations between the data gathering and analysis phases in my study. This is reflected in both my contributing publications and my thesis. Theoretical sampling was central to my theory development process. This facilitated (a) the refinement of my data-gathering process and (b) the alignment of the focal phenomenon with pertinent theoretical concepts.
The principle of contextualisation.	Rich descriptions of the empirical setting can be found in Chapter 5. This provides insight into the relevant national, county, and organisational setting. I also spent a considerable amount of time familiarising myself with the local cultural setting and context. This led to a deeper understanding of the reasoning guiding decisions and actions taken in the empirical case.
The principle of interactions between researchers and subjects.	Having acquired adequate knowledge of the context, the researcher is supposed to remain detached and maintain objectivity. I am an outsider to both the organisation and the country. This provided a healthy degree of separation and facilitated an independent understanding of the interview data.
The principle of abstraction and generalisation.	It is not possible to generalise a single case study to other empirical contexts. Nonetheless, the abstraction of focal phenomena to theoretical concepts can lead to theoretically generalizable contributions. The pragmatic process also accommodates the possibility of speculating about future trajectories. Reflection-based findings are not confined to the given empirical case. Instead, they

[2] As we will see in later chapters, I consider generalisability to be the abstraction of my empirical observations to a theoretical conceptualisation and contribution (Walsham, 1995).

	represent generalised reflections on CPSS use by OCSs in the digital future.
The principle of dialogical reasoning.	I was open to adapting and developing my theoretical preconceptions. I, therefore, used an inductive approach during my analysis. This allowed the data to shape and influence my selected theoretical lens.
The principle of multiple interpretations.	I have not only relied on my interpretation. I also discussed my findings with the participants and seniors in my research team who were more familiar with the context and dynamics under study.
The principle of suspicion.	I have corroborated informants' recounts with various actors occupying various positions within the organisation. I then followed up on any contradictory statements.

4.3. Chapter Summary

In this chapter, I presented a comprehensive overview of the approach, methods, and procedures employed while investigating my focal phenomenon and answering my research questions. I also provided a structured description of my qualitative study's design and the rationale guiding my ontological and epistemological positions. This is intended to secure my study's validity, reliability, and rigour.

I have identified construtivism as a supporting paradigm to pragmatism. This allowed me to acknowledge the significance of the individuals involved in the study's subjective experiences and perspectives. It provides a deeper understanding of the contextual complexities and social constructs influencing our understanding of CPSSs' innovative development and use in OCSs. I also explored the meanings and interpretations of data, thereby enabling a more nuanced and holistic analysis.

I would like to think that this pragmatic study strikes a suitable balance between objective data collection and a meaningful exploration of participants' viewpoints. This should, in turn, foster a comprehensive and contextually relevant understanding of the focal phenomenon.

In the next chapter, I provide a detailed description of the empirical case, the context setting, and the relevant details.

5. Empirical Case Overview

In this chapter, I provide an in-depth description of the case background. A description of Norwegian health services provides a backdrop to understanding both the organisation of work in that system and the relevant empirical case.

5.1. The Norwegian Health System

Norway covers an area of 385,207 square kilometres and has a general population of just over 5,4 million people (Statistics-Norway, 2022). Over 80% of the population lives in cities and surrounding urban areas (Saunes et al., 2020). Most of the population is of Norwegian descent. There is, though, a growing immigrant population, comprising people from the European continent, Asia, and Africa. The average life expectancy is currently 81 years for males (expected to increase to 88 years by 2060) and 84 years for females (expected to increase to 90 years by 2060).

Trends in recent years (2018 onwards) indicate a growing population of inhabitants aged 65 and older. This has resulted in a notable increase in the old-age dependency ratio (proportion of inhabitants aged 65 and older versus inhabitants aged 15–64). This fact makes efficient healthcare service delivery to the ageing population a national priority (Saunes et al., 2020). There are, consequently, specialised health programs for the elderly. The Norwegian health system is based on the Nordic welfare model, where all the country's inhabitants have access to universal health care. Inequalities and social differences are, however, still evident.

There are three distinct administrative levels in the Norwegian health system: (1) state, (2) regions, and (3) municipalities. Figure 5-1 provides an overview of the organisation of these three levels. The Ministry of Health and Care Services is the ultimate authority. It generally sets the policy standards and allocates budgetary funds and activity-based payments to health actors (municipalities and regional health authorities). The two directorates – the Directorate of Health and the Directorate of eHealth – are subordinate to the ministry. They are largely used for policy and agenda implementation and oversight (Ringard et al., 2013). They do not have authority over lower structures but provide leadership and policy direction in accordance with national legislation and regulation.

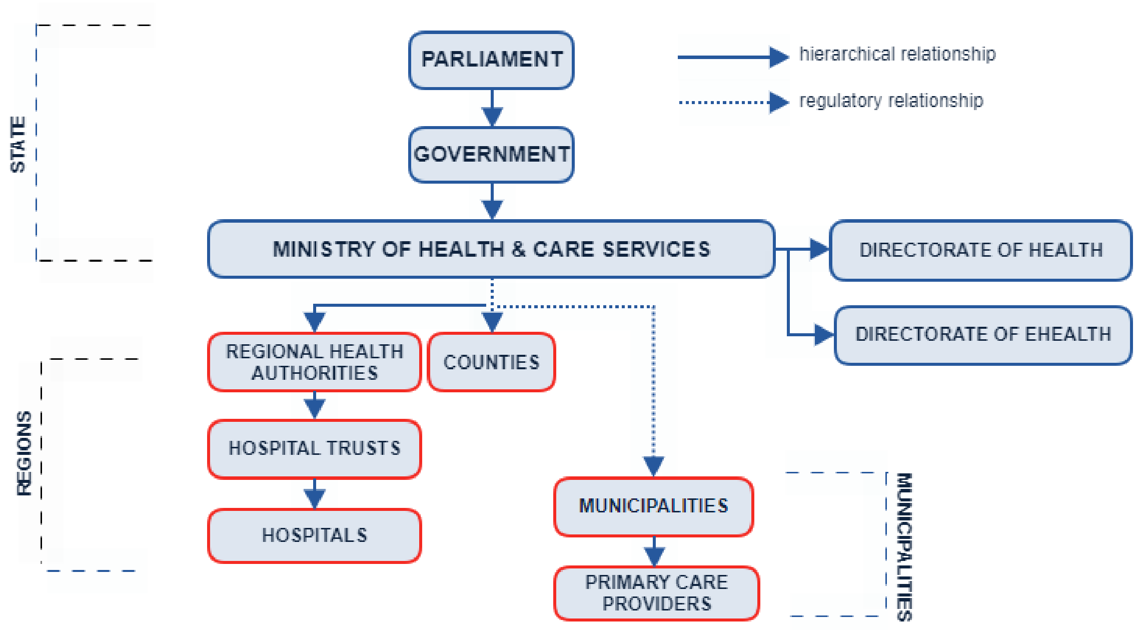

Figure 5-1:Overview of Norwegian health system

There is an established network of governance structures administering primary and specialist healthcare services. Administration is decentralized through four regional health authorities (see Figure 5-1). These authorities own hospital trusts and are responsible for secondary specialist care delivery in the regional hospitals. Primary care is administered by the municipalities, which employ general practitioners (GPs) and oversee social care services (e.g., home-based services and care in nursing homes).

Counties provide oversights related to health service assurance and act as an appeal body for municipal-level decisions (Ringard et al., 2013; Saunes et al., 2020). The national health authorities provide shared digital information infrastructures and resources (such as a shared broadband network, drug prescription registry, and disease surveillance systems). The hospitals and municipalities, in turn, make decisions concerning the digital systems used when provisioning health care services. For purposes of the empirical study, I consider the entities in the Agder region belonging to the boxes outlined in red (see Figure 5-1) to be the OCS under study.

5.2. National Healthcare Digitalization Initiatives and Service Models

In 2017, Norway's healthcare expenditure was pegged at 10.4% of GDP. The innovation of clinical pathways and service models at primary and secondary care levels has been prioritised. The goal is to enhance citizens' quality of life and improve the overall efficiency of the country's health services.

I now discuss a notable Norwegian healthcare digitalization initiative, the welfare technology programme.

5.2.1. National Welfare Technology Programme

The Directorate of eHealth acts as an arm of the Ministry of Health and Care Services. It provides support to municipalities in implementing digitally enabled solutions to improve health services. This was the case when the welfare technology program was launched in 2013. Welfare technology refers to the use of technology to improve the delivery of health services and care support (especially to vulnerable and socio-economically disadvantaged groups) (Bygstad, 2017).

The welfare technology program's primary objective is to revise the health service model for chronically ill older patients. Doing so can save time and costs while affording older patients a degree of independence. The programme focuses on the development and use of technologies (e.g., telemedicine and telecare) in improving the efficacy of Norway's welfare services. The programme is an ongoing collaboration between government, academia, and the private sector. It is widely acknowledged as fostering the design and implementation of innovative technologies for supporting the elderly and those living with disabilities. Funding and resources are directed toward development and educational costs. The goal is to raise awareness and nurture positive societal attitudes toward technology.

Since its 2013 inception, the welfare technology programme has become an integral part of municipal health and care services. In fact, 80% of Norwegian municipalities have been or are involved in projects using welfare technology solutions (Bygstad, 2017).

Implementing welfare technology involves interactions between technology, people, and organisations. In some implementation processes, it is a matter of getting the technology to work within existing work processes. In others, it is a matter of changing the relevant work processes due to the new technology's introduction.

5.3. Agder County

Figure 5-2: Map of Agder County depicting municipalities (source: snl.no)

In this section, I describe the context of my study (Agder County). Agder County is located in the southern part of Norway. It was formed in 2020 following a merger of East Agder and West Agder. The county has a population of approximately 315,000 people and is spread over a geographical area of about 16,456 square kilometres (Statistics-Norway, 2022). There are 25 municipalities in Agder County (as of 1 January 2020). Specialist healthcare in Agder is organised in a hospital trust and block funded by the government. The health and care services ministry overseas and administers the county health authorities.

The block funds that the government provides to Agder County are paid into the Sørlandet Hospital Trust, which employs 7,000 staff (Statistics-Norway, 2022). The trust is a collective of several hospitals, health clinics, and medical centres. The largest hospitals are Sørlandet Hospital Kristiansand and Sørlandet Hospital Arendal (Omland, 2014). The delivery of health care services is, though, the product of a collaboration between regional, national, and municipal health authorities. The county hospitals and other facilities provide specialised care, often based on referrals from municipal primary care providers.

The municipalities are responsible for organising and coordinating primary health care in Agder County. This involves GPs, emergency medical services, and preventative care (Statistics-Norway, 2022). Citizens are assigned a local GP who is the first point of contact for their health-related needs. GPs are expected to provide a primary screening for all patients and have the prerogative to refer patients for treatment at a specialist facility when necessary. The municipalities are also responsible for social services. These services cater to vulnerable groups (e.g., the elderly and those living with disabilities and/or mental health problems).

Digital healthcare is taken seriously in Agder County (Kyllingstad et al., 2021). The county has, for instance, taken several steps toward organizing eHealth and welfare technology program initiatives in its jurisdiction. Since 2013, the county has also provided funding and support for (a) the development of welfare technology strategies aligned with national objectives and (b) the implementation of welfare technology solutions, such as digital home follow-ups (Kyllingstad et al., 2021).

Most municipalities in Agder County offer eHealth services, telemedicine, and digital health applications. The county also maintains productive collaborations with technology vendors, healthcare providers, and the local university. The goal is to identify areas where technology can be used to improve patient care, interventions, and outcomes. The county has also spearheaded initiatives implementing digital health solutions aimed at optimizing health service access, efficiency, and delivery.

I now discuss the history and organisation of different digital health initiatives in Agder County.

5.3.1. Agder's Regional Coordination Group

Established in 2015, the Regional Coordination Group (RKG) for eHealth and welfare technology is a joint municipal initiative in Agder County. The motivation was a recognition of the relevance of digital health solutions and the prominent role they can play in improving health service deliveries. The group consists of representatives from municipalities, healthcare providers, and other relevant stakeholders in the county. This composition encourages balanced input and seems to reflect the needs of both healthcare professionals and patients (Kyllingstad et al., 2021).

Since its inception, RKG has facilitated the development of a shared digital health strategy across municipalities. It has also coordinated the implementation of several digital health solutions. Some of RKG's initiatives involve the joint procurement and implementation of welfare technologies across all Agder municipalities. RKG also coordinates ongoing projects addressing the implementation of telemedical solutions, referred to as digital homecare, and digital self-care tools.

RKG has secured holistic and broad-based implementations of eHealth solutions in various Agder County municipalities. This has been instrumental in supporting the organisation of innovation projects in Agder County. That said, eHealth projects are still organised independently at the hospitals (governed by a regional health authority) and municipality levels (governed independently). The municipalities run independent innovation projects and thus have different strategic approaches.

The structural dynamics of Agder County's health system feed into an understanding of the overall decisions made at county, municipal, and/or hospital levels. I now discuss remote patient monitoring initiatives in Agder County.

5.3.2. Digital Follow-Up

Backed by the welfare technology program, a 2018 pilot project was launched in Agder County for digital home follow-ups. A total of 25 municipalities set up a regional telemedicine service accessed through three county telemedicine clinics and (later) integrated into municipal homecare and follow-up services. This involved what came to be called a 'digital follow-up.' The idea was to include hospitals in the Sørlandet group, specialist doctors, and 300 GPs (some in private practice). But this was not immediately realised.

The first deployment of this solution in Agder comprised a 'service kit' containing a Wi-Fi-connected tablet with restricted functionality and Bluetooth-connected biomedical sensory devices (see Figure 5-3). Qualified health personnel operated the service's backend, ensuring that the kits were correctly configured and that the correct data was transmitted to the telemedicine clinics. The patient data for this solution is stored on a separate database, one that is independent of the other record systems in the hospitals and municipalities. Municipal carers, GPs and specialist doctors can access this data by logging into the telemedicine clinic platform.

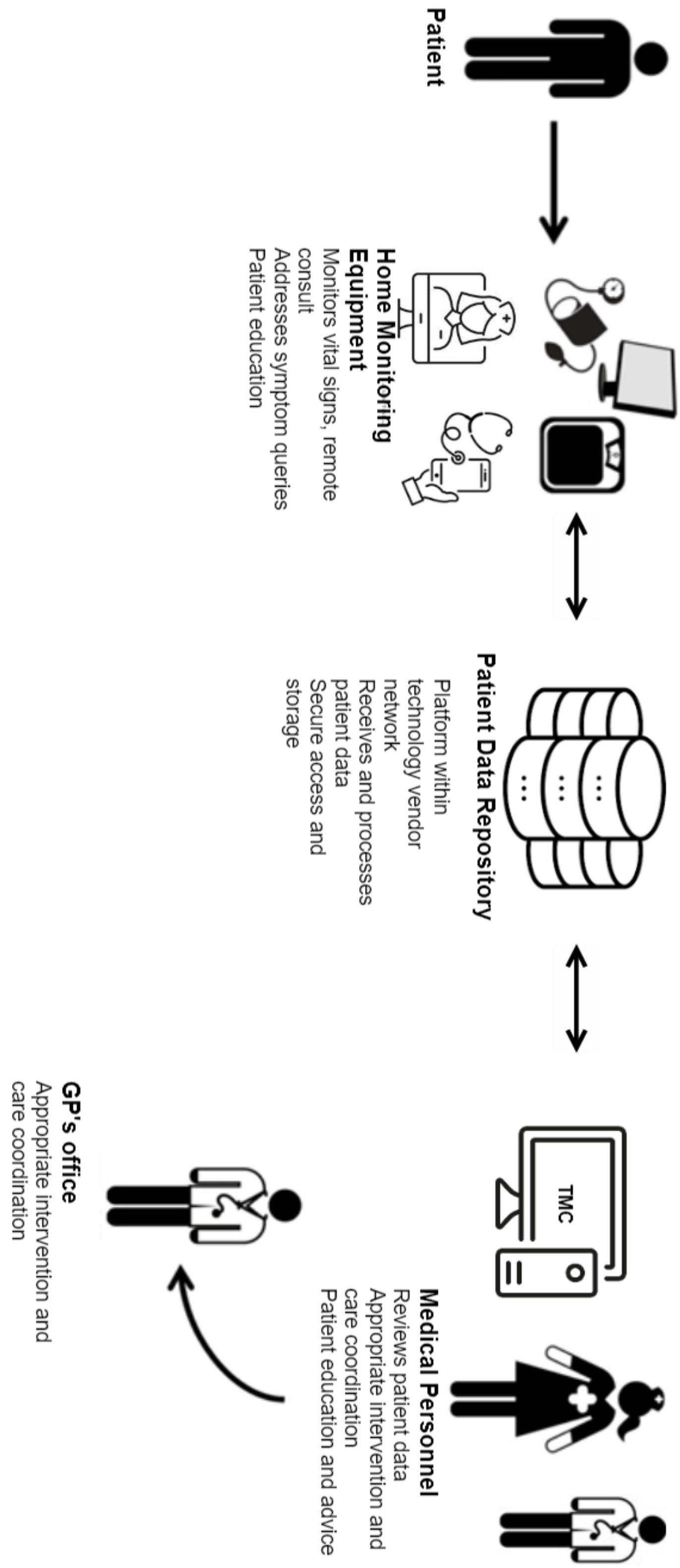

Figure 5-3: Illustration of a digital follow-up

This service was focused on patients living with chronic conditions, such as pulmonary heart disease, chronic obstructive pulmonary disease, and diabetes. The service model was mutually beneficial, offering a comfortable degree of patient independence. It was also expected to yield reduced care costs for municipalities and hospitals in the long term. However, the project required significant initial investment, and several municipalities were reluctant to 'buy into' the long-term investment and scale the service. Low digital literacy was also a challenge when it came to older patients. This initiated conversations about promoting a culture of change and raising digital competence levels in specific patient demographics. The county has maintained these ambitions and remains committed to expanding digital follow-ups to serve more patients and cater to more diagnosis groups.

Based on years of efforts and achievements in digital care, Agder County is active in European region innovation networks. In recent years (2020 onwards), the county has played a pivotal role, championing innovations expected to lead to the merger of various patient journal platforms into a single electronic record per patient.

This is when COVID-19 entered the scene. I now describe events occurring at the beginning of 2020 after reports of the COVID-19 virus first began emanating from China.

5.3.3. Agder During the First Phases of the COVID-19 Pandemic

The COVID-19 pandemic took hold of continental Europe a few months (January/February 2020) after the first reported outbreak in China (December 2019). Although we have seen similar diseases, the novel SARS-CoV-2 virus was far more aggressive and led to highly unfavourable patient outcomes. As is well-known, the health impacts have been devastating. There have also been cascading effects related to the novel constraints the disease posed and the countermeasures taken to curb the waves of infection (WHO, 2020). The ripple effects of restrictions and lockdowns affecting large parts of the economy demonstrated how a health crisis can easily morph into an economic and social one.

In the period leading up to the first infection wave in Norway, the county's leaders-initiated crisis response protocols in anticipation of the kind of high infection numbers seen in other European countries (like Italy). The health directorate provided guidelines and recommendations to local county health authorities. There was an awareness that things could be incredibly challenging, and this instigated crisis preparation and mitigation activities. At the time of writing (March 2023), the Norwegian authorities have reported a total of 400,000 infections and 1,300 deaths (Statistics-Norway, 2022). These are significantly lower numbers than those reported in the rest of Europe. In Agder, the burden on the health system was significant. However, the region was, though, relatively less impacted than Norwegian counties with higher populations.

The Agder authorities implemented measures like social distancing, contact tracing, quarantining, and widespread testing to lower infection rates. They also worked toward increasing health service capacities to accommodate an anticipated influx of COVID-19 patients. The operational constraints created by the pandemic presented an opportunity to explore and experiment with extant digital healthcare solutions. A decision to repurpose the digital follow-up solution (discussed in Subsection 5.3.2) was among the early initiatives.

My focus in this thesis is on the innovative developments leading up to and occurring during both (a) the initial phases of the crisis (first infections in Norway were reported in February 2020) and (b) subsequent phases (up until the first quarter of 2022). I will discuss events in some of the municipalities, a county hospital, and GP offices, but not all Agder County healthcare actors. This represents a snapshot of the OCSs' innovative use of digital follow-up (the CPSS) at county level. The role of digital follow-up in the county is mediative, providing a digital alternative during medical routine completions and health service deliveries to COVID-19 patients. In my discussion, I consider and often refer to digital follow-up as 'the CPSS.' This technology-mediated crisis response initiative in Agder County's public health service is the focus of my empirical study. Although these events are at the heart of the crisis, it must be understood that they do not provide a holistic picture of the pandemic's full impact. They also do not provide an exhaustive account of people's experiences in the county.

I now provide a detailed description of the pertinent empirical case.

5.4. Case Description

The first case of infection in Agder was confirmed on 09 March 2020. Early reports indicated a high mortality rate for older patients, a vulnerable patient group enrolled in the welfare technology project. This group's plight caught the attention of the team working on the digital follow-up project. This signalled the beginning of an innovation project, one that is still unfolding in Agder County.

As mentioned, digital follow-ups had been in use for a while, but a COVID-19-specific clinical protocol obviously did not exist. The current service model requires manual distribution and logistics. It was not a scalable model, which was not ideal for catering to the projected numbers of COVID-19 patients. The hospital system needed to be buffered from floods of patients. But it was also important to ensure that patients received the expected level of care. Several revisions and changes needed to be considered. At least three stand out:

1. A new patient screening algorithm for COVID-19 patients was required.
2. The ‘service kit’ comprising a tablet and select medical biosensors needed further consideration.
3. Digital follow-ups were initially designed for and used by an older adult demographic. This needed to change for COVID-19 patients.

A team of medical doctors, technology vendors, and other county resource providers participated in developing a suitable algorithm. Extended information gathering was also conducted. This channelled emerging and verifiable data, statistics, and information about signs and symptoms from mainstream sources (such as the World Health Organisation and the Norwegian Health Directorate). The digital follow-up process was updated, and the new COVID-19 module was deployed by 19 March 2020 (a mere three weeks after the first reported cases). Although the Agder County project team decided to develop a COVID-19 module, the choice to implement it was made at the municipal level. Following a March 2020 lockdown and an infection peak in April 2020, the first infection curve in Norway flattened. Things stabilised somewhat as the country headed into summer. The project team used this brief intermission to consult with their wider networks and make further adjustments and requirements in anticipation of the next infection wave.

The second wave occurred during the fall and winter of 2020. The infection curve steadily rose from October 2020, peaking in November and December 2020. From this time onward, municipalities and county hospitals used the repurposed digital follow-up protocol.

The third wave of infections occurred in the spring of 2021 and peaked in April 2021. The new waves were characterised by the emergence of new virus variants.

Digital follow-ups were available and used to varying degrees in various municipalities during the infection waves. The government also implemented stricter measures to slow down the spread of infection. They notably restricted gatherings and closed non-essential businesses. Since the third wave, infections in Agder have remained relatively low. That said, new variants could emerge as the virus continues to spread and mutate.

The focus of my empirical study is twofold:

1. The design, development, and deployment of the COVID-19 module.
2. The processes, routines, and procedures followed during the organisation, innovative development, and use of the digital follow-up tool.

Figure 5-3 provides a timeline highlighting the relevant empirical case's key phases (between February 2020 and March 2022). The timeline represents a logical sequencing of pertinent activities during that time. I have arranged the relevant events into three distinct phases: (1) initial preparation and response, (2) recovery/resolution, and (3) evolution. This is a simplified and linear depiction of the key activities and events. The actual execution was naturally more iterative and complex.

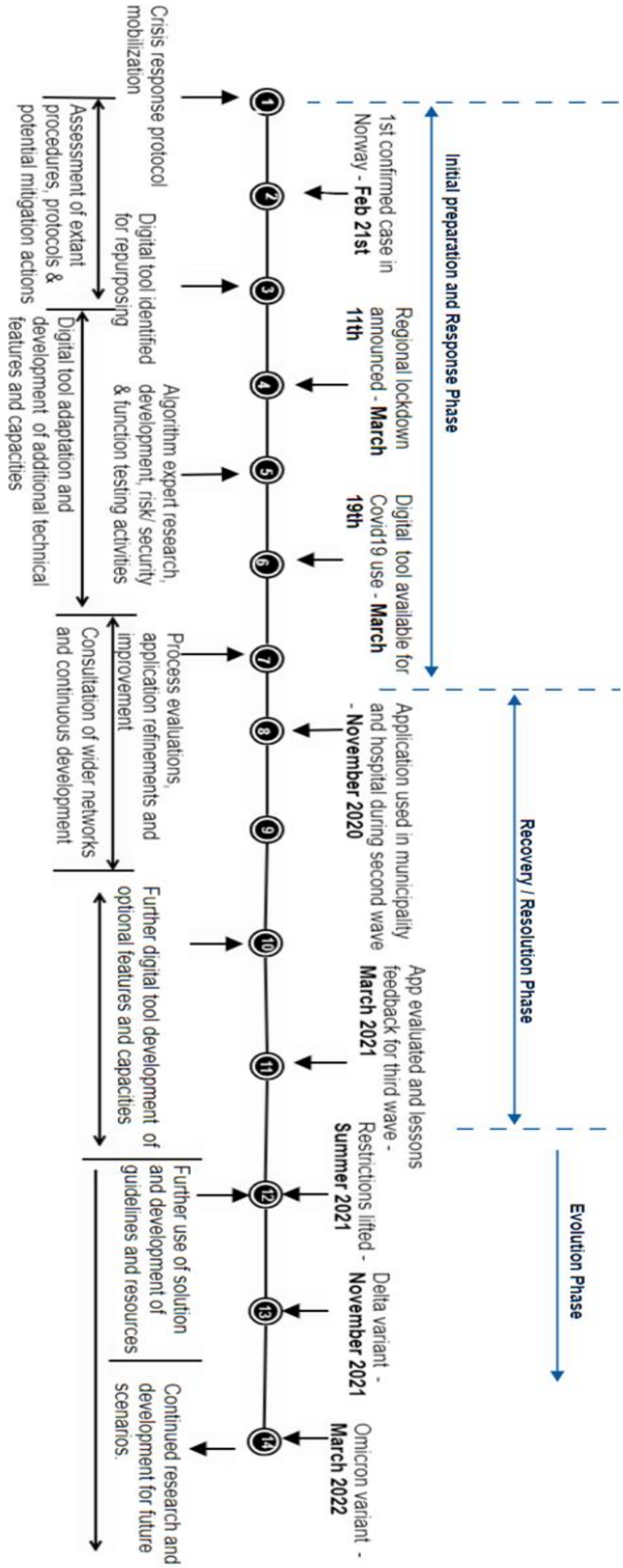

Figure 5-4: Timeline of CPSS development events

5.5. Chapter Summary

In this chapter, I described the relevant empirical case, specifically the highlights and challenges involved when integrating CPSSs during crisis response efforts. I focused on the use of a CPSS in response efforts related to the COVID-19 pandemic in Norway's Agder County. I also discussed Norway's health sector, shedding light on Norwegian health services' structure and functioning.

I contextualized the roles played by various digital initiatives and strategies implemented across the Adger health sector to address challenges leading up to and occurring during the pandemic. My overview of Agder's digital response to COVID-19 serves as a foundational understanding for subsequent chapters. It, in turn, contributes to a broader understanding of the implications when CPSSs are used in OCSs more generally.

In the next chapter, I summarise the five research publications contributing to my thesis.

6. Research Publications

I now give an overview of the research papers included in this thesis. Table 6-1 presents a list; full-text versions are available in Appendix B. The papers are numbered in the order in which they contribute to the thesis.

The five papers are standalone publications and make individual contributions. In this chapter, I will, nonetheless, discuss how they contribute to my overall thesis. As mentioned in Chapter 1, I will reflect on these papers in three phases:

1. Initial response (Papers 1 and 2).
2. Recovery and resolution (Papers 3 and 4).
3. Learning and evolution (Papers 3 and 5).

Excepting Paper 4, all the papers are empirical and follow the case described in the previous chapter. Paper 4 is primarily conceptual. It implements a bibliometric approach with illustrative empirical cases drawn from publicly accessible secondary data in the smart health and transportation sectors.

Table 6-1 lists the respective authors, titles, and publication outlets. In the proceeding sections, I will provide some details about each publication, specifically insights into each one's focus, analysis, and findings.

G. Table 6-1: Overview of research publications

	Publication	**Outlet**
1	Magutshwa, S. and Radianti, J. (2022). Is this Digital Resilience? Insights from the Adaptation and Exaptation of a CPSS.	*Proceedings of the 55th Hawaii International Conference on System Sciences (HICSS).*
2	Magutshwa, S. (2022). Rethinking the Improvisation of Digital Technology: A Niche Construction Perspective.	*Australasian Journal of Disaster and Trauma Studies*, 26, 235–251.
3	Magutshwa, S., Aanestad, M., and Hausvik, GI. (2022). Beyond Crisis Response: Leveraging Sociotechnical Transformability.	*Proceedings of the 13th Scandinavian Conference of Information Systems (SCIS),* Helsinge, Denmark.
4	Magutshwa, S. and Radianti, J (2021). A Qualitative Risk Identification Framework for CPSS.	*Proceedings of the 18th International Conference on Information Systems for Crisis Response and Management (ISCRAM).*

5	Magutshwa, S. and Radianti J. (Under review). Digital Resilience in Action: Cultivating positive Recovery Outcomes.	*Pacific Asia Journal of the Association of Information Systems.*

6.1. Phase 1: Initial Response

Papers 1 and 2 are based on P1 activities (Table 4-1) in the data generation process conducted from June 2021 to November 2021. In my empirical case's P1 phase, clinicians and organisations administering health services had faced an uncharacteristically challenging period. This was typified by significant patient load and institutional pressure. Papers 1 and 2 narrate the early preparatory and response activities taken in Agder County from two different perspectives – preconditions for actions and intervening actions (see figure 4-3).

6.1.1. Paper 1: Identifying the Pre-Existing OCS Conditions for a Resilient Crisis Response

Magutshwa, S. and Radianti, J. (2022) Is this Digital Resilience? Insights from the Adaptation and Exaptation of a CPSS. *Proceedings of the 55th Hawaii International Conference on System Sciences (HICSS).*

Focus

In Paper 1, we assess pre-existing conditions in the relevant health OCS that led to some of the initial response efforts. We set out to understand the underlying OCS potentials, factors, and attributes that facilitated the adaptation and reuse of the CPSS-based digital follow-up tool at the onset of the pandemic.

Reflections

Our findings highlight how developing the COVID-19 module was unanticipated. In answering SRQ1 (How are CPSSs adopted, integrated, and repurposed in OCSs during crises?), we find that repurposing the digital follow-up tool bridged disruptions and eliminated some constraints related to care continuity (Magutshwa et al., 2022).

A project team in the Agder region identified the digital follow-up tool's potential relevance and took initial action in developing the COVID-19 module. They relied on a pre-existing network of collaborators. The presence of boundary pushers (or 'visionaries') and a versatile staff complement was instrumental in the OCS's initial crisis mobilisation and willingness to explore novel clinical pathways for delivering care to COVID-19 patients over the long term.

We also apply the 'digital resilience' lens to answer SRQ2 (Which organisational capacities are necessary when utilizing CPSSs to deliver critical services during crises?). In doing so, we assume the capacity perspective to resilience, defined as "a suite of adaptive capacities that self-organise in response to a changing environment" (Norris et al., 2008). OCSs' capacities (preconditions) are enacted during resource mobilisations facilitating decision-making. They also boost operations and reduce risk in the face of unknowns. This is a *resilient* response.

The theoretical reflections in this paper broach a key insight, one that has two components:

1. An understanding of digital resilience as an embedded OCS capacity triggered by an exogenous shock.
2. A deeper insight into the enactment of digital resilience in OCSs through observations of the supporting processes of adaptation and exaptation.

Spontaneous opportunities are realised during ongoing adaptations, thereby revealing novel evolutionary pathways. Not only was the system adapted for a new purpose, but there were notable and fundamental changes in its use.

6.1.2. Paper 2: Identifying Short-Term Innovations, Revised Techniques and Routines in an OCS for Resilient Crisis Responses

Magutshwa, S. (2022) Rethinking the Improvisation of Digital Health Technology: A Niche Construction Perspective. *Australasian Journal of Disaster and Trauma Studies*, 26, 235–251.

Focus

In Paper 2, I focus on identifying the improvised processes and routines that (a) emerge due to an ongoing crisis and (b) were enacted in the relevant OCS as the COVID-19 module was developed. I also trace the core processes implemented in the relevant OCSs' crisis repertoire and the pursuant activities that led to positive outcomes.

Reflections

In Paper 2, I attempt to answer the following research question: "How does the radical improvisation of digital health technologies emerge and develop during a health crisis?" In doing so, I offer a novel conceptual model of the embedded processes and activities followed during the innovative development of the COVID-19 module. Empirical evidence suggests that a crisis triggers dormant OCS capacities and that this, in turn, leads to improvised routines and innovative responses. The four main processes I identified are as follows:

1. *Perception of a threat under tentative crisis conditions*. This addresses OCSs' self-assessments of preparedness and actions taken in anticipation of the first COVID-19 infections.
2. *Identification of potential mitigation and fortification actions*. This addresses (a) the activation of crisis response protocols and (b) their supplementation with revised techniques and routines prior to the first wave of COVID-19 infections in Norway.
3. *Design and continuous structure and resource refinements*. This addresses the technical requirements and adjustments made for the COVID-19 module.
4. *Implementation and post-crisis adjustments and developments.* This addresses (a) decision-making related to the COVID-19 module tool's use in municipalities and (b) the continuous learning required in the changing environment created by waves of infection following the first wave.

The tracing of these processes during the data-generation phase (P1) produced a logical sequence of the key steps and processes followed in the relevant OCS (see Figure 5-4). Paper 2 contributes to a deepened understanding of how OCSs simultaneously respond to crises and integrate crisis learning into their policy and resource fortifications for the future.

The theoretical analysis in Paper 2 frames the improvisation of routines and processes to repurpose a CPSS as a niche construction. This is an evolutionary process where the environment creates acute conditions that steer the evolutionary direction along an unanticipated trajectory (Arthur, 2009). The pandemic created a 'hostile' environment for the OCS. In a matter of weeks, there were resourceful, short-term innovations. There was also the adoption of new knowledge and new techniques and routines. This was all observable as the OCS coordinated the

COVID-19 module's development, a development that occurred at a previously unimagined pace. This in itself was an anomaly in the health sector (a sentiment echoed by interview participants). Papers 1 and 2 inform the thesis in several ways (see Figure 6-1). Specifically, they provide insights into the OCS's positioning before the onset of the crisis and the mitigating actions addressed (SRQ1).

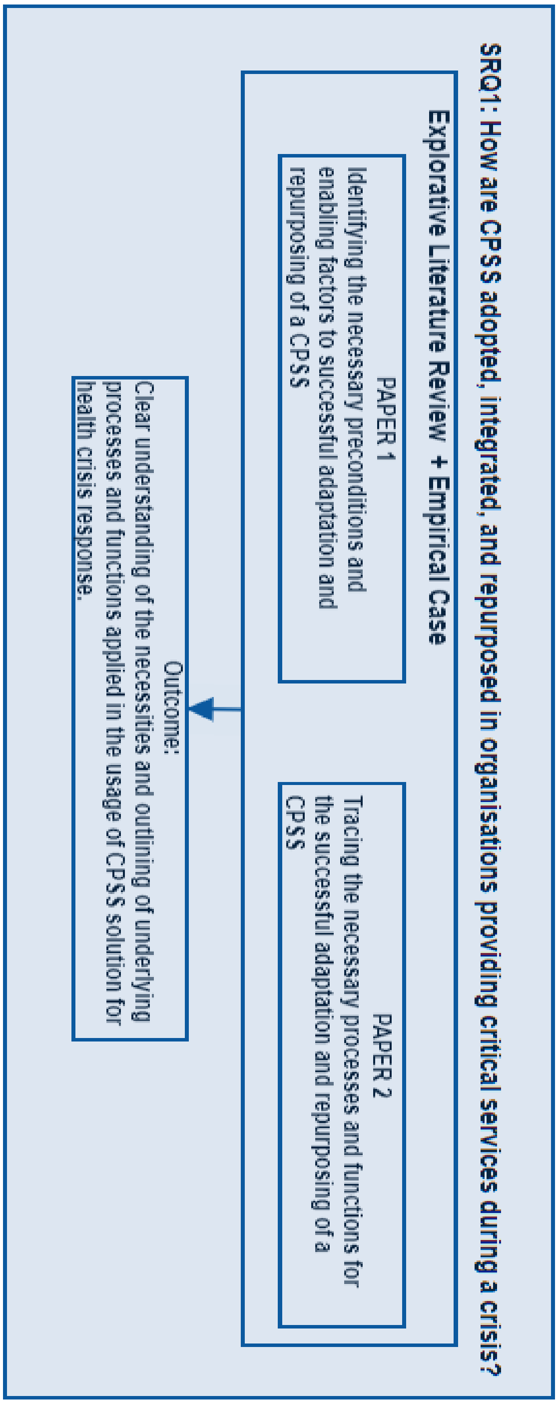

Figure 6-1: Papers 1 and 2's contributions to answering SRQ1

The enabling factors and preconditions identified and discussed in Paper 1 provide insight into the circumstances that foster responsiveness in OCS environments, which is a prerequisite for a pragmatic study. Pre-crisis conditions and operations have a direct impact on OCSs' capacity to generate adequate crisis responses. The positive recovery outcomes realised in this case might not have been realised without (a) constructible CPSS technology, (b) pre-existing relationships with vital stakeholders, (c) a versatile staff complement, and (d) positive psychosocial attitudes to health technology.

Both papers have an evolutionary 'flavour' to them. We apply evolutionary micro-processes to deepen our understanding of the initial OCS response efforts observed in P1. Papers 1 and 2 are vital for my characterization of digital interventions. They are also vital for understanding how pressured selection during a crisis is enacted in an OCS to secure preparedness for impending crises.

6.2. Phase 2: Recovery and Resolution

In addition to earlier data generation activities, Papers 3 and 4 are based on data generated in P1 and P2 from November 2020 to January 2021 (Table 4-2). At this stage, the OCS had undergone extensive changes in its attempts to bridge the operational disruptions the pandemic had caused. In P2, the OCS routines and operations displayed clear progressions toward care continuity for COVID-19 patients. Papers 3 and 4 narrate a range of responsive and continuous adjustments related to the challenges and user requirement shifts that occurred as new virus strains emerged.

6.2.1. Paper 3: Combinatorial Innovations and their Long-Term Retention in OCSs

Magutshwa, S., Aanestad, M., and Hausvik, G. I. (2022). Beyond Crisis Response: Leveraging Sociotechnical Transformability. *Proceedings of the 13th Scandinavian Conference of Information Systems (SCIS),* Helsinge, Denmark.

Focus

Paper 3's underlying premise involves a duality related to how a crisis can present itself as both a calamity and an opportunity. In this paper, we follow the development of COVID-19 module functionalities and care procedures (as coordinated in the relevant OCS). The OCS underwent an orientation shift from simple crisis response to differing implementation strategies selected by municipalities based on varying needs, internal structures, and defined processes.

The virus continually 'reinvented' itself via new strains. We, consequently, sought insight into the capabilities an OCS requires when facing a future of non-reducible uncertainty and sustained vulnerability.

Reflections

Interviews during P2 and P3 revealed that there were various sentiments toward changes made to established routines and techniques when the OCS implemented short-term coping strategies. Our interest lies in positive crisis recovery outcomes, specifically those with the potential to shape and influence OCSs' future developmental trajectories. Our research question in Paper 3 is as follows: "What is required for organisations to transform in the face of disruptions and breakdowns?" Paper 3 reveals aspects of the short-term innovations the OCS coopted as coping strategies, specifically those that would likely be practically useful and worth carrying into the OCSs' future operations.

At this stage, definitive attitudes had formed in the OCS, and I identify these through (a) two municipalities (one large and one small) and (b) a regional hospital (both of which are featured in the relevant empirical case). The smaller municipality and the hospital decided to use the CPSS. After a few rounds of deliberation, the larger municipality opted out. The project team expresses a reluctance to deviate from the kind of less 'experimental' clinical care pathways often upheld by bureaucratic structures in larger municipalities. The smaller municipality and the hospital, in contrast, embraced short-term innovations that leveraged the COVID-19 module 'as designed'. The regional hospital assumed a long-term perspective regarding both (a) using the tool for monitoring end-stage COVID-19 infection patients and (b) the pursuit of further adaptations to the CPSS tool (notably for facilitating self-management in HIV patients). (I will discuss the theoretical implications of these different attitudes to coping strategies and the future in the next chapter.)

Paper 3 presents an analysis of the relevant OCS's processes and steps during the COVID-19 crisis. We find that transformative thinking was (and still is being) triggered by the (ongoing) crisis. Some organisational actors seem to think of the relevant changes in a temporary, 'crisis response' sense. However, project team members largely recognise how robust learning strategies and feedback loops are central to securing short-term recovery and long-term innovation retentions.

6.2.2. Paper 4: Processes for Identifying Iterative Risk and Determining Tolerable Risk for OCSs in Crisis

Magutshwa, S. and Radianti, J (2021). A Qualitative Risk Identification Framework for CPSS. *Proceedings of the 18th International Conference on Information Systems for Crisis Response and Management (ISCRAM).*

Focus

CPSSs often represent innovative solutions meant to assist in completing OCS operational routines. In Paper 4, we consider the potential emergence of novel risk due to innovations. We also explore resultant cybersecurity implications. We consider the adequacy of prevalent risk assessment approaches. We also question how the novel risk and vulnerability introduced by CPSS solutions in OCSs can be identified and understood.

Reflections

We attempt to answer the following research question: "In what way can a qualitative organisational risk approach to CPSS analysis provide useful insights into CPSS risk assessment approaches?" In doing so, we find that the nature of the risk introduced by CPSSs is pervasive. It can also infiltrate or emanate from other parts of an OCS. We, therefore, formulate a risk identification framework, one that attempts to capture and reflect such an assessment. Our intention is not to challenge prevailing risk assessment techniques. It is, rather, to offer a complementary step, one that can enhance what is already available.

Paper 4 represents an investigation and systematization of the system architectures, attributes, and security vulnerabilities of the CPSS technologies adopted in healthcare. We set out to achieve this by adopting a qualitative risk identification (Q-ID) framework. We interpret CPSSs as multi-layered organisation-wide sensor-based systems considering both tactical and strategic risk implications. The risk identification procedure comprises four distinct steps: (1) mission definition, (2) process identification, (3) vulnerability and threat identification, and (4) risk classification. This framework is pivotal for risk-based decision-making in OCSs, where determinations must be made regarding what should be immediately addressed versus what can be left to chance. This essentially involves determining acceptable risk levels.

A premise guiding the Q-ID framework's development states that resources, technological capabilities, and organisational processes can be both interdependent and result in cascading risk. The framework provides building blocks for understanding unforeseen risks and vulnerabilities arising when using CPSS solutions in OCSs.

The notion of risk is pronounced in the empirical case. Participants in P1 and P2 emphasised the importance of identifying and managing perceived risk. They also emphasised how determining acceptable levels of risk accelerated the development and implementation of the COVID-19 module while ensuring that it was safe, effective, and sustainable for both clinicians and patients. Technology vendors also expressed considerable commitment to the implementation of secure development procedures.

SRQ2 demands an exploration of the capacities OCSs utilise when leveraging CPSSs during a crisis. Papers 3 and 4 are intended as contributions to addressing this question (Figure 6-3).

Paper 3 highlights how innovative initiatives can generate variety and flexible reconfigurations in the OCS while still requiring support from the OCSs' decision-making structures. This symbiosis ensures that the relevant innovations are both adopted and scalable.

Paper 4 addresses the harmonisation of the (technical and non-technical) resources comprising CPSS solutions (such as the one seen in the empirical case). The risk identification approach proposed in Paper 4 illuminates how innovation can be a double-edged sword – solving a real world and potentially creating new risk. It also emphasises the importance of risk identification and tolerance in ensuring the progress of secure innovation projects and delivering positive recovery outcomes. SRQ3 ("Which novel risks and vulnerabilities might the innovative development and use of CPSS expose OCSs to?") aims to unpack emergent risks in CPSS environments. Paper 4 offers a literature-based reflection, one that questions how innovative CPSS uses in OCSs lead to unanticipated risks and exposures.

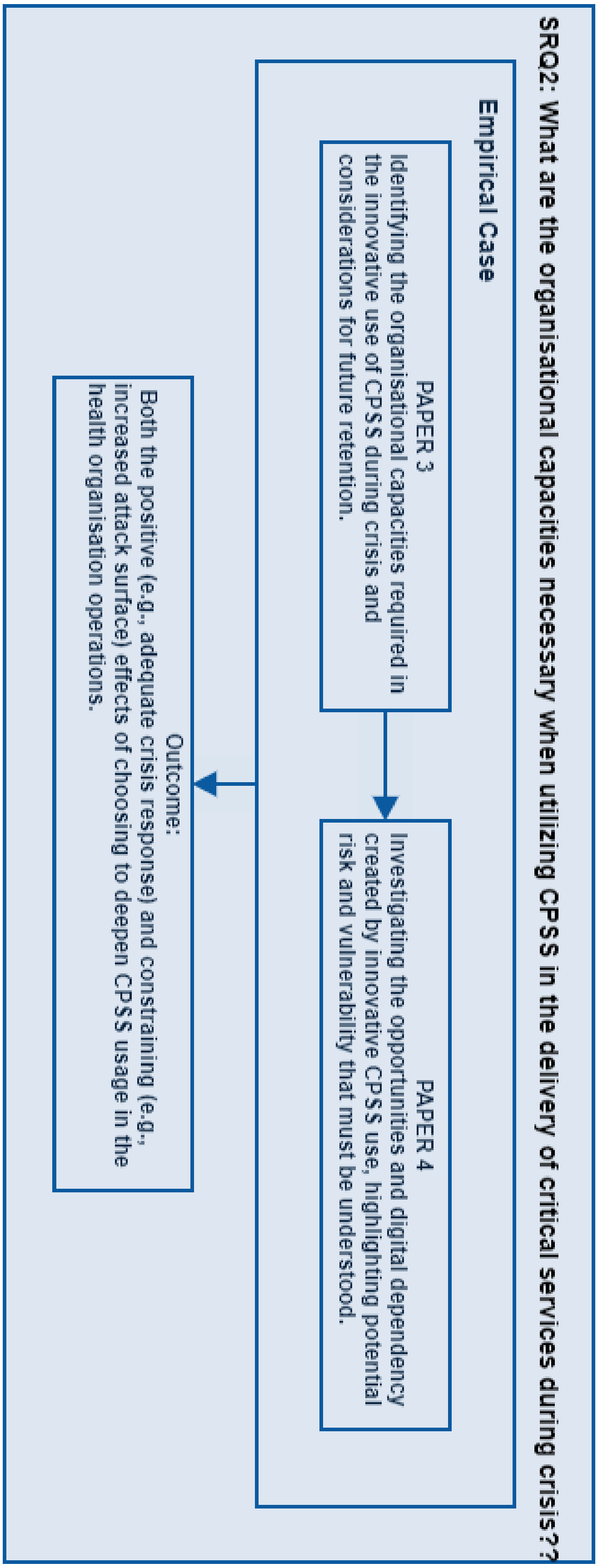

Figure 6-2: Papers 3 and 4's contributions to answering SRQ2

In Chapter 8, I reflect on the risks and vulnerabilities that can arise when deciding to evolve health services toward the increased use of CPSS solutions.

6.3. Phase 3: Learning and Evolution

In addition to earlier data generation activities, Papers 3 and 5 are based on P3 activities between January 2022 and March 2022 (Table 4-3). During P3, we encouraged participants to speculatively reflect on contributions the CPSS tool might make in the health sector's digital future. The participants' point of departure was often related to what made the OCS vulnerable in the past and how to best avoid such vulnerability in the future.

Participants readily described the CPSS tool's sought-after functionalities and potentially beneficial enhancements. They also identified support roles that the CPSS could play during future health service deliveries. This is narrated in Paper 5 (I have already discussed Paper 3).

6.3.1. Paper 5: Transformable Learning and Evolution in Resilient OCSs

> Magutshwa, S. and Radianti, J. (Under review). Digital Resilience in Action: Cultivating positive Recovery Outcomes. *Pacific Asia Journal of the Association of Information Systems.*

Focus

The final interviews conducted in Phase 3 of the data-gathering activities led to insights into how legacy systems facilitate solution generations in unanticipated future scenarios. Paper 5 focuses on the organisational technology, functions, and routines that secure OCS operations during ongoing crises. We distinguish the reused, novel, and sought-after functionalities that can help an organisation survive a crisis. Specifically, we highlight how the relevant OCS leveraged a CPSS to provide decentralised, simplified, and varied options. These options helped build up tolerance to the frequent and continuing waves of COVID-19 infections.

Reflections

We set out to answer the following research question: "What processes are implemented for resilient health organisations to realize benefits and improvement after recovery from major shock?" We conclude that the empirical case exemplifies a ‘growth while in chaos’ approach. We then conceptualise this as a positive recovery outcome of resilience.

In 2020, the technical aspects and components of CPSSs played a significant role. Unique constraints placed technology centre stage. Yet, as the crisis continued, there was a shift in focus from generating digital solutions to wider organisational adjustments based on new learnings. From 2021 onward, there has been a delicate balance between opportunity and challenge, one that must be maintained in OCSs to secure continuity and adaptation.

In Paper 5, we discuss how the CPSS tool (a digital asset of the OCS) has been leveraged in response to a crisis. We also consider the merits of this decision and explore the recovery outcomes. Our discussion of the core CPSS functionalities and processes accords with the analytic framework. As mentioned, there are three pertinent functions: (1) reused, (2) novel, and (3) sought-after. I will briefly explicate these in turn.

Reused functions

Reused functions are competencies and specific technical functionalities connected to the pre-existing CPSS tool. They were leveraged in the decision to pursue the adaptation and repurposing of the CPSS. Reused functions address remote symptom monitoring, rapid service deployment, and possibilities of malleability and flexibility during data collection processes.

Novel functions

Novel functions highlight the new functionalities and processes developed in 2020. They include (a) a software application with integrated secure user authentication, (b) concurrent improvised research, (c) user-led testing, (d) iterative solution developments, (e) strategic decision-making by health personnel through flexible and agile structural arrangements, and (f) care transition protocols for late-stage infections and patient recovery data gathering. These novel system functions and processes engendered expanded capacities and enhanced the overall service model.

Sought-after functions

Sought-after functions are the features and processes that stakeholders identified as potentially beneficial enhancements to the system feature suite. These include the following:

- Reduced system fragmentation through seamless CPSS solutions and national health records systems integrations.

- Enhanced support for health personnel through assistive technologies and process innovations. This is to counter anticipated future healthcare worker shortages.
- Security models that can consider social aspects of a CPSS solution for a deeper understanding of apropos risks and vulnerabilities.

Based on the novel and sought-after functions, we came to a twofold conclusion: (1) a crisis can be beneficial as its intensity increases and (2) an OCS can realise positive recovery outcomes leading to long-term evolution.

6.4. Chapter Summary

In this chapter, I reflect on the contributing research papers. This involved a brief outline of each paper's individual focus and its contribution to the thesis. I focused on establishing a common thread connecting the publications and establishing a collective meaning. I also offered insights into how the papers contribute to filling gaps related to answering SRQ1–SRQ3.

In the next chapter, I detail the development of my thesis' primary contribution. This is a model of the evolution of a DI in a state of unstable equilibrium.

7. Modelling an Evolving DI in a state of Unstable Equilibrium

Before the COVID-19 crisis, the OCS in Agder was relatively stable. However, the crisis perturbed its equilibrium. To restore equilibrium, the OCS updated a pre-existing CPSS (the digital follow-up tool). This was done through several rounds of changes to the algorithm and implementation strategy. These changes secured patient services and helped offset the health crisis' impact, ultimately restoring equilibrium (at least to some significant degree).

It is important to note that the changes made to the CPSS mean that the OCS is no longer stable (in conceptual terms). It is, instead, in a state of unstable equilibrium. Updates to the CPSS over the course of different infection waves continuously altered (and might still alter) the state of the OCS. Arguably, it will never return to its original state. The OCS remains in perpetual flux; it traverses periods of stabilisation and destabilisation, never achieving stable equilibrium (Fischer & Baskerville, 2022). In this thesis, I have conceptualized the OCS as a DI comprising technology, social systems (people), and physical infrastructure. The CPSS is a socio-technical arrangement of these components within the DI. It emerges from relationships between technology, organisational routines, and physical infrastructure. In sum, my empirical case exemplifies a DI in unstable equilibrium.

In Papers 3 and 5, we discuss the Agder municipalities' decisions related to implementing the CPSS in their locale. We observed three distinct types of response strategies in our study.

First type of response strategy

In the first instance, the smaller municipality elects to roll out the updated CPSS 'as designed.' Here, the municipality makes operational adjustments and adaptations to accommodate the revised care protocols that the CPSS solution provides 'out of the box.' I consider this to be a resilient approach. The municipality leans toward a combination of social and technical changes. These changes move it further from its original state, thereby contributing to the OCS's dynamic nature.

Second type of response strategy

In the second instance, the larger municipality requests further modifications to the CPSS. This is to ensure that it aligns with the municipality's predefined protocols and procedures for COVID-19 patient care. The use of the tool is then routed through GP's offices. This maintains the underlying principle that the GP is the primary patient caregiver. As before, the CPSS does not return to its original state. Although there is a limited degree of social change, I still consider this a resilient approach. In opting not to use the CPSS, the larger municipality limits further operational adjustments and explores use of other pre-existing clinical pathways (e.g., video consult) to secure equilibrium. They do not push for novel innovative changes instead pursuing optimised use of familiar and well-tested innovations with limited enhancements to the technology itself.

Third type of response strategy

The third instance involves a municipality completely refraining from using the CPSS solution. Decision-makers, instead, stick with adjusting the patient services that are already in place. Although the CPSS is available, they see no need to 'fix what is not broken' and do not think about technical change very much. They, instead, mostly focus on social change, which is more familiar. I consider this approach to constitute 'predilection with stability,' i.e., resisting change and limiting efforts to what is tried and tested, but it is still resilient. The relevant municipality must allow for some degree of change even if it decelerates and chooses a direction that is misaligned with the prevailing sentiment. Although a municipality following the third type of response strategy does not use the updated CPSS, it remains available (as a dormant capacity). This is because the municipality is part of the OCS.

Ultimately, the OCS deploys the CPSS to create new opportunities for municipalities to explore when deliberating their crisis response strategy. The OCS is prepared to and must accommodate any of the above three approaches, which it does. The empirical case exemplifies how the OCS learns, adapts, and capitalises on an accumulation of short-term innovations to maintain secure operations during a crisis. The three response strategies necessary for acquiring new knowledge and establishing new routines and techniques. These allow the OCS to restore balance and secure temporary stability in its operations during an ongoing crisis.

In conceptual terms, the DI (the OCS) orchestrates a socio-technical arrangement to restore equilibrium and secure temporary stability. This is only possible due to pre-existing and inherent capacities (the CPSS, a diverse staff complement, and the like). These capacities facilitate a pivot from destabilisation and disequilibrium to continuous change and ultimately evolution.

Innovation, adoption, and scaling are known generative mechanisms of DI evolution (Henfridsson & Bygstad, 2013). Nonetheless, the operationalisation of accumulated innovations in a DI due to a crisis (as seen in my empirical study) constitutes a novel observation. It is an observation of the relevant generative mechanisms being actualised in the face of a crisis.

There is a distinction between equilibrium and stability in the unstable equilibrium model (Harder Fischer & Baskerville, 2018). This distinction informs my understanding of (a) why the DI never truly reaches stable equilibrium and (b) how it continues to change in its state of unstable equilibrium. The changes that were made to accommodate the municipalities' various needs reflect how a DI in unstable equilibrium resorts to dynamic resiliency as a necessary capacity when navigating intermittent periods of stabilisation and destabilisation. This insight means that my thesis is nicely positioned to contribute to the current understanding of DI evolution and generative change. This occurs specifically via a model of how a DI in a state of unstable equilibrium operationalises resilience to restore equilibrium and secure temporary stability.

In this chapter, I discuss this thesis' main research question (How do OCSs innovatively develop and use CPSSs when responding to crises and evolving toward secure operations in unstable environments?). In doing so, I will outline a dynamic resilience model for DIs. This involves going a step beyond simply identifying the mechanisms of DI evolution and addresses how those mechanisms actualise. I would like to think that my model represents a necessary contribution to the IS domain, current research work, and the topical literature.

I now propose an integrated model, one that identifies and explains DI evolution in terms of multi-level, dynamic, and socio-technical change. Contra prior recovery-oriented models, dynamic resilience does not emphasise stability. It does not involve a return to a prescribed 'normality' per se. Instead, it involves a suite of capacities facilitating a dynamic state of constant adaptation. This adaptation reconfigures and rearranges DI components during a crisis.

In the proceeding sections, I will describe the development of my dynamic resilience model's various phases.

7.1. Toward Dynamic Resilience

I now identify and formulate the nested resilience processes in DI operations during a crisis. I do so based on the empirical findings discussed in Chapter 6. I am also guided by both Boh et al.'s (2023) conceptualisation of resilience (Figure 3-1) and Sakurai's (2021) model (Figure 7-1). As in Chapter 6, I will arrange my model development into three phases: (1) initial response, (2) recovery and resolution, and (3) learning and evolution (Sakurai, 2021). I will discuss these phases and the sub-activities through which dynamic resilience is operationalised in the next three subsections.

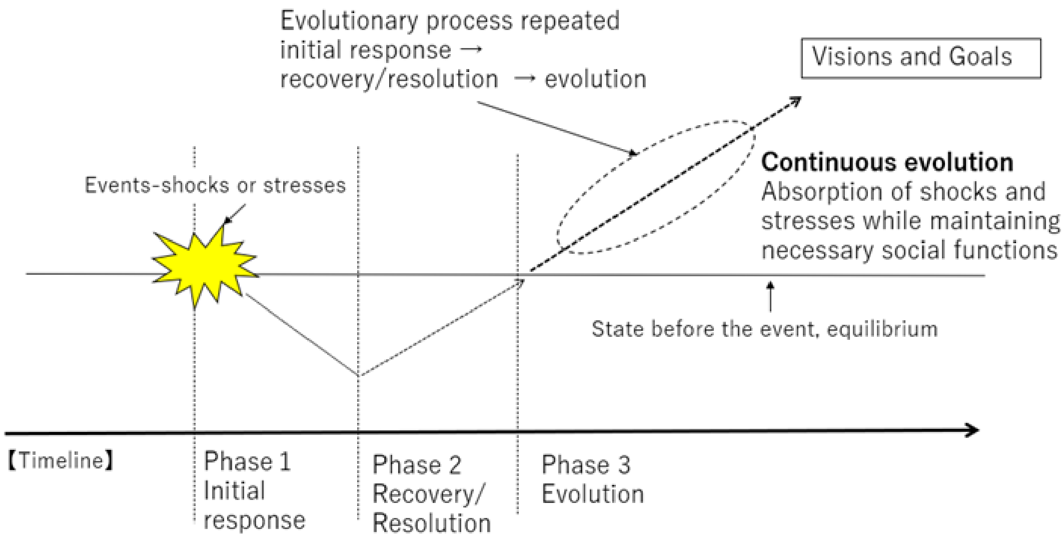

Figure 7-1 Sakurai's phases of resilience

7.1.1. Phase 1: Initial Response

The first phase is derived from Papers 1 and 2. Initial response is characterised by the onset of a crisis (a destabilising contextual force). The crisis is perceived as a threat to the DI, which forces it into a process of **pressured selection**. Pressured selection is the first stabilising process enacted in the DI. It serves to identify available resources for securing operations and counteracting the destabilising force. The stabilising process is enacted through the nested processes of *preparedness, spontaneous responsiveness, and skills development.* The nested processes detail how the stabilising process (in this case pressured selection) is operationalised.

Preparedness

Preparedness refers to the mobilisation of pre-existing knowledge, techniques, digital assets, and established routines anticipated to be useful for countering constraints caused by a crisis. In Paper 1, we identify the preconditions for the relevant CPSS's successful adaptation (discussed in Chapter 6). These preconditions essentially embody preparedness in the DI.

The nested process is comparable to an inventory checklist, an assessment intended to (a) determine what is readily available in the DI (inventory) and (b) what the crisis demands of the DI so that the latter can not only survive but also thrive. Preparedness involves identifying and erecting consequence-reducing barriers while incorporating *spontaneous responsiveness* to ensure successful outcomes.

Spontaneous responsiveness

Spontaneous responsiveness is triggered following the sensing of constraints or challenges that go beyond the scope of existing digital assets, techniques, and established routines. The purpose of *spontaneous responsiveness* is the rapid formulation of improvised routines and short-term innovations. Speed is an essential ingredient, and human sensors are instrumental for continuously sensing contextual forces, revising routines, and formulating new techniques.

In Paper 2, I discuss the changes necessitated by the realisation that an impending crisis will be very demanding on an OCS. A series of actions are taken to counterpoise a perceived deficit (during *preparedness*) in available resources. Such efforts relate to the adaptation of the affected operational routines (physical patient care in my case). This extends to a revision of roles, decision-making protocols, and structures in the OCS. Paper 2 details instances where the OCS project team and technology vendor made exceptions (such as changes to their regular working methods) when attempting to deliver the COVID-19 module in the shortest possible time.

There is also an underlying symmetry between the idea of responsiveness and the notion of exaptation (discussed in Paper 1). Exaptation is an evolutionary micro process necessitated by the need to cope with novel environmental constraints. It leads to the subsequent use of otherwise dormant secondary features (Magutshwa & Radianti, 2022). This behaviour is consistent with the notion of **pressured selection**. During *spontaneous responsiveness*, the aim is to leverage resources to generate necessary and novel short-term innovations, techniques, and improvised routines. A notable outcome of this nested process is the identification of skills gaps that necessitate capacity building and *skills development*.

Skills development

Skills development is naturally a key activity in the relevant context. It actively supports *preparedness* and *responsiveness* efforts through optimising human capabilities. Human sensors, a diverse staff complement, and boundary pushers (discussed in Paper 1) are instrumental during an OCS's threat perception response efforts. In Paper 2, I note the ongoing expansion of human capabilities as the CPSS innovation project progressed. This represents a spontaneous response, one that is meant to address the challenges that the COVID-19 crisis posed.

A DI's social systems change and evolve during *skills development*. This allows for the forging of new pathways and the realisation of necessary and novel short-term innovations, techniques, and improvised routines. Essentially, skills development involves upskilling a DI's social components. This upskilling has a direct impact on the DIs' progression and learning we observe in later phases of crisis response efforts.

In sum, *Preparedness*, *spontaneous responsiveness*, and *skills development* are nested processes of pressured selection. The DI operationalises **pressured selection** in response to destabilising contextual forces (a crisis). This, in turn, paves the way for restoring equilibrium.

7.1.2. Phase 2: Recovery and Risk Identification

A DI might be at equilibrium following the onset of a crisis and resultant response efforts. This equilibrium will, though, be unstable due to adaptive changes. A key assumption here is the high likelihood of further destabilisation. This means that the DI must recover and reach a level of resolution, one that maintains the state of unstable equilibrium. Here, the failure of specific functions (e.g., traditional, in-person patient monitoring) does not necessarily lead to a systemic failure (as in, e.g., cases of patient service denial).

To attain unstable equilibrium, a DI must operationalise **variation**. This involves consolidating short-term innovations, adopting new skills, and reviewing improvised routines and techniques. The goal is to establish a replicable crisis recovery protocol. This can be completed via the nested processes of *reflective anticipation and risk identification*.

Reflective anticipation

During *reflective anticipation,* an assessment of crisis response experiences informs decision-making related to the selection of viable modifications and reconfigurations of established routines and techniques. The purpose of *reflective anticipation* is to review accumulated innovations generated in the initial response phase. The goal is to determine useful crisis initiatives that can anchor the recovery process or potentially contribute to stabilising future digital entities (Magutshwa et al., 2022). The flexible arrangement of components in a DI provides the flexibility needed to derive a catalogue of options (accumulated innovations). These are the options available to a DI when it attempts to restore equilibrium and ensure reduced susceptibility to future destabilisations.

Recent experiences are the basis for *reflective anticipation*. However, contemplating future scenarios ensures that the relevant OCS retains enough variation to accommodate a range of (foreseeable and unforeseeable) circumstances.

Risk identification

Reflective anticipation aids in the selection of viable modifications. However, identifying short-term innovations, adopting new knowledge, and revising pertinent techniques demands a *risk identification* and mitigation process. *Risk identification* involves proactively surveying what might pose a direct threat to both achieving the restoration of equilibrium and the DIs' operational objectives. This is an iterative process where positive outcomes are realised through building redundancy, accumulating diversity, and acquiring a propensity for failure (Magutshwa & Radianti, 2021).

It is, of course, not possible to avert all risks. That said, one can (a) establish tolerable levels of residual risk to mitigate against future disturbances and (b) plan for that which is unanticipated ('known unknowns'). Essentially, to realise recovery, a DI must successfully build up what we might call 'passable tolerance.' This involves a DI's inherent instability and potential failure being continuously shaped and shifted from one digital configuration to the next despite sustained instability.

The dual function of *reflective anticipation* and *risk identification* serves to operationalise the process of **variation** during a crisis. This restores the DI's equilibrium and enhances reduced susceptibility to future destabilisations.

7.1.3. Phase 3: Transformability and Evolution

When in unstable equilibrium, a DI is in perpetual flux. It never reaches stability, but it can sufficiently recover to restore equilibrium. Following recovery, the infrastructure switches into a cycle of learning-based formative change aimed at the **retention** of new skills, knowledge, and resilience to future crises.

Technology evolution theorists have documented how an artefact can be invented by building on knowledge associated with previous artefacts or documented techniques and routines (Ziman & Ziman, 2003). Phase 3 describes how an unstable DI – one that has restored its equilibrium – evolves through the nested processes of *proactive transitions* and *learning.*

Proactive transitions

There are periods of experimental transformability during *proactive transitions*. These have the sole purpose of expanding the DI's capacity. This process serves to influence and structure changes integrated into the DI during long-term *learning*, which, in turn, engenders evolution.

It is not entirely possible to demarcate *proactive transition* and *learning*. This is because, in my view, these processes are complementary. They create an infinite loop, one that is active throughout phase 3. *Proactive transitions* inform the learning process and past learnings influence future *proactive transitions*. This exemplifies an iterative process.

Transformability is a precursor to evolution. Here, a DI experimentally reconfigures accumulated innovations, new skills, and knowledge prior to effecting long-term changes. Changes realised during transformability are, consequently, highly flexible, and adjustable. They are largely meant to tide the DI over the crisis and extract pertinent learning points.

Learning

Learning is distinguishable from the adaptation seen during pressured selections based on predefined structures. *Learning* forms new emergent structures, structures that were previously unknown (Johnson and Gheorge, 2013). *Learning* also informs *proactive transitions* and operationalises anticipatory capacities, which is necessary for the realisation of *transformability* (Magutshwa et al., 2022).

In paper 3, we discuss how transformability is one of DIs' known capacities. It is instrumental to positive recovery outcomes where both current entity and future digital entities are strengthened. Although recovery-centred change is a relatively simple coping process, long-term change and evolution require both time and careful strategizing.

In sum, we can think of *proactive transition* and *learning* as the chisel and hammer that foster the **retention** of accumulated innovations and lead to DI evolutions.

7.2. An Integrated Framework for Dynamic DI Resilience

In this section, I integrate the above three phases into a conceptual framework, one that describes the relationships between the processes in and outcomes of DI evolution.

My model potentially advances IS theory by extending knowledge of the high-level processes (pressured selection, variation, and retention) that are triggered by a crisis and enact DI evolution. My novel contribution involves documenting the nested processes described in Phases 1–3. These nested processes describe (a) how pressured selection, variation, and retention actualise in DIs and (b) how this leads to a recombination of the infrastructure, knowledge, and techniques used during prior problem-solving endeavours.

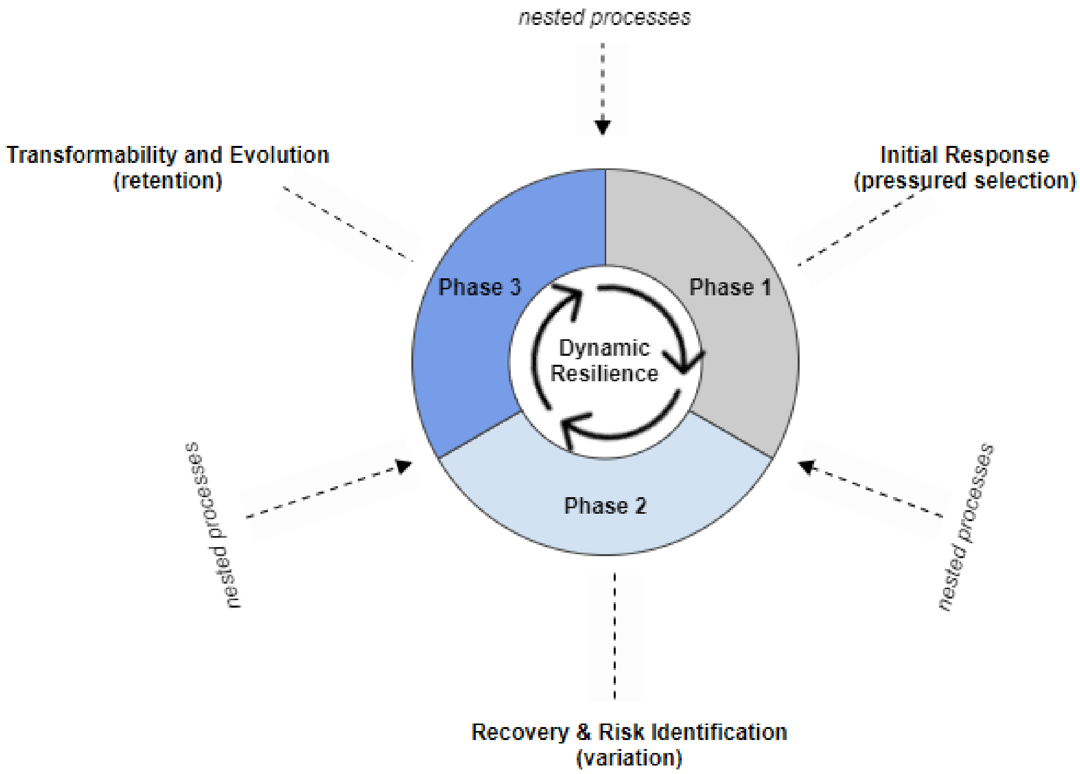

Figure 7-2 A static snapshot of dynamic resilience

Figure 7-2 illustrates a single instance (a 'snapshot') of dynamic resilience. This can be likened to an isolated disruption, one in which the DI goes through the various phases in a closed and cyclical manner. Sakurai's framework (Figure 7-1) is a linear depiction of what I envision to be cyclical. This claim is based on observations in the relevant empirical case. There, most processes, and routines appear to be iterative, with no demarcated start/stop sequence.

While Sakurai (2021) focuses on recovery and evolution, I introduce **risk identification** as both (a) a supporting process to recovery and t**ransformability** and (b) a precursor to evolution. The dynamism of the DI is rooted in a successful transfer of benefits leading to modifications and positive recovery outcomes. The DI strives to maintain a state of unstable equilibrium, where a temporarily stable configuration emerges and secures its operations. An accumulation of dynamic resilience iterations (Figure 7-3) goes beyond the static snapshot. It reflects the variety of digital configurations that emerge during sustained periods of stabilisation and destabilisation.

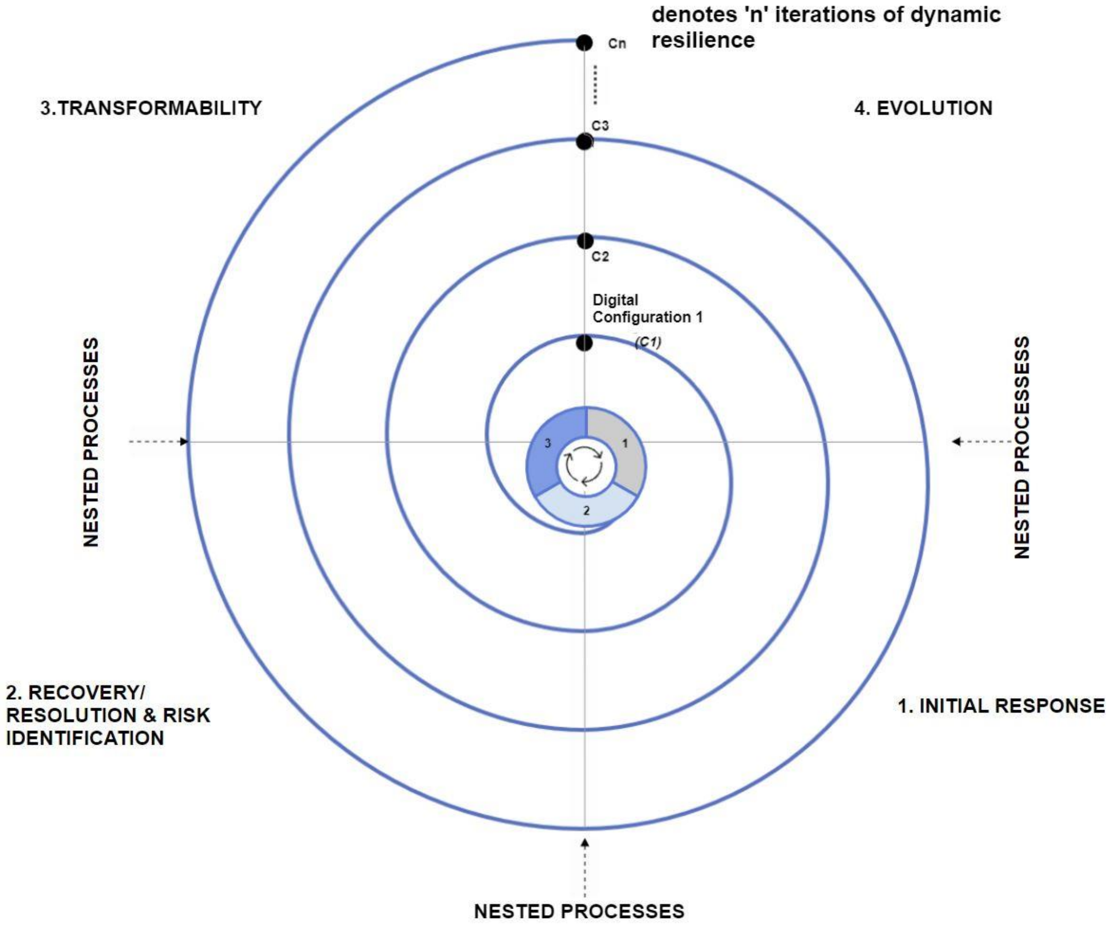

Figure 7-3 Modelling dynamic resilience (up to n iterations)

In the empirical case, the crisis is a contextual force destabilising the DI but also triggering stabilising processes. I contend that dynamic resilience is a stabilising process in DIs, one that facilitates initial response efforts and ensures equilibrium restoration. It also fosters the retention of new knowledge and accumulated innovations to secure future digital entities through evolution. If so, then we can consider MRQ to have been addressed in conceptual terms.

We can, moreover, gain a novel insight by viewing the DI's post-crisis state from the unstable equilibrium perspective. In punctuated equilibrium theory, stability is largely equated with equilibrium, and the restoration of equilibrium signals the end of a crisis and a return to stasis. It is possible to trace the stabilising processes using punctuated equilibrium as exemplified by similar studies of response efforts to the

COVID-19 pandemic (Boh et al., 2023; Liu et al., 2023). However, in using unstable equilibrium and understanding this key distinction between stability and equilibrium, my work goes a step further to show how stabilising processes are operationalised and in so doing identifies the nested processes.

There is also the matter of DI evolution and its intersection with generative change in the DI. Both evolution and generativity are driven by adaptation to changing environments. They are also both characterised by the emergence of new functionalities and capabilities not present in the original DI. That said, generativity focuses on the immediate future while evolution focuses on long-term progressions. The dynamic resilience model extends our understanding of the operationalisation of generativity and evolution in DIs.

Following recovery (equilibrium restoration), the DI learns through transformability. This is a documented DI capacity (Magutshwa et al., 2022). It is instrumental in positive recovery outcomes, outcomes where both current and future digital entities are strengthened. Transformability enacts immediate change and is critical for restoration and maintenance of equilibrium.

Digital configurations are outcomes of transformability. They also inform the selection of useful traits relevant to DI evolution. This insight bridges a conceptual gap between evolution and generativity in DIs; it confirms they are complementary processes.

A DI in unstable equilibrium exists in a state of transit. Dynamic resilience represents the stabilising processes. Nemeth et al. (2011) define systemic resilience as "the ability of systems to mount a robust response to unforeseen, unpredicted, and unexpected demands and to resume or even continue normal operations". Boh et al. (2023) define resilience as "the capabilities entities develop to absorb a major shock, adapt to disruption caused by such a shock, and transform into a new stable state, where entities are more prepared to deal with major shock".

Drawing from Nemeth et al. and Boh et al., I define **dynamic resilience** as follows:

> *A suite of* ***innate capacities (some active and some dormant)*** *that a digital infrastructure possesses. These capacities are* ***rapidly initialised*** *in response to a shock. This* ***restores equilibrium*** *and* ***secures temporary stabilisation*** *while* ***proactively transferring useful attributes****. This leads to*

*the entity's **transformability and evolution**, such that it **is less susceptible to future shock**.*

My model is useful in two ways:

1. It grants an understanding of the role and operationalisation of dynamic resilience in a destabilised DI to restore equilibrium and secure temporary stability through a series of stabilising processes.
2. It allows the identification and classification of the nested processes that actualise dynamic resilience in the DI.[3]

In the next chapter, I reflect on some of the practical implications of my study, specifically the use of CPSSs in OCSs. I discuss the increasing criticality of the roles CPSSs can play in a digital future and what this means for OCSs evolving in that direction.

7.3. Chapter Summary

In this chapter, I detailed my thesis' primary contribution. I outlined the concept of **dynamic resilience** and presented the **dynamic resilience model** for DIs in a state of unstable equilibrium. I discussed the model's architecture, outlining its key components, adaptive mechanisms, and nested processes. I also clarified resilience's role in the generativity and evolution of DIs. My model emphasises the dynamic nature of DIs experiencing destabilisation. It offers a scalable lens catering to various levels of infrastructural complexity.

I now conclude my thesis.

[3] According to Prout (1996), we can think of these processes as "the source of action regardless of their status as human or non-human".

8. Reflections and Conclusion

In this chapter, I summarise my thesis' motivation, objectives, findings, and implications. I also discuss my study's limitations and offer some recommendations for future research directions.

8.1. Thesis Summary and Contributions

The use of CPSSs and other digital assets by OCSs during the pandemic has been lauded as a resilient response. That said, the pandemic also exposed a fragility in these systems, nearly bringing health services to a halt. The crisis can be seen as both a disaster and an opportunity leading to short-term innovation and potential long-term OCS evolutions.

In this thesis, I examined a case in Norway's Agder County, where a CPSS solution was used in response to the pandemic. A pre-existing remote patient monitoring tool was adapted for monitoring COVID-19 patients. The pandemic was a unique learning experience and awakening to a previously unfathomed nature of crisis.

The use of CPSSs in OCSs is an example of DI evolution, which can be thought of as a 'balancing act' between destabilisation triggering change and stabilisation ensuring persistence. The COVID-19 pandemic can be thought of as representing bouts of destabilisation triggering stabilising processes in the relevant DI. These processes involve a recombination of digital assets, knowledge, techniques, and routines. This, in turn, represents the operationalisation of resilience leading to DI evolution. This view is supported by the IS literature, where resilience theory is gaining traction. This means that my approach deviates from the punctuated equilibrium model.

My study answers how OCSs innovatively use CPSSs to respond to crises and evolve toward secure operations in unstable environments. The dynamic resilience model clarifies the role of resilience in the generativity and evolution of DIs. The unstable equilibrium model captures the sustained destabilisation occurring during the pandemic. It provides a way to understand the 'balancing act' of continual stabilisation and destabilization through the operationalisation of resilience.

Theoretical Implications

One of my thesis' key contributions lies in identifying nested processes of dynamic resilience. These processes operationalise generativity and evolution in DIs. I defined dynamic resilience as follows:

> *A suite of* ***innate capacities (some active and some dormant)*** *that a digital infrastructure possesses. These capacities are* ***rapidly initialised*** *in response to a shock. This* ***restores equilibrium*** *and* ***secures temporary stabilisation*** *while* ***proactively transferring useful attributes****. This leads to the entity's* ***transformability and evolution****, such that it* ***is less susceptible to future shock****.*

My work provides insight into how DIs enact stabilising processes and leverage disruptive moments to initiate change and explore new technological and organisational directions. This begins work aimed at understanding how generative DI mechanisms – such as innovation, adoption, and scalability – actualise and lead to positive recovery outcomes.

Practical Implications

There is much to learn from the COVID-19 crisis. The level of uncertainty, the pace of change, and the cross-sector interdependencies we observed and experienced between 2020 and 2022 suggest that there is a likelihood of similar occurrences in the future. Preventative measures (which are the norm) proved to be inadequate. Decision-makers and policymakers in OCSs who use (or are exploring the use of) CPSSs should take steps to ensure preparedness for future crises that could pose similar challenges.

Research Limitations

The content of my thesis represents a reinterpretation of what I learned in the three-year period during which I completed my PhD. It has, however, not been the kind of linear process suggested above.

The pandemic disrupted the stability of research settings. In retrospect, I realise that I, myself, had to be 'resilient' while conducting my work. I had to make adaptations and adjustments throughout the process to accommodate terms dictated by the pandemic. The first reports from China of a novel virus occurred only eight weeks into my PhD. Although it presented an opportunity to study a unique occurrence, the pandemic has also limited my work quite significantly. In this section, I detail some of the challenges to and limitations of my study and how they might act as pivots for future research.

Data Collection

My study focuses on the Norwegian context and only includes experiences in Agder County. All data sources, narratives, and reports are likewise connected to the Agder region. Due to the decentralised nature of Norwegian healthcare administration, it is not possible to claim that this thesis represents experiences outside Agder.

Moreover, the emotional toll, stress, and uncertainty associated with the pandemic likely influenced the participants' responses and perspectives. Also, much time has passed since the data collection period. Although the impressions shared in this thesis were accurate at the time, they are potentially subject to change. This impacts the validity of the information provided during the interviews. I focus on only three municipalities in the Agder region, this is a small representation of the region, and my findings should be understood in this light.

I decided to use semi-structured interviews because of (a) the potentially rich narratives and (b) the opportunity to observe the interview subjects. The idea was that I would benefit from an understanding beyond mere words, one that also included non-verbal cues. However, lockdowns and social-distancing measures made it difficult to conduct face-to-face interviews. The absence of physical presence and a shared space likely impacted rapports from and trust-building with participants. Changing most interviews to a digital format limited the extent to which I could connect with and observe informants' demeanours and mannerisms.

Background Literature Selection

In answering sub-research question 1, my main objective in the literature review was to understand CPSSs and reveal experiences related to their implementation in the health sector. My literature search was mostly limited to CPSS-based remote patient care (primarily telemedicine). It could, however, have included specialist healthcare services (e.g., robotics), where other sensor technologies are used. This mainly occurred because of a dual focus on the solution and the nature of the problem. The result is that my literature review does not represent the experiences of all CPSS-based efforts in the relevant healthcare services. If the scope had been widened beyond telemedicine, then I might have obtained different results. This could, in turn, have affected my response to sub-research question 1. As such, the findings in my review could have been more insightful and relevant to furthering knowledge of the effectiveness of CPSS-based solutions in settings beyond remote patient care.

The Proposed Model

It is possible that I simplified an otherwise complex real-world problem when relationally interpreting the findings in my empirical data. I cannot be certain that my dynamic resilience model adequately captures the complexity of the enacted processes. I also cannot be certain that my assumptions hold in all contexts for all variables involved in the model. This may be pursued through the use of the model to view other CPSSs, in other crisis scenarios to validate the dynamic resilience model.

Although assessed against established theory, my proposed model's processes are yet to be compared with real-time data. The model is translatable to a practical implementation, but this requires specific data and expertise. These will hopefully be accessible in future research.

8.2. Future Research

My thesis findings open several research opportunities, opportunities that can further our understanding of resilience in DIs and how OCSs realise CPSSs' potential. Based on the contributions and limitations already discussed in this chapter, I now turn to opportunities for future research.

One of the main research directions in my thesis relates to determining how DIs securely evolve in a state of unstable equilibrium. I have observed a pattern for adaptation, learning, and transformation during a crisis and how these may be routinised in the long term. However, it has not been possible for me to capture the long-term routinisation in my work. This would only be possible through a longitudinal study, where gradual evolution can be observed. It is possible that other elements would emerge in such a study, elements that could provide a deeper understanding of dynamic resilience's operationalisation and long-term benefits.

The introduction of CPSS technology changes routines, the stakeholders involved, and service delivery incentives. I have observed how elements like power and control play out differently in the OCS when a crisis occurs, and resilience is salient. Although cooperative during the height of a crisis, decision-makers appear less willing to make 'radical' decisions when operations stabilise somewhat. Exploring dynamic resilience from a competence, leadership, and operational risk perspective could contribute to a deepened understanding of how these elements drive or inhibit resilience. It could make a valuable contribution to policy implementation.

There is also an opportunity to explore how CPSS-based systems in OCSs are designed and deployed. The findings in my thesis are useful for understanding the embedded processes and relationships that are enacted and enable the rapid generation of response efforts in a time-constrained context. Recognising other possible sources of disruption and how OCSs can leverage CPSSs would be useful in the design of CPPS-based systems with reduced susceptibility to (known and unknown) threats or crises. Notably, this could apply to the development of a novel design (kernel) theory for DIs.

8.3. Chapter Summary

This chapter serves as the culmination of my thesis. I have critically evaluated the entire research journey and synthesised the key findings. I also provided a comprehensive overview of my study's outcomes, the significance of my research, and potential avenues for future exploration.

I have candidly discussed the limitations of my research process. These include constraints, and/or unanticipated challenges that could have impacted my study's outcomes.

The reflections in this chapter explore the core findings of my research. They highlight the significant discoveries, patterns, and insights derived from my data analysis. This is crucial because it (a) showcases the extent to which my research objectives have been met and (b) contributes to overall knowledge and understanding of the relevant subject area.

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10. Appendixes

Appendix A. Interview Guide

A. Begin the conversation (5 min.)	
Interviewer self-introduction. Check if participants have read the information sheet. The general structure of the interview/check for interviewee questions.	
Explain the purpose of the study. The extent to which we have engaged in the existing literature and our brief understanding, brief definition/discussion of essential terms to be used.	
Ice-breaker question for the interviewee: Can you describe your role and how long have you been working here?	Could you begin by telling me about your role and how long you have been working here?

B. Content Questions to the candidate (45–60 min)	
Adoption and Usage	
a) Provide a chronological account of recent events/activities of interest. b) Who was primarily responsible? c) How did you get an overview of what was happening? d) How would you describe the initial reaction among employees/your team? a) How long did it take for a plan to be tabled?	Ok. Could you share a few details about the DHO system – how long it has been in use and who has been using it? Any idea of numbers? Do you remember when Covid-19 caught your attention – in the news or otherwise? Did the pandemic come up in conversations among colleagues at work? What was the general sentiment? When did you realize it would come to Norge? What steps were taken in preparation for the pandemic outbreak in Agder? Who initiated this preparation process, or did everyone already know what to do?
b) Who were the primary sources of information used when determining the solution's requirements spec? c) What key functionalities/aspects did you identify as vital for the solution? d) Did you consider alternative solutions/ approaches? e) Approximately how long did it take to develop the solution? f) Are you aware of what the pilot user impressions were? g) What were the test/pilot user demographics? h) Why? The goal behind this? ▪ Why not?	How did you (or the team) decide what to do? Did you formulate a feasible strategy based on guidelines or follow the instructions as given? Did you have to consult anyone else on what to do? To what extent were health personnel consulted? What did you consider to be the most important goal at the time? Were there many possibilities other than the DHO system? Did you have to make significant changes to the DHO system before it could be used for COVID-19 patient monitoring? How would you describe the implementation process? How long did this preparation take? Did you do any pilot tests prior to deployment? Who participated in the tests – age, gender etc? What did they have to say? Did you need to make any other changes following testing? Is this the way things have always been done or did you have to do things differently? Were there time constraints?

	Was it a particularly stressful time?
a) How is the remote monitoring system used in practical terms? b) Do you provide sufficient training to the patients? c) What sort of information does it harvest? d) Have health personnel and patients been comfortable using the system? ▪ Why not?	Let's focus on the actual system now: How exactly is it used when monitoring patients? How do health personnel feel about using the system on patients? Did they require training? Does it provide continuous monitoring or are the readings prompted? What sort of information does it collect from the patient? Is the data identifiable? Are the patients trained on how to operate the different gadgets and apps? Are the patients given a choice as to whether they would like to use the system or not? Have some patients expressed reluctance to use the system? Do you know the reason why they were unwilling? Do you still think DHO is a great option for monitoring COVID-19 patients? Do you think anything can be done to improve the DHO system in patient monitoring? Do you think the system makes a significant difference to healthcare service?
Challenges, Risk and Vulnerability	
a) In what way(s) does this system change the clinical process? b) How do you know the system provides accurate readings? c) What happens if the system fails? d) Did you conduct a risk and vulnerability assessment? e) Were you aware of any shortcomings that it might have presented? f) In which ways did you anticipate that the solution would impact users?	Do you think that the system affects the work of a nurse or doctor? How so? Are you sure that the system provides accurate readings? How? What would happen if the system suddenly stopped working? What happens when a patient loses internet access? What happens when a patient gets too sick to operate the system? Did you conduct a risk and vulnerability assessment? Are you willing to share it or discuss the contents with me? Were there any new or unexpected vulnerabilities that you identified in this process? With full knowledge of the possible risks, is it still a good idea to use the system? In your opinion, can the system be trusted?
Organisational Capabilities	

a) Has this experience, and by extension, the pandemic impacted your workflow? b) Are you planning for or thinking about future pandemics or another wave of infections? c) Do you feel adequately equipped and prepared? d) Why? In what way? ▪ Why not?	What did you learn from the overall implementation process? Would you do anything differently? In your opinion, is this a positive or negative outcome? Has the pandemic changed the way you view and approach your professional work? In what ways? Do you feel prepared for future pandemics/another wave of infections? Do you think systems like the DHO have a place in the future of healthcare service?
a) Who else (individuals/teams/departments) do you think were impacted by this experience? b) We have discussed the socio-technical assemblage of infrastructure. Which aspects/attributes did you consider to be vital to your overall outcome? c) Why? In what way? ▪ Why not?	Who do you think had to do the most work during the pandemic (individuals/ teams/ departments)? What do you consider to be the most important factors in the work environment that led to this outcome? Do you feel prepared for disasters of a different kind – cyber, geographical, power loss etc? Do you think things have gone back to normal or there have been permanent changes?

C. Concluding the conversation (5 min.)	
Thank the interviewees for their participation. Check if they have any final questions of their own. Assure the interviewee of confidentiality and anonymity.	Is there any further information that you have in mind and would like to share? Thank you for taking the time to share your experiences with me so candidly. As already mentioned, this is 100% confidential, and both your and the organisation's anonymity is guaranteed.
Check if the interviewee is willing to participate in any follow-up interviews for clarifications (or follow-up studies) should the need arise.	In the next few days, I will begin transcribing this interview. I might have a few follow-up questions on points requiring further clarification. Would you be willing to participate in any follow-up interviews with me?
Inform the interviewee of how they will learn of the study's results.	If you are interested, then I am happy to share the study results with you. Let me know if I should send you the abstract of the study when it is ready.

Appendix B. Research Publications

#1 Magutshwa, S. & Radianti, J. (2022). Is this Digital Resilience? Insights from the Adaptation and Exaptation of a CPSS. *Proceedings of the 55th Hawaii International Conference on System Sciences (HICSS)*. IEEE Computer Society Press.

#2 Magutshwa, S. (2022). Rethinking the Improvisation of Digital Health Technology: A Niche Construction Perspective. *Australasian Journal of Disaster and Trauma Studies, 26*, 235–251.

#3 Magutshwa, S., Aanestad, M., & Hausvik, G. I. (2022) Beyond Crisis Response: Leveraging Sociotechnical Transformability. *Proceedings of the 13th Scandinavian Conference of Information Systems (SCIS)*, Helsinge, Denmark.

#4 Magutshwa, S. & Radianti, J (2021) A Qualitative Risk Identification Framework for CPSS. *Proceedings of the 18th International Conference on Information Systems for Crisis Response and Management (ISCRAM).*

#5 Magutshwa S. & Radianti J. (Under review). Digital Resilience in Action: Cultivating positive Recovery Outcomes. *Pacific Asia Journal of the Association of Information Systems.*

Is this Digital Resilience? Insights from Adaptation and Exaptation of a Cyber-Physical-Social System

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Abstract

This paper is based on a qualitative case study that explores the adaptation and customisation of a Cyber Physical Social System (CPSS)-based patient monitoring solution for use during Covid19 in the Norwegian health sector. The study seeks to answer the following research questions: 1) what are the preconditions that enable the adaptive use of a CPSS in crisis response efforts? 2) what are the contributions of the adaptive use of technology in the building of digital resilience in a health organisation? The study identifies five main themes that emerge as enabling factors forming a basis for the preconditions to adaptive use of the CPSS. We conclude with a discussion on the practical and theoretical implications of this research and how it contributes to crisis management and digital resilience theory.

Keywords: pandemic response, cyber physical social system, digital resilience, adaptation, exaptation

1. Introduction

In recent years, Information and Communication Technologies (ICTs) have emerged as key elements in the strengthening of societal resilience in times of crises. Resilience primarily diminishes the shock value through the expansion of the capacity to adapt to uncertainty [1]. A current, far-reaching crisis that has come with great uncertainty and emphasizes the need for resilience through use of ICT and digital alternatives is the Covid19 pandemic. People and organizations across various sectors have pursued numerous health and operations principles, leading to different outcomes.

In the health sector, we see how digital health technologies have been centralized, and integrated into coordinated strategy and pandemic response efforts [2]. This application of digital technologies in different aspects of Covid19 planning and response is now an important area of Information Systems and Technology research [3]. These digital technology applications have been studied and linked to the building of digital resilience of people and organisations. For example, how digitally resilient organisations are better equipped to adapt to uncertainty and change using their technological channels and resources [4] .

Of course, the application of digital solutions in the health sector is not a new practice. Countries such as Norway have systematically introduced digitalised healthcare service for over 10 years and possess varied experience on the affordances and capabilities that health technologies provide [5]. However, the far-ranging implications of the Covid19 crisis, such as mandatory social distancing, and capacity constraints in hospitals, give rise to a rather unique set of circumstances that have caused a shift in how these health technologies should be deployed and managed.

An instance of this is in personalised healthcare, where we see the continuous usage of various sensors and digital technologies to capture the biomedical and clinical data from patients treated at home, allowing remote monitoring. Using remote sensing techniques, these technologies have complemented health personnel in varying degrees through the virtual care platforms that include video conferencing and digital patient monitoring. The systems are designed to be a secure intermediary between patients and health personnel and emulate typical patient monitoring practice. In terms of Information Systems (IS) research, such system architectures are conceptualized as Cyber-Physical-Social system (CPSS). In these systems, humans work closely alongside sensors, enabled devices to complete processes and operations. The CPSS ecosystem creates avenues of the possibility for collaboration between software, hardware, and social components across a wide range of modalities.

Theoretically, systems within the CPSS paradigm are reconfigurable, and known to advance capability, adaptability, scalability, and resilience [6]. A study focusing on understanding the role of such technology in digital resilience building in a health organisation is timeous[7]. While the benefits of using CPSS technologies in healthcare are well documented, there are also uncertainties, risks, and threats associated with their usage. IS and Computer Science literature is rich in studies that investigate the CPSS risks in terms of the technical aspects. However, due to the 'social' nature of this technology, the non-technical aspects of CPSS must

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also be understood and equally scrutinized as the technical dimensions.

This paper is based on a qualitative case study that explores the adaptation and customisation of a CPSS for use in Covid19 patient monitoring in the Norwegian health sector in the Fundi region, an anonymised name of the case study location. This study has the potential to provide practical insights into the enabling factors and attributes of the CPSS tool and its usage that foster adaptive use in pandemic response efforts. The paper addresses the following research questions:

- **RQ1:** What are the preconditions that enable the adaptive use of a CPSS in crisis response efforts?
- **RQ2:** What is the contribution of the adaptive use of technology in the building of digital resilience in a health organisation?

The contributions of this study lie in efforts to build a body of knowledge concerning the adaptive use of CPSS technology in health crisis response. This study also contributes to theory building on digital resilience building in organizations, which will extend current understanding of the resilience concept in health crisis response, and crisis management in general. The paper is organized into seven sections. Section 1 introduces the goal, research question and contribution of this research. Section 2 is a review on related works, while section 3 presents the case study. In Section 4 we explain the methodology conducted in this research. Section 5 presents the results from the interview, while the discussion and implications of the results are presented in Section 6. Section 7 concludes the paper and addresses the limitations of this study.

2. Related Works

This section provides an overview of two areas of research in the literature. Firstly, the overview of how CPSS are progressively implemented in critical sectors, with specific focus on the health sector. Secondly on the use and contribution of ICT to the digital resilience building to withstand the challenges emanating from crisis. The first literature selection is based on highly cited publications related to CPSS, details application domains, and deployments of CPSS in engineering, computer science and information systems. The second analysis is based on a set of recent and relevant literature discussing the application of ICT in crisis settings, in some cases Covid19, and how this ICT technology enables a digital resilience strategy to cope with system shock caused by the pandemic and other crises.

The CPSS paradigm is a somewhat new interdisciplinary concept, whose origins can be traced back to the widely known cyber-physical systems (CPS). CPSSs are defined as engineered systems that are built from a seamless integration of computational algorithms, physical, and social components [6, 8]. The systems connect nature, cyber-space, and society with specified rules, typically harvesting data from the physical environment through sensor technologies, further including human actors that are a part of the system and possess their own "cognition, preferences, motivation, and behaviour" [7]. In the literature, CPSS are referred to with a variety of research discipline specific terms such as Socio-Cyber-Physical Systems , Cyber-Physical-Human System [9]. The terms emphasize the socio-technical nature of the systems. A recent trend has seen the implementation of CPSS in critical sectors, in application domains such as personalised healthcare, emergency response, and smart manufacturing [5]. In healthcare, CPSS are also often referred to as Medical Cyber-Physical Systems (MCPS). The systems are integrated into mission-critical process, where patients, clinicians, smart medical devices, embedded software, and remote networking capabilities work collaboratively to meet vital health service goals [10].

The Covid19 pandemic has triggered the emergence of such digital technology initiatives in higher numbers. We have seen innovative and improvised use of CPSS technologies as tools for pandemic preparedness and response in various domains. These varied applications have enabled forecasting of resource allocation based on patient survivability data, hospital capacity monitoring, and tracking of infection rates. Kohn [4] asserts that IS-supported adjustment to disruption, where people overcome technical, and motivational challenges to maintain a level of productivity in the same level as prior to disruption are considered digitally resilient. While the pandemic has accentuated the beneficial aspects of digital technologies and how they enhance resilience in healthcare, the use of CPSS in the health sector demands a level of reliability, predictability, and safety. These ecosystems are not without complications. They present with many unknown threats and risks, triggered by combined technical, operational, and social factors. Patient data protection and privacy are the primary concerns when dealing with CPSS. In addition, the non-technical aspects and human-induced risk have not been emphasized in the literature and must be addressed in research [11].

This surge of various technology-based solutions in response to crisis has led researchers to further emphasize the importance of research on how the application of digital technologies in crisis response efforts builds digital resilience in organisations[12]. Digital resilience is described as "the phenomena of designing, deploying, and using information systems to quickly recover from or adjust to major disruptions from external shocks" [13]. Scholars have suggested several dimensions of resilience in different domains such as in crisis management and disaster recovery, cybersecurity, business continuity and information systems[14, 15]. In [16], the authors conceptualise a resilience for the IS research domain that the authors in [12] refer to as an IS resilience. The authors in [12] conceptualise digital resilience as a phenomenon enabling the resilience of the supra-system, i.e., the resilience of the organisation using the IS. This highlights a shift in research approach, from analysing resilience as just a system property [13], to an ecosystem centric approach, factoring in the immediate environment in which the system operates [12].

In this paper we assume an ecosystem perspective and define digital resilience as the "capacity of individuals, organisations, and society to make effective use of digital technology to prevent, anticipate, absorb, and adapt to major challenges and to continuously evolve and transform in a productive and sustainable manner" [17-19]. This perspective aligns to disaster resilience approaches[20], where it is important to identify not only how the system is resilient[21], but what it is resilient to and how it exhibits that resilience [22]. We assume this stance for two reasons, firstly, the nature of the crisis - Covid19, has impacted organisations on multiple fronts, and emphasizes the need for investigation of a resilience that emerges as a direct consequence of the use of digital technologies such as CPSS in crisis response efforts. Secondly, we focus on CPSS- type information systems, due to the mission-critical role they progressively play in critical societal processes. The qualitative dissimilarity of CPSS components (social, physical, and computational) highlights a need for the investigation of resilience within these systems from an approach that considers not only the technical aspects but the full system composition.

The literature analysis highlights how IS research does not provide solid frameworks or models leading to understanding digital resilience in IS, instead it offers "a rather shallow and narrow understanding of resilience" [12, 16]. Majority studies focus on theoretical conceptualisation of digital resilience, while limited studies analyse the empirical aspects such as dimension indicators. It is a challenge to attempt to measure digital resilience because it is a theoretical concept. However, the assumption of an ecosystem perspective facilitates process thinking and this fosters the possibility of empirical observations of multi-dimensional indicators for digital resilience [7, 22]. Organisations implement innovative, collaborative, and secure approaches to their strategic decision-making in times of crisis. These are well documented in research [23]. However, there is value in revisiting these dimensions within the context of adaptive use of a digital technology[24]. The use of existing digital technologies in crisis response efforts may ultimately contribute to the building of digital resilience in organisations and the analysis of the strategic and technical processes could reveal such connections [6]. The following section details the case study and how the study is designed and executed.

3. Case Description

We used the Fundi region in Norway as the case study. The region has been a part of the National Welfare Technology program since 2013, with multiple digital healthcare projects targeting chronically ill (e.g., diabetes), and elderly patients. The 'digital-follow-up' analysed in this study, is based on an earlier technology, initially designed in partnership with Org-X, the technology vendor for use in the welfare technology program. In the initial patient protocol, the patient was allocated a kit, comprising a smart tablet, condition dependent biosensors, and medical measuring equipment for home use.

From a system architecture perspective, the patient and all the infrastructure can be referred to as a CPSS. The body vitals were captured with the help of the patient, transmitted through a Wi-Fi connection, and then monitored remotely via telemedicine centres (TMS) in the municipal health services. In the case of complications and other emergency issues, the real time support and follow up is also enabled through video, messaging, or telephonic calls. The service was tested in hospital environments, and at a later stage for mental health patients.

When the pandemic hit Norway in February 2020, upon the realisation of the possibility of the hospitals being flooded with patients, a project group with experience in digital follow-up (CPSS tool) in the Fundi region made an assessment and decided to adapt this digital follow up tool to anticipate the likely overcapacity issue of the hospitals in the region. However, this was an intuitive decision, based on the multiple years of experience with digital home follow-up. The update was done in cooperation with the same technology vendor *Org-X*. Over a period of 2 – 3 weeks, a newly introduced Covid19 module was developed with a deployment protocol that allowed the patients to 'bring their own device – (BYOD)'. It was believed that the adaptive use of existing digital patient monitoring technology to remotely monitor and consult with Covid19 patients would provide a buffer to and enhance the capacity of the health service and potentially contribute significantly to crisis response efforts. This study follows this recreation process of the CPSS monitoring tools and monitoring protocols for Covid19 patients.

4. Methodology

This research is an exploratory case study in essence[25]. To address our research questions posed in the Introduction section, we used combined qualitative techniques for collecting the necessary empirical data for analysis. Figure 1 is an illustration providing oversight of the research procedure.

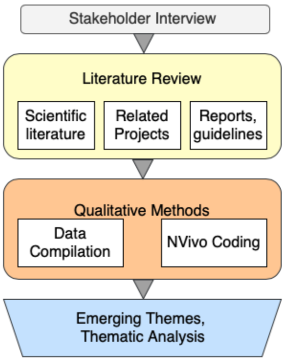

Figure 1: Overview of research methodology

4.1. Research Procedure

Given the exploratory nature of this study, we began with implementing stakeholder interviews, as explained further in Section 4.2. This empirical study follows the progressions in the development of the Covid19 module, from strategic decision making, through to the technology development, implementation, and evaluation. The relevant stakeholders that were involved in this repurposing process of the welfare technology to Covid-19 patient monitoring were identified. The relevant informants included clinicians, technology vendors, and managerial personnel. We then conducted a preliminary literature review for identification of research gaps and thematic corroboration. We selected recent, highly cited, scientific publications that identify the prevailing understanding of the key concepts of digital resilience and CPSS ecosystems. The activities and findings related to the literature analysis are mainly discussed in the 'Related Works' section of this paper. We further collated and analysed the secondary data sources from related welfare technology projects, reports, and guidelines. These are primarily organisational documents linked to usage history of the digital tool in the organisation and experience reports following use of the tool for Covid19 patients.

Data was compiled and coded using NVivo, a software tool used for qualitative data coding and categorisation, and for maintaining the consistencies of the results. The NVivo coding process also helped the analysis process such as identifying the emerging themes and conducting thematic analysis, such as the identification of the enabling factors leading to the successful adaptation of the digital tool.

4.2. Data Collection and Interview Process

The data collection was carried out in two phases. The first phase was done in July 2020, focusing on understanding the early version of the *digital follow up tool* and how it was adapted for monitoring Covid19 patient. We began with a live demonstration with Org-X, the technology vendors. In addition, the data collection and analysis of records, documents, meeting minutes, and reports supplied by the Fundi region were done at this stage.

Table 1: Study informant profiles

÷	**Position**	**Organization**
Inf-1	Head of Digital and Enterprise Services	Org-X
Inf-2	Digital Solution Lead	Org-X
Inf-3	Head of Research & Medical Doctor	Fundi Municipality
Inf-4	National Welfare Technology Program Manager & ex Rescue Medic	Fundi Region
Inf-5	eHealth Research Innovation Manager	Fundi Municipality
Inf-6	eHealth Advisor	Fundi Hospital
Inf-7	Nurse	Fundi Hospital
Inf-8	Project Lead – Digital follow-up (Design) & ex Nurse	Fundi Region
Inf-9	General Practitioner	Fundi Municipality
Inf-10	Project Lead – Digital follow-up (Security)	Fundi Region
Inf-11	Welfare Technology Distribution Lead	Fundi Region

Follow up interviews were then conducted with Informants 1 and 2 (see Table 1). These interviews provided details on the technical background of the CPSS solution, and the necessary adjustments required for use in Covid19 patient monitoring. A second data collection cycle was done in the period between November 2020 and January 2021. This phase was geared towards understanding the experiences linked to the implementation and evaluation of the Covid19 module of the solution. Due to changing Covid19 restrictions in the country, the interview format was blended, some were implemented digitally using the Zoom platform, and also in person, when possible. All but one of the interviews were conducted in English, so there was also a process of translation from Norwegian to English in addition to the transcription process. The total time used for the interviews were 24.5 hours and the data was managed and processed on NVivo.

4.3. Data Analysis

It is nearly impossible to separate the interview and analysis phases of the research. The processes were often entangled and characterised by multiple iterations between the data and literature. In [25], the authors propose a systematised approach to inductive research in which the interview data is categorised in three phases. Inspired by this, the data analysis was completed in three iterative analytic phases. In phase 1, we identified the descriptive keywords and text extracted from the interview transcripts. And because we intended to use the 'ecosystem perspective' at this stage, it was necessary to identify the involved subsystems within the health organisation, this would be a safeguard for ensuring representation from all involved subsystems (details on this are further discussed in section 6). We traced the legacy systems, identifying the system roots, and what was in existence prior to the shock. The second phase involved the logical sequencing of the steps and procedures as they were executed throughout the project and identification of emerging themes. The third phase was sense making, a combination of conceptually mapping the themes identified in phase 2 and finding a deepened understanding of the empirical observations through a theoretical lens. The results were analysed following an interpretive stance, focusing on the identification of enabling factors in the steps taken during the design, development, implementation, and evaluation of Covid19 patient monitoring module.

5. Results

This section reports the findings of the study. It is arranged in a narrative style, providing insight into the context, actions, and general experience from the informants' perspective. The results are organized into five main themes: Covid19 Response timeline, Knowledge and Skill Gaps, Innovation and Digital Alternatives, Leadership and Collaborations, and Risk and Security.

5.1. Covid19 Response Timeline

At the onset of active cases (February 21st, 2020) in Norway, the crisis management protocols in the Fundi region had already been mobilised in line with national guidelines. Considering the uncertainty, a suitability assessment of existing infectious disease management and response procedures and protocols had to be done. The study informants expressed that they realised that there was inadequacy of existing prescribed strategy and preparation as stipulated in the crisis management plan for this nature of an infectious disease. It was at this point that the decision to develop a Covid19 module for digital monitoring was made. As mentioned in Section 3, the motivating factor behind the decision to develop a Covid19 module for the digital monitoring was to buffer the hospital system from floods of patients and limit physical contact between healthcare professionals and infected patients. On March 11th, a day sooner than national government, the Fundi region called for residents to go into lockdown. Based on the timeline, the development work on the digital tool was already underway at this stage, and by March 19th , the solution was available for use. The following subsections are a summarized description of the key details of the project relevant to this study's objectives.

5.2. Knowledge and Skills Gap

A key hurdle identified at the very beginning of the project has been the limited availability of knowledge on the disease. Competence building was initiated well in advance, prioritising crisis response strategy, patient care, and health personnel safety. A great deal of resource/personnel allocation, and structuring was required, to ensure representation of all stakeholders. While the digital tool had been in use in the health service for years, it had only been used for widely known, well researched conditions such as diabetes, heart failure, and pulmonary disease. Monitoring algorithms had been developed for these conditions based on years in medical research. Inf-3 recalled: "*the problem with COVID-19 was we didn't know all the symptoms… we had to read as much as we could and get a specialist to come in and try to build the algorithm and further develop the algorithm as we went on*". The development of the algorithm was a key component of the Covid19 module, and despite the knowledge gap, the team had to ensure it would capture all essential aspects of the disease. A team of medical doctors including a pulmonary specialist was assigned the task of developing the algorithm. Further information was sourced on an ongoing basis from organizations such as the World Health Organization (WHO), and the Norwegian Health Directorate. With content and protocol covered, the technical development was then headed by Org-X, a long-standing partner of region. Inf-1 said*: "It was a hectic time and stressful because we worked a lot, maybe around 70 hours on some of the weeks".* This was by and large a result of a series of further changes required for the Covid19 module beyond just the algorithm (these are discussed later in the next section). The presence of predefined organizational structures and partnerships with institutions such as Fundi hospital, and Org-X were key contributors to the hastened progression in this phase of the project.

5.3. Innovation and Digital Alternatives

Further significant changes were made to the system to customise it for Covid19 patient use. There was a marked difference in patient demographic, from elderly, chronically ill patients to practically anyone. For one, the system deployment strategy needed to be revised, to accommodate greater numbers and improved accessibility. The previous protocol had involved the provision of tablets, and this was not economically feasible and had to be reviewed. This was where the BYOD came in. Patient registration was migrated to a web interface and a downloadable application available in the Google and Apple stores. Org-X had to make internal changes to accommodate some of these emerging requirements. Inf-2 recalled: "*the web development, this is normally not something we do within Org-X. Normally, we provide an all out of the box products that maybe need some kind of installation or configuration*". This meant patients could create profiles, self-register and continue to do their own daily assessments. The self-assessment was a patient questionnaire in the application, developed with the help of medical personnel which would be used to determine the severity of the patient's condition. This was a major change that introduced a wide range of security and technical complications. Migration from a secure, password locked tablet also meant user identification and authentication became priority.

There had not been integration to the population registry before, but for the new protocol, this became a prerequisite. A separate installation was ordered for the authentication, and it was integrated with the Norwegian Population Registry through an electronic personal identification system called BankID. This automated registration and self-assessment was particularly useful for patients in the early phase of infection. Inf-4 shared: "*My hypothesis was if you don't know how they're doing (before hospital admission), you don't know how to prepare the (health) system.".* Inf-8 shared about the value in end-stage/post-infection monitoring: "*it might be of interest to follow up long term effects of COVID-19 for those who have only partly recovered.*" . This approach enabled continuous refinement of the patient registration questionnaire and follow up algorithm as new information became available. Also, there was added value, an opportunity to harvest data on the long-term patient recovery patterns. Once the system was ready, a round of testing was done by Org-X during the development phase. It was an improvised testing regime, and Inf-2 described it as follows: "*we did a lot of testing, just in a different way. on healthcare providers, ourselves, every spouse in the organization was registered as a test guide… even my mother-in-law*". Pilot testing and implementation then followed.

5.4. Leadership and Collaboration

At this point it is important to note that the Fundi region acts as the administrative body for several municipalities that are located within the region. While the project team responsible for the development work of the Covid19 module operated at a regional level, when it came to the decision to implement the system, it had to be made at a municipal level. Inf-11) recalled: "*we contacted the municipalities we already had collaboration with, to see if they could test it out and some of them did and some of them didn't."* The municipalities were given the prerogative to further customise the roll out strategy based on their individual needs. This study included two different municipalities. The first, named Goodwill (pseudonym), had concerns on the use of the TMS centres for the data monitoring, and preferred that the municipal general practitioners (GPs) incorporate the tool into their practice. The project team set up this course of service and did another round of testing, located in a GPs practice following six patients that had been ill between March and May but recovered. The leadership of Goodwill municipality eventually opted out of the solution, citing the need for further technical development, and training. At another pilot test, at the Fundi Hospital, ten Covid19 patients who were at various stages of infection were used as test subjects. Input was given on usability and content and used to improve the self-assessment questionnaire, algorithm, and application user interface.

The hospital opted to use the solution to monitor end stage infection patients, that could be given early discharge and sent home to complete recovery with the monitoring kits. The solution was ready for use but as it were, infection numbers in the first wave (February to June 2020) of the disease were relatively low in the Fundi Region and interest in the solution waned. The project team used the intermission to take a break for reflection. The time allowed for extensive assessment of the system, with in depth consultation of experts. Inf-4 recalls: "I *had some discussions with some friends in a pretty big international network - out of Italy and out of Asia, US region, to see how they are doing it, application user managers and designers*". The feedback informed a learning process at this stage that was used in further refinement of the system. In November 2020, reports emerged of an outbreak in the Fundi region's Shaka municipality (pseudonym). The municipality had prior experience with the digital follow-up and the project team approached the municipality to propose use of the solution for the outbreak. The leadership opted in, with no requirement for any further changes to the roll out protocol. The application was used to monitor 65 patients and following its usage, an evaluation process followed.

Based on a report that captured the user sentiments of patients through a post treatment survey revealed that patients found the solution to be *"brilliant and very easy to understand and use"*. Most respondents gave positive feedback when prompted if they had felt increased security due to availability of the application.

5.5. Risk and Security

The nature of the Covid19 crisis and the chosen response strategy of the Fundi Region required the consideration of risk and security from a tactical and a strategic perspective. *The project manager (Inf-4) said: "My nightmare was a headline in the papers about a patient data leakage. Because we were going from a few patients on an iPad tablet format working on 4g, where the risk is low, it's completely different stuff when you're on your own device, on iOS, Android, it's on Wi-Fi".* Tactically, there needed to be technical changes made *because of* the decision to deploy the system *on a larger scale* through an application and a web interface. The change in user demographic had risk and security implications because while an elderly, eighty-year-old user on a locked tablet was unlikely to be malicious. The possibility of younger people, with greater technical skills and harmful intent on Wi-Fi was a threat that needed to be addressed. Steps to mitigate potential risk at physical infrastructure level were taken. Inf-2 recalled: *"risk assessment? we really did that, together with the Fundi region and Goodwill municipality. We had consultants to perform the penetration tests of the technical solution to make sure it would secure personal data"*. Two-factor authentication was introduced as one of the several steps taken to securing the application. However, further internal structures and steps were taken to safeguard against strategic risk, at the social components level [26]. Inf-10 said: "*Org-X told us that it was secure, but we put together our own task force just working to see if we have all the boxes checked before we went to launch".* An example of the strategic risk identified during this process was the possibility of the algorithm not capturing the deterioration of a patient. It was of utmost importance that patients receive the acceptable standard of care, and system redundancy protocols had to be decided on. The general trend was that patients would have a sudden dip on day 5. So, even if a client had been classified as 'green' by the algorithm for 4 consecutive days, on the fourth day, a clinician was to call them and confirm their condition through video or telephonic consultation, thereby verifying the system data. This was a clinical decision made to ensure patients still received optimal clinical care while at home. The following section details the analysis and discussion of the results section.

6. Discussions and Implications

This case was selected for two reasons, firstly, the digital monitoring tool was not designed for use in the clinical management of Covid19 patients, this was an adapted application. Secondly, the adaptive changes made to the application led to novel roll out protocols and it was one of the early applications of digital solutions used in the monitoring of Covid19 patients at various stages of infection. It is not a complex instance of technological adaptation as the tool was already in use in the health sector. However, the examination of the short- and long-term events builds a narrative that may be used to understand the suitability and effectiveness of similar solutions in the context of crisis. The choice to use an interpretive approach for this case analysis was necessitated by the need to understand the strategic decision making and adaptation of the CPSS technology from the informant's point of view. The reflections and narratives provided by the study informants in the previous section provide detailed insight into their experiences. They highlight how innovative, forward-thinking approaches and digital alternatives are required for them to generate a viable digital follow up solution for Covid19 patients. It is remarkable how the organisational leaders express an openness to 'lacking knowledge' and build capacity through collaborative leadership and network consultations. The findings make it possible to draw insights from their past experiences, extract the necessary lessons and make theoretical projections, visualizing novel applications or future possibilities for CPSS technologies in the context of crisis. The following section provides further discussion on the findings and the key outcomes and contributions of the study.

6.1 Discussion

Prior to delving into reflection on the Covid19 module development, a key assumption in this study is the use of the 'ecosystem' perspective. As mentioned in the 'Data Analysis' section of the paper, it is important for this study to define the health organisation ecosystem and how the different subsystems are integrated. Figure 2 is an illustration of the health organisation ecosystem. The Covid19 pandemic is the crisis domain and a pivotal shock or stressor to the health organisation. Because of crisis induced uncertainty, the crisis response strategy of the health organisation was in the short-term focused on the leveraging of the available and usable digital health technologies. It emerges that for this project digital health technology, physical healthcare, and social subsystems are instrumental in the generation of response efforts to the crisis in the organisation.

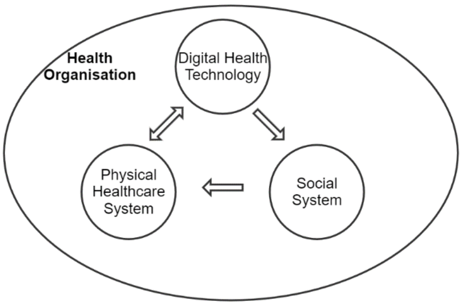

Figure 2: The health organisation ecosystem

The point of the study is to learn about how a technology module was developed to solve critical operational constraints posed by the pandemic. This proposition is consistent with other studies that emphasize how crisis results in unstable conditions that favour the search for and identification/ development of innovative solutions even with limited information on the crisis domain [17, 22]The first question RQ1, seeks to identify the preconditions within the health organisation that enable the adaptation of the CPSS tool for use in Covid19 patient monitoring. An 'adaptable' system is documented to have the capacity to sense, trigger, select applications rules to facilitate the necessary changes. Four main themes emerge as enabling factors in the findings, i.e., knowledge and skills gap, innovation and digital alternatives, leadership, and collaboration. They form a basis for the identification of preconditions. With this understanding and that of the health organisation ecosystem, it is possible to trace and identify these enabling factors and highlight how the CPSS digital tool possesses various traits and attributes located within the subsystems identified in Figure 2. It emerges in the data that the process of adaptation in this project was a continuous and connective process comprising multiple iterations. Because the CPSS comprises of different elements of the subsystems, they all interacted to generate a comprehensive digital monitoring solution. Table 2 summarizes the main preconditions identified in the study that led to the successful adaptive use of the CPSS technology. There are technical, social, and physical infrastructure factors that led to this outcome, and this is shown in Table 2. The process iterations are a response to the need to continuously learn in support of the incremental innovation during the technology adaptation process. A key insight is that the technical attributes of the CPSS tool (digital infrastructure constructability and diversity) is a key enabler to the swift customisation of the technology.

Table 2: Enabling factors for technology adaptation

	Preconditions for Adaptation
Digital Health Technology	• Technological/ digital infrastructure constructability and diversity. • System instrumenting to minimise complexity and maintain possibility of multiple system abstractions.
Social System	• Presence of human sensors and human infrastructure • Pre-existing interrelationships among vital stakeholders
Physical Healthcare System	• Cumulative long-term growth in health technology research and development • Availability of versatile staffing compliment • Short-term training and Capacity building
Cognitive Traits	• Presence of boundary pushers and visionaries
Socio-economic status factors	• Readily accessible stable, high-speed internet connectivity • User education and positive psychosocial attitudes to health technology

The digital follow-up is an embedded CPSS, integrated into a wider healthcare services network with interactions between other computational systems (patient records management) and physical human and medical systems (clinicians, doctors, patients, biomedical sensors). The CPSS is instrumentalized within the health organisation to optimize scalability, fast response time, with minimal complexity in the clinical management of Covid19 patients. The availability of human sensors and infrastructure is an instance of versatility of the system and the social layer integration. Patients are primarily a part of the system to receive healthcare, however, they also have a secondary role, that of human sensors, used to complete the monitoring process and monitor for algorithm inaccuracy. It is also important to note the socio-economic status factors – these are directly linked to the local environment/ country. The ready availability of high-quality internet connectivity, and positive psychological attitudes to health technology by the patients is key in making the solution relevant.

6.2. Implications: Is it Digital Resilience?

Concerning the practical implications, by deepening the analysis, we can stratify the preconditions identified in Table 2 differently, i.e., *strategy-driven preconditions* and *technology-driven preconditions*. **The technology-driven preconditions** naturally highlight the key enabling attributes of the CPSS technology and how the nature of the technology strengthens the resilience of the health organisation. Due to the close interactions among the cyber, physical, and social subsystems, the CPSS possesses multiple mechanisms for communication, sensing entities, and end user maintenance. This is what makes the tool adaptable in technical terms. *A combination of improvised research and strategic decision-making* generated the innovative Covid19 module to cope with negative effects of the pandemic before effective vaccines and other viable treatment channels were available. **Strategy-driven preconditions** are emphasized in the self-organisation and persistence displayed by the human actors in the social and physical systems whose cognitive traits, and positive psychological attitudes inclined them towards flexibility, creativity, self-organisation, antifragility[27], and learning. Uniquely, the identification of preconditions such as socio-economic status factors reveals that the multi-layered architecture of the CPSS ecosystem enables it to contribute to not only the digital dimension of resilience but possibly to organisational and community resilience factors as well.

Recall that RQ2 asks about the contribution of the adaptive use of technology in the building of digital resilience in a health organisation. The theoretical implications of the study serve to address this RQ2. We contribute to the emerging literature on digital resilience by delving into the adaptation process and proposing insights on digital resilience building through crisis-driven innovation and adaptation of digital technologies. The themes of innovation and adaptation emerging from the data are consistent with our understanding of resilience, which we define as "*the quick regaining of essential capabilities to perform critical missions during crisis and smoothly return to fully stable operations*".

In this case, the decision to implement a novel clinical management methodology on Covid19 patients was wholly necessitated by the nature of the crisis. Adaptation of technology in times of crisis is highlighted as also found in the literature dealing with the digital resilience [28, 29]. However, our study is unique in terms of the fact that the digital follow up tool was initially adapted for remote monitoring of patients with well-studied diseases, but eventually secondary features prove useful for additional purposes such as the Covid19 case. In our study, this is demonstrated from the decision to use the tool on late-stage infection and recovering patients for long-term data gathering purpose. At this point the technology has not only been adapted for a new application area, but it is also further exapted. *Technological exaptation is conceptualised in theory as the repurposing of traits, technologies, processes, skills, and resources for emergent uses that they were not initially designed for* [30-32]. The generation of new knowledge about the disease is an exapted use of the digital monitoring tool. Adaptation and exaptation often occur in combination in crisis conditions resulting in a dynamic innovation process. It is a connective, and continuous process.

A key identifier for exaptation is that:

- the adaptation and innovation emerge without the need for a project to start from scratch, and implementable based on short-term developments to address any new requirements.
- the agility and flexibility of arrangement and governance of decision-making structures in an organisation while in crisis.

In digital resilience theory, a combination of technology and individual capacities is used to expand the support structure following a disaster or crisis by harnessing the available resources, possibilities, and opportunities [24]. However, existing literature is underdeveloped and does not identify indicators for digital resilience. This study finding provides insight into this area and shows how the Covid19 crisis creates an environmental niche that demands technological adaptation and eventually exaptation. Digital resilience is found to be less of a static state and more like a process of building capacities. This is demonstrated by how the Covid19 crisis leads to the assimilation of new knowledge and new intelligence from the emergent crisis management tools. Digital resilience is perceived as *resultant* from the shock/stress caused by the pandemic. Although this study is not designed to measure digital resilience, it provides insight into how it may be observed through the identification of the digital resilience dimension indicators found in this study, i.e., adaptation, innovation, and the unexplored – exaptation. This is a novel finding and a contribution to digital resilience theory.

7. Conclusions and Limitations

In this study we attempt to build a body of knowledge concerning adaptive use of CPSS technology in health crisis response, the *strategy-driven preconditions* and *technology-driven preconditions* leading to this phenomenon are highlighted. We also contribute to digital resilience theory, through identification of exaptation and adaptation as dimensions for indicators. The limitation of this study is threefold: Firstly, this study observed the Covid19 response in the period March 2020 – January 2021. It is likely there have been further developments following extended usage of this system and changes in the pandemic response strategy, this is not within the study scope. Secondly, digital resilience is a relatively new dimension in resilience literature and requires further operationalizations and measurements. Thirdly, this study is conducted in a developed country setting that satisfies all the enablers, it would be informative if further research focusing on the enabling factors of digital resilience in developing countries was conducted. In this case, this limitation is an opportunity for future researchers with interest in the further exploration of the topic.

7. References

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Rethinking the improvisation of digital health technology: A niche construction perspective

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Abstract

The COVID-19 pandemic has sent shock waves through healthcare organisations and catalysed an impromptu digital shift, creating a demand for telemedicine and other digital health technologies. Under such conditions, improvisation, adaptation, and innovation emerge as core dimensions to an organisation's capacity to generate a response to crisis. This paper integrates a process perspective on the radical improvisation of a digital health technology and investigates how the radical improvisation of a digital health technology emerges and develops during a health crisis. Through a combination of supporting case evidence and literature, a multi-phase conceptual process model anchored in the crisis management cycle and illustrating the radical improvisation of digital health technology is developed and proposed. We conclude with discussion on the long-term implications of radical improvisation and crisis learning, with possible theoretical explanation using niche construction theory, and providing suggestions for future information systems and crisis management research.

Keywords: *digital health technology, radical improvisation, crisis response, COVID-19*

The COVID-19 pandemic has been a critical shock that has threatened healthcare organisations on a global scale resulting in unstable operational environments plagued with stress and uncertainty. While organisations ordinarily have predefined crisis management routines, protocols, and procedures, there are rare instances where the nature of crisis creates circumstances that render planned strategies inadequate. Such has been the effect of COVID-19, and it has catalysed an impromptu digital shift (Whitelaw et al., 2020). We see health organisations deviating from set protocols and procedure, radically improvising, and leveraging digital technologies at their disposal to respond to the uncertainty created by the pandemic (Levallet & Chan, 2018; O'Leary, 2020; Wickramasinghe & Seitz, 2021). The term 'radical improvisation' indicates an improvisation where emergent, unplanned strategy is implemented during crisis (Gkeredakis et al., 2021; Vera & Crossan, 2005). Consider how health organisations are using mobile applications to locate and provide information about people infected with COVID-19. In most instances these have been systems that were specifically designed for this purpose at the onset of the pandemic. However, in some cases, these have been systems that were already in use in the health network, underutilised but finally proving highly relevant due to the emergence of a specific nature of crisis (O'Leary, 2020). The latter are an example of radical improvisations in health organisations.

Effectively, the process of improvisation facilitates an organisation in the optimization of available resources to generate a response to crisis. Improvised use of digital technologies is a valid and viable alternative in the formulation of reliable process for response efforts where planned strategy is rendered irrelevant. However, while technology serves a necessary purpose the process is not so straightforward (Suarez & Montes, 2019; Vendelø, 2009). There is a need to understand these 'improvised technologies' – how they work, how and why they were chosen, and what are the implications of their use? Consequently, the use of technology in COVID-19 response efforts has become a major area of research for information systems (IS) and crisis management researchers (Aman et al., 2012; O'Leary, 2020; Pan et al., 2012; Stieglitz et al., 2018). Crisis management and

IS literature is rich in studies where ICT plays a supportive role to improvisation and crisis response (Stieglitz et al., 2018; Ting et al., 2020) . A common genre of studies are application areas where ICT supports typical roles such as communication and coordination, where the use of ICT is already standardised and widely used (Fischer et al., 2016). There are also studies that focus on specialised technological solutions that are designed for implementation in crisis response (Adrot & Robey, 2008; Granåsen et al., 2019; Jefferson, 2006). This is an 'incremental improvisation' where an organisation makes updates or changes during a crisis that are aligned to the standard operating procedures (Aman et al., 2012). However, in recent years the contribution of digital technologies to improvisation and crisis response has shifted from what was a 'supportive' to a centralised role that emphasizes a more 'radical improvisation.' This type of improvisation is consistent with the formulation and implementation of emergent, unplanned strategy which we have observed during the COVID-19 crisis, and it is far less commonly studied, yet it must be addressed (Vera & Crossan, 2005). Limited studies focus on ICT that is designed for an established use within an organisation but swiftly repurposed as a part of crisis response efforts. This research gap results in a lack of understanding of the conditions under which the radical improvisation of ICT emerges and develops.

The ongoing COVID-19 crisis illuminates this shift towards the radical improvisation of digital technologies in several sectors and makes it possible for scholars to learn about radical improvisation of digital technologies. It enables an exploration of the notable triggers that give rise to the radically improvised use of technologies in response efforts to a health crisis. This paper is based on a qualitative study that explores the repurposing and customisation of a digital health technology for use in COVID-19 patient monitoring. The study presents the unique opportunity to analyse the leveraging of an existing digital health technology in real time. The empirical case study also gives unique insight into improvised actions taken in a health organisation as it adapts to challenges and constraints created by COVID-19. This paper assumes a process-oriented approach and initiates a quest for a deepened understanding of the radical improvisation of digital health technologies in crisis conditions. The work contributes to crisis management and IS literature by capturing the process dynamics and proposing a conceptual process model for the radical improvisation of ICTs based on empirical findings and literature analysis. Therefore, the question to be answered is: How does the radical improvisation of digital health technologies emerge and develop during a health crisis?

The methodological approach of the paper is an explorative case study incorporating related literature analyses. The rest of the paper is organised as follows. The Previous Studies section follows and summarises a literature analysis on selected related works which serve a basis for the conceptual discussions later in the paper. The Case Description is next and is followed by the Methodology. A description of study findings and the discussion of findings follow in that order. The Conclusion and Limitations section concludes the paper.

Literature Background

This section focuses on two interrelated research streams, firstly detailing how digital health technologies have been progressively explored, accepted, and applied in healthcare service delivery in recent years. The first analysis is based on highly cited publications related to digital health technology in the information systems research stream and other relevant domains. It reveals the current discourse and deployments of telemedicine in healthcare service delivery. Secondly, an analysis on the capacities and functions that the use of such technology's avails to a healthcare organisation during a crisis. The second analysis centralises the COVID-19 pandemic as the crisis context and is based on a set of literature focusing on the use of digital health technologies in COVID-19 crisis response efforts. The aim is to uncover how digital health technologies create opportunities for radical improvisation in crisis response efforts and overall crisis management strategy.

Digital technologies are known to facilitate connectivity and innovation and oftentimes, the introduction of a single innovation stream may yield countless further innovations of organisational value (Agarwal et al., 2010; Gkeredakis et al., 2021; Jha et al., 2016; Wang, 2021). The potential benefit and eventual use of technology solutions in the monitoring of chronic diseases is a natural progression in the use of technologies such as sensors, wearables, and mobile applications to solve societal problems (Bardhan et al., 2020; Payton et al., 2011). ICT play an enabling role in healthcare. Commonly referred to as digital health technology/telemedicine/telecare emerged in response to operational challenges (ageing populations, increased service demand, and limited staff resources) faced by the healthcare sector. For the purposes of this paper, we define telemedicine as "the application of computer and communications technologies to support healthcare provided to patients at remote locations" (Aanestad et al., 2019; Austin & Boxerman, 1997; Bower et al., 2011). The systems are designed to allow remote data exchange between patients and clinicians using various interactive data communication mediums e.g., cloud computing, biomedical sensors, artificial intelligence (Shah et al., 2016).

There is growing emphasis on the identification of alternative, non-traditional approaches to patient management and healthcare delivery through telemedicine is classified as 'store-and-forward' or real-time or remote monitoring. In store-and-forward, the technology is integrated for the capturing, pre-storage, and transmission of digital images and clinical information. In real-time, the clinical data and information is captured through a synchronised, interactive process between the patient and clinician such as video consultations. In remote monitoring, the patient vitals are monitored from remote distances with the aid of specialised medical equipment such as sensor technologies for the diagnosis, treatment, and prevention of disease and injury (Burke & Weill, 2018). Common trends in application include remote patient care, electronic health records, and smart medical devices, and automated decision support (Qiu et al., 2020).

As with any innovation initiative, there are factors (drivers and inhibitors) affecting the adoption of such systems. These may be technological e.g., a lack of appropriate infrastructure or data integration, regulatory e.g., Physician and equipment licensing , institutional e.g., lack of management support or individual e.g., privacy and security concerns (Yeow & Goh, 2015). Several systematic reviews argue that telemedicine provides affordable, punctual, and convenient treatment pathways (Bardhan et al., 2020; Ross et al., 2016). While the systems harness forward-thinking, technological progressions, they also generate high volumes of new real-time data types, that dictate new data management and usage protocols (Grisot et al., 2019) and introduce new avenues of risk, threat, and vulnerability (Qiu et al., 2020). So far, IS research examines multiple concepts related to digital health technologies with a balanced focus on the favourable and non-favourable effects experienced as a result of the use of telemedicine (Ellimoottil et al., 2018). However, the emergence of the COVID-19 pandemic has forced a shift in the healthcare delivery systems and accelerated digital health solutions implementations. We have witnessed the rapid implementation of infection control and monitoring measures, adapted to standard operating procedures. While telemedicine solutions prior to the pandemic were considered optional extras to clinical management pathways they have taken centre stage (Sun & Wang, 2021). Through the implementation of reactive crisis management strategies, telemedicine and other eHealth solutions are now considered a necessity. The use of digital technology in this way, to cope with crisis conditions is relatively new, and not fully explored theoretically. Research towards developing practical and refined pandemic crisis management processes, models and frameworks in the health sector is emergent and timeous (Hattenbach et al., 2020). The next subsection focuses on the application of digital health technologies in COVID-19 response efforts.

Emergent Responses to COVID-19 through Digital Health Technology

It is not possible to discuss the role of digital technologies in the response to COVID-19 without briefly discussing the crisis management cycle. Crisis management refers to administrative approaches that are used to address crisis situations through preparation and planning. Traditionally, these are outlined through predictive scenarios and examination of potential weaknesses in organisations in anticipation of future disruption (Quarantelli, 1988). In crisis management theory, the crisis management cycle comprises of six stages – risk assessment, prevention, preparedness, response, recovery, and learning. In light of this cycle, it is visible that following a crisis, an organisation may emerge in an improved or worsened state or direction (Pursiainen, 2017). When responding to crisis or disruption, organisations can either revert to a known state and, recover normal operations or capitalise on the opportunity presented by change and introduce solutions that extend beyond mere improvisation and adaptation (Manyena et al., 2011; Russpatrick et al., 2021; Walker et al., 2004). This thinking contrasts with disaster studies, where crisis recovery is characterised by efforts to return to known, stable state (Sakurai & Chughtai, 2020; Sakurai & Kokuryo, 2014). Thus, organisations, when supported by a flexible infrastructure, can maintain their operational capabilities as they adapt and respond to challenges posed by various disruptions and threats (Boh, 2020; Haque et al., 2014; Hartvigsen et al., 2007).

The COVID-19 pandemic is a crisis that has proven to be beyond the capacity of the planned management structures and processes in most health organisations

(Magutshwa & Radianti, 2022). While there were crisis response strategies in place for epidemics such as influenza, that include rapid, systematized response to mitigate infection rates, and maintain steady operations. However, COVID-19 has presented novel constraints and challenges not considered in existing policies and strategy and as a result, forced organisations to implement reactive crisis management strategies. In the information systems discipline, COVID-19 is characterised as an unprecedented existential threat, which brought out the best of society. A related discourse emerged that focuses on how health systems needed to be redesigned/reimagined to accommodate a more proactive response pattern as opposed to the traditional reactive approach (Rai, 2020). The COVID-19 pandemic is widely acknowledged as having been transformative, challenging individuals, organisations, and countries to revise health service models, and what they consider innovation.

Digital health solutions have emerged as viable approaches to various aspects of healthcare delivery (contact tracing, smart medical devices, and wearables) and response to COVID-19 induced challenges and constraints. Health technologies have been implemented across various phases of the crisis management cycle with varied impact and outcomes in health organisations. The development and implementation of such solutions has been rapid and fast-paced, with limited research in some instances and it has created avenues of research aimed at understanding these operational adjustments and adaptations (Djalante et al., 2020; Gkeredakis et al., 2021). These accelerated innovation processes have facilitated human resource allocation, and strategic decision-making process in health organisations. Due to the critical nature of work, the health sector is known to be a conservative and highly restrictive operational environment, with strict regulations governing policy strategy, and operations at all levels. Innovation changes in this sector are known to take extended periods of time – months or years in some cases. The pandemic has challenged this stance, and in some cases “removed barriers to experimentation and acceleration in the health-tech sphere” and there has been a marked increase in experimental use of telemedicine solutions for in and out-patient monitoring in hospitals (Oborn et al., 2021) . Naturally, the availability of highly reconfigurable and accessible digital platforms has been pivotal in these response efforts, but it has also meant a shift in organisational practices , and development of new skills to accommodate these digital work environments (Floetgen et al., 2021). This inclusion of complex institutional dynamics highlights how the crisis response efforts using digital technologies may also generate tensions due to the interruption or change in organisational practices as swift changes are put into effect (Orlikowski & Scott, 2021).

The literature reviewed in this section highlights the novelty and dynamism that the COVID-19 crisis has introduced to the health sector and illuminates research gaps and areas of contribution for this study. This study has the potential to build on extant crisis management theory through the analysis of how crisis creates conditions for experimentation and enables the innovation and improvisation processes in health organisations. This investigation of the use of digital technology during a crisis will also contribute to information systems literature by providing insight into the technology development process, highlighting dependencies that use of these technologies creates and the novel forms of risk that this entails.

Theoretical Background: Niche Construction Theory

Niche Construction Theory (NCT) is historically a branch of evolutionary biology that emphasizes the capacity of organisms to influence and modify their environment and inadvertently influence the evolution of other species due to pursuant environmental changes. These processes of environmental selection and adaptation/ modification are referred to as niche construction (Lewontin, 1982; Odling-Smee, 1988). In NCT, niche construction is an evolutionary process, where the environment is modified based on the selection pressures experienced by organisms. So fundamentally, the change and evolution process unfold according to natural selection and niche construction. Adaptations are products of both selection and niche construction processes. While it is originally associated with the biological sciences, NCT has also been incorporated into ecology and the human sciences and used in the formulation of evolutionary frameworks in those research streams (Laland et al., 2007; Odling-Smee et al., 2013). Effectively, a two-way process exists between humans and environment – the human may alter the environment in response to a ‘problem’ and said solution leads to new ‘problems’ in the changing environment, which emerge because of the prior niche construction. Thus, niche construction theory provides useful conceptual tools and theoretical insights for integrating technological evolutions (Luksha, 2008). Humans modify their environments through technological innovation, routines, and processes. NCT is also applied as a theoretical lens in studies pertaining to complex technological systems. Interesting parallels are drawn between biology and technology as NCT is applied in studies that investigate the design of technological modules through natural selection or a redesign for current use. The rapid emergence of a new niche is characterised by "technological continuity and functional discontinuity" (Andriani & Cohen, 2013). Niche construction processes are thus seen as pervasive in evolution of technologies. However, the challenge remains, how to conceptualise the leap from modification/adaptation to design for unanticipated use.

The theory explains how humans acquire knowledge during niche construction through embedded informational processes that influence and shape future decisions through learning and development at distinct levels, i.e., individual, team, organisational. This inherited and learnt information is instrumental to and underpins niche construction. Learning and development are quite significant and further guide the niche construction process. For instance, a technological solution may be introduced into a health organisation to improve overall service delivery but create new constraints for patients and medical personnel such as poor patient experience. Humans may then respond to this novel constraint on multiple levels of the organisation. At individual level, through offering capacity training to all patients and staff, and at organisational level through further technological evolution, by incorporating patient-centred design principles (Klecun, 2016) that optimise patient experience. From this example it is evident that niche-constructing traits go beyond ordinary adaptation and influence future decisions in a manner that shapes the overall evolutionary dynamic and pathway of a technology. The possibility of a bifocal lens of the evolution of technology and the environment makes NCT ideal for the study of human innovations and complex systems. Distinctions can be easily drawn between two aspects of niche construction—environment alteration and subsequent evolution in response to a constructed environment (Andriani et al., 2020; Andriani & Cohen, 2013).

The operational environment factor could not be more important in a study focusing on the use of digital technologies in response efforts to a health crisis. The rapid development and deployment of digital technologies experienced during the pandemic has rendered what were ordinarily stable health organisations environments as now 'unstable' (Fischer & Baskerville, 2022; Rodon & Silva, 2015). This calls for novel approaches that will provide deepened insight into the required triggers and processes. This paper selects the Niche Construction perspective on this basis and argues that by highlighting the operational environment ramifications of changes that crises bring about in health organisations we may reveal and understand future evolution pathways in the use of digital technologies in health organisations (Magutshwa & Radianti, 2022). It is possible to view and analyse the radical improvisation process as an adaptation/modification following a negative environmental selection (COVID-19). NCT further helps link crisis response efforts to longer term technology evolutionary changes, and potentially leading to a deeper understanding of how digital technologies change over time. The next section is a case description that details the empirical context of the study.

Research Gap and Potential Contributions

Although COVID-19 presents with novel constraints that demand a rethinking of existing core practices and goals for many health organisations, it is also likely to require changes on a broader scale, i.e., organisational transformations that are not necessarily linked to COVID-19. The use of digital technologies in pandemic response efforts would have had impact on multiple levels the technical components must be matched to suitable organisational capacities and social functionalities. Crisis provides a unique opportunity to review mitigation plans, refocus priorities, and reimagine strategy to similar challenges. Digital technologies emerged as prominent components of service delivery solutions deployed in critical services such as health, finance, and energy. The shift from physical to digital modalities creates fundamental changes in social interactions, organizational routines, and practices. With most organizations and societies resolute not to be 'fooled twice,' we observe the integration of lessons learnt during the crisis into novel routines and practice. Literature published prior to 2020 does not account for an exogenous shock like COVID-19 and literature published following the pandemic does not account for the sociotechnical arrangements required when using digital technologies. Further, only a few papers explore how the emergency measures taken could potentially impact the decision making and evolution pathways of the digital technologies in the long term. Majority of the papers present a high-level abstraction on the use of ICT supported solutions during the crisis but do not explain how decisions being taken in the short term could shape or influence the future. While the focus of prevalent IS research on technological and organisational capabilities is insightful, it tends to hinder the use of evolutionary frameworks in the understanding of phenomena. This paper applies an evolutionary framework to go beyond the use of the solution and its capabilities to consider the theoretical implications that provide insight into how the short-term crisis efforts could influence future use of digital technology in the health sector. This is a new way of thinking that not only considers adaptations but also the possibility of exaptation. NCT, although used in other social science, economics, and management disciplines has seldom been taken up in the IS discipline. The use of this theory to explain both the crisis response actions and the follow up reactions to the changes positions this study well to contribute to crisis management and digital health technology literature in IS.

Case Description

The Norwegian health Directorate for eHealth provides support to Norwegian municipalities to implement welfare technology through the National Welfare technology program. The program was established in 2013 to promote innovation initiatives in health and social welfare services in municipalities. The aim of the program is to fully integrate welfare technology into the health service by 2021, thereby improving service quality, and saving on time and costs. The Fundi region (pseudonym) in Norway has a project team affiliated to the National Welfare Technology program and have run multiple 'digital home follow-up' projects in different municipalities. They target patients that are chronically ill (e.g., heart disease) or suffering mental disorders. The region has three established telemedicine centres (TMS centres) in the municipal health services.

The service allows elderly, chronically ill patients a degree of independence while they continue to receive an acceptable level of care. The patient vitals are monitored remotely by qualified health personnel using a selection of biosensors and real-time follow up through messaging, video, or telephonic calls (see Fig. 1). When the patient makes a reading, input data is transmitted through a Wi-Fi connection to a cloud-based server for processing by clinicians located at a monitoring station. Medical personnel then provide advice and feedback to the patient based on this data. When the COVID-19 pandemic came to Norway, the Fundi region anticipated strain on the health service. An assessment of the suitability of this digital solution used in the welfare technology program for COVID-19 patient monitoring was conducted and the decision to repurpose 'digital-follow-up' for COVID-19 patient monitoring was made. The design and development of the digital-follow-up system had been a collaborative effort. It involved Org-X, a health technology vending company responsible for the technical development of the solution and its digital platform. They also included various clinicians with specialisation and expertise in the relevant, common comorbidities such as hypertension, diabetes, heart disease, and chronic obstructive pulmonary disease (COPD). They provided input in the design of algorithms and ensuring the solution was in alignment to existing clinical practise. The basis for the decision to use digital-follow-up was experience with COPD patient monitoring, a different pulmonary disease and so this was viewed as a 'further development' of the original system.

Consistent with the process and practice followed in the initial solution design, the Fundi region assigned the digital-follow-up project team and the relevant, pre-existing collaborators to design and develop the COVID-19 module. Fig. 2 provides an overview of the different collaborators involved in the design, development, and implementation of the COVID-19

Figure 1
Remote Patient Monitoring Application

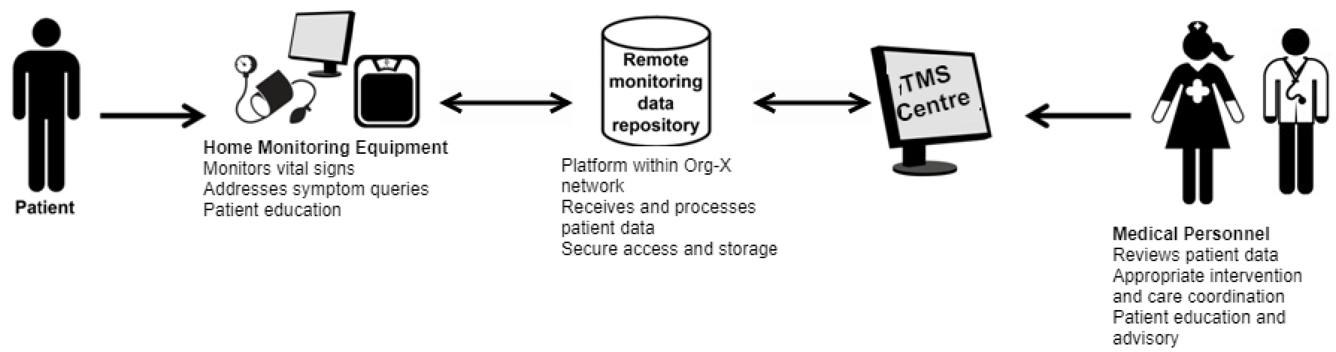
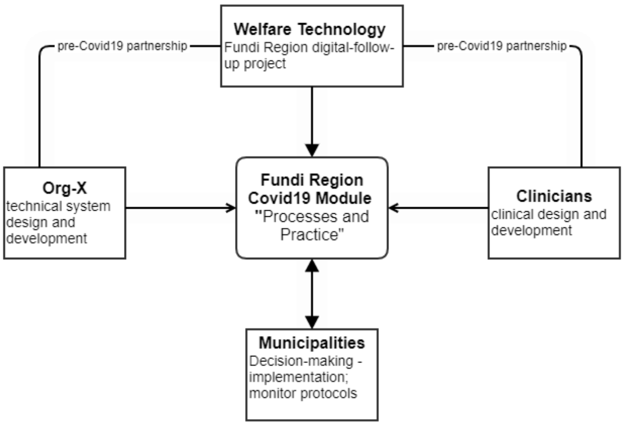


Figure 2
COVID-19 Module Design Collaborators Overview



module. The main innovation and development drivers for the project was the emergence of a destabilising health crisis. Healthcare professionals, crisis management, and technology development experts collaborated in delivering a service to a targeted segment of patients while educating themselves on a little-known disease. In a period of 2 – 3 weeks the new application was available for public use and would provide a buffer to the health service and potentially contribute significantly to crisis alleviation activities. The focus of this study is on the radical improvisation processes and practise implemented in the design, and development of this COVID-19 module. The following section is a description of the methodology used in this study.

Methodology

The research is designed as an exploratory case study. The intended outcome of the study is focused on unpacking the process of radical improvisation of a digital health technology and arriving at an adequate understanding of how this organisational response emerges and develops. A combination of qualitative research methods is used to address the main research objective.

Fig. 1 provides an overview of how the research was conducted. The activities and findings related to the literature analysis are outlined in the Literature Background section of this paper. The literature analysis serves to re-examine the nature and definitions of crisis management routines and improvisations as they exist in literature. The study covers how the project develops in relation to the technology development, tactics, and decision making with various stakeholders including the technology vendors, clinicians, and managerial personnel. Interview transcripts, and other secondary data - reports, and meeting minutes were compiled and coded using NViVo – a data management software used in organisation and structuring of qualitative data.

Data Collection

Consistent with process tracing research practice, the data gathering activities are characterized by repetitive cycles of asking participants how and why different responses and actions were taken. The study traces the actions followed by people belonging to the different collaborator groups described in Fig. 2, who were engaged in the repurposing of the remote patient monitoring solution. This ensures that all key perspectives of the organisations involved in the project were covered. Fieldwork is conducted primarily within the research and innovation project team of a municipality in Norway, but also includes various technology and healthcare professionals who collectively contributed and had responsibility for the project through its divergent phases.

The study had a first phase, in July 2020. This component of the study had a focus on understanding the COVID-19 module of the remote monitoring tool and its development. This phase also involved the analysis of a collection of documentation – reports, meeting minutes, and system documentation, and a live demonstration of the digital-follow-up tool and discussions with staff from Org-X, the technology vendor.

In this second phase, the specific focus was on the practicalities of the implementation of the monitoring tool. Ten interviews were conducted with eleven study participants (Table 1) in total, lasting approximately 22 hours in

Figure 3
Research Methodology

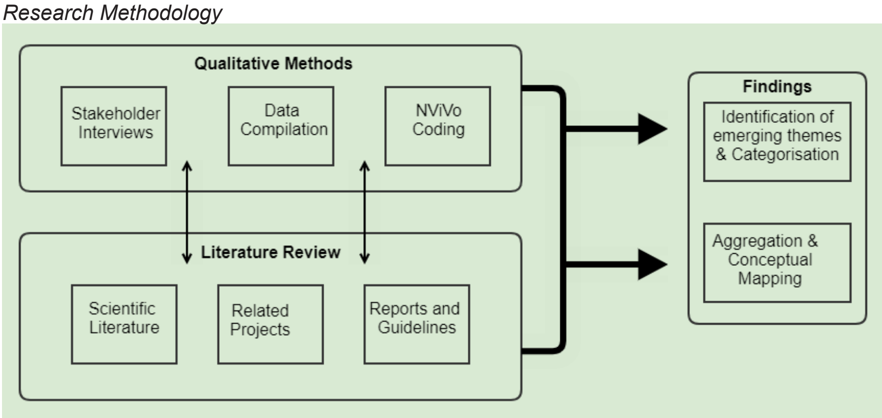


Table 1
Study Informant Profiles

	Position	Organization
Inf-1	Head of Digital and Enterprise Services	Org-X
Inf-2	Digital Solution Lead	Org-X
Inf-3	Head of Research & Medical Doctor	Municipality
Inf-4	National Welfare Technology Program Manager & ex Rescue Medic	Fundi Region
Inf-5	eHealth Research Innovation Manager	Municipality
Inf-6	eHealth Advisor	Fundi Regional Hospital
Inf-7	Nurse	Fundi Regional Hospital
Inf-8	Project Lead – Digital follow-up (Design) & ex Nurse	Fundi Region
Inf-9	General Practitioner	Municipality
Inf-10	Project Lead – Digital follow-up (Security)	Fundi Region
Inf-11	Welfare Technology Distribution Lead	Fundi Region

total. The participants interviewed for the study included the Project Lead for the National Welfare Technology Program, eHealth Research Innovation manager, Head of Research, medical doctors, nurses, crisis, and technology experts from the different stakeholder groups associated with the project. Table I details the study informants and their level of expertise.

Data Analysis

For analysis, (Gioia et al., 2013) provides a systematic presentation of the data analysis phase that enables the categorisation of interview data into first, second and third orders. Drawing inspiration from the Gioia methodology, the data analysis follows an interpretive stance and plays out in three iterative phases. These are identification of descriptive keywords and direct quotation of interview subjects in the first order; creation of a logical sequence of steps and process mapping in the second order; and finally, aggregation involving a conceptual mapping of the second order themes to existing literature and theory in the third order (Gioia et al., 2013).

The discussions focus specifically on the work done in the development of the COVID-19 module of the monitoring tool following people assigned in various stages of the project (Lapointe & Rivard, 2005). The first analytic phase consisted of organising all the data from the various sources in chronological order. Descriptive codes were then selected, paying attention to preserve the informant's keywords and statements. The data was coded according to specific dates, actions, meetings, and roles. This was because specific interactions among the actors were linked to specific processes or practice. In the second phase, the data coded and arranged in phase one was analysed to identify the connections and linkages, to reconstruct the various stages and key processes related to the COVID-19 module development. These would provide deepened understanding on how the Fundi region operated from one stage to the next. The stages and key processes comprised the second analytic phase codes, and they are used in a reconstruction of events through a logical sequencing, this is discussed further in the Discussion section of the paper. The third analytic phase the second phase codes are mapped to theoretical concepts identified in the literature that give further explanation and understanding to the order of events and actions taken. The outcomes of the data analysis are discussed in the following sections. Firstly, in the next section where the findings of the study are described, followed by the Discussion.

Results

This section focuses on describing the findings of this case study and provides details of the information provided by the study participants. It is a narrative approach with descriptions of the context, activities, and structures from the perspective of the interviewees. The section highlights the key emerging themes, observations, and outcomes of the study.

Perception of Threat Under Tentative Crisis Conditions

In Fundi region, some of the earliest reports of COVID-19 infections surfaced in February 2020 and impacted nursing homes where elderly patients live. The region was prompted to mobilise its crisis management protocols at a local level in line with National guidelines. Mobilisation of structures such as organisational crisis management routines, departure from known patterns of action, protocols and procedures, and role switching are evident. Informants recalls: "*We established a crisis organization that met on a regular basis, and let many persons work from home office, the head of the crisis management he very soon got an important role in how to run the organization.*" There are also invisible structures such as dynamic information and knowledge structures formed as specific knowledge and skills gaps related to COVID-19 were identified. The uncertainty of the possible disruption was also evident. One of the informants said, *"We were not prepared to cope with this kind of the contagious disease… There was a large focus* *on the hospital sector, and we could have an overload."* Existing structures are fundamental in the early crisis response process, they provide harmonised execution within the rhythmic order set by the structures (Pan et al., 2012).

The fortification of the crisis management team with a wider selection of staff, with varied expertise was necessary and is seen as an early indicator of resource reallocation. Informants describe how they begin an idea development, solution-oriented process. The project lead recalled: "*I was thinking will we have, in the worst-case scenario thousands of patients with COVID-19 in isolation? … trying to put myself in a jam and ask what we then do? thinking that maybe we can just take that Welfare Technology Project and scale it."* The priority was the formulation of a solution, even if it leads to novel thoughts, activities, and organisational relationships. Members of the project team emphasize how their attention firmly shifted in this direction. *"How can we contribute to this situation that we're all in? How can we contribute to the safety of the patient?"* The primary concern was the need to shield the hospitals from floods of patients. However, there was also a need to ensure the expected standard of care. An informant said: "The *lack of PPE underscored the importance of providing online and digital follow up."*

Identification of Potential Mitigation and Fortification Actions

The 'digital follow up' approach would cater for other possibilities as well, such as the quarantine of teams/shifts of health care workers following exposure, which could have rolling implications on available staffing resources. Remote patients follow up meant such personnel could still perform their duties even though confined to their homes. The main objective of this process within the context of the study was the scanning of the operational environment to identify avenues to solution and counter measures that could be introduced for COVID-19 patients. Informants said: *"we looked up on the opportunity to use these experiences following up patients with COPD, heart failure and diabetes, that it would be possible to develop an application for follow up of COVID-19 patients*". The changes were sourced from existing digital solutions within the health services operations. Speaking of the remote patient monitoring tool, an informant said*: "so naturally, of course, like we've already mentioned that the technology was already there."* However, the mere availability of a potential solution was not enough. Further considerations and consultations needed to be made concerning how to adapt the system infrastructure for use in COVID-19 patient monitoring. This prompted information gathering and planning activities on the disease. The presence of predefined organisational structures and partnerships with the local hospital and technology vendor are highlighted as key contributors to the hastened progression in this phase of the project. The need for the determination of relationships that exist within these structures and among stakeholders was also a necessary step.

Design and Continuous Refinement of Structures and Resources

Following the identification of organisational and technical adaptations crucial for crisis mitigation, this process focused on the development of a COVID-19 module for the approved digital follow-up tool. Multiple stakeholders comprising clinicians, technical, and administrative personnel were brought to the table and worked collaboratively over a two-week period to make the necessary changes to the existing remote monitoring solution. Informers recall: *"we had to figure out how can we make that adjustment and it be good and dynamic towards the patients, so they feel they're taken care of*." This collaborative, joint effort, involving human resources from multiple organisations is a demonstration of inter-organisational trust among the various collaborative decision-makers and stakeholders. Among the series of changes that was required, the first was an assessment of the existing distribution strategy. The service has previously been rolled out to patients using custom designed kits, but the decision to migrate the service to an application and a web interface was made. The application and web interface would be replacements for the tablet used in the previous monitoring regime. This adaptation meant a 'bring your own device (BYOD)' protocol was possible. This was ideal in the interest of scalability, prompted by a need for wider distribution numbers (to cater for the anticipated COVID-19 patient numbers), dynamism, and ease of access. Secondly, the development of the follow up algorithm that would be used in patient monitoring was required. Informants stressed: "*there was no algorithm to follow up people with COVID-19. And we didn't at that time have very many facts about what to predict or that algorithm.*"

The project team quickly realised it was beneficial to assume an iterative design and development approach. There was experience in monitoring Chronic Obstructive Pulmonary Disease (COPD) patients, but a new monitoring algorithm needed to be developed for the novel COVID-19. A group of medical doctors, including a pulmonary disease specialist was set up to participate in the algorithm development. There was a clear need to monitor patients before, during, and beyond peak infection, for varied reasons. Concerning patients in the early phase of infection, the project leads shared: "*My hypothesis was if you don't know how they're doing (before hospital admission), you don't know how to prepare the (health) system. So do we prepare for forty patients in the healthcare system, or do we just prepare for five?"* Another team member shared about the value in end-stage/post-infection monitoring: "*it might also be of interest to follow up long term effects of COVID-19 for those who have only partly recovered, and not necessarily recovered completely.*" Such an approach enabled continuous refinement of the patient registration questionnaire and follow up algorithm as added information became available. It also meant there was added value, an opportunity to harvest data on the long-term patient recovery patterns from the disease.

Due to time limitation, and the impending crisis, the design and implementation were expected to happen in tandem. The project lead recalled: "*my project (approach) is just start stop and make improvements there and then do another one (pilot test) and go back and forth and optimize as we go forward. But that mindset is not a culture here, and they give good reasons for it sometimes.*" Typical testing protocols were not possible. Some of the test subjects used included, clinical staff that had contracted the disease, family members and close contacts of people involved in the system development. Interestingly, due to changes in user demographic (previous users were elderly) and roll out strategy (BYOD) there were far reaching security implications that needed to be considered. A lot of emphasis was placed on securing the application, the system would manage patient data and be susceptible to attack. It needed to be secured. Two rounds of risk assessment and penetration testing were conducted by an external service provider before the level of risk was deemed acceptable. Informants recall: "*My nightmare was a headline in the papers about a patient data leakage. Because we were going from an iPad tablet form working on 4g, where the risk is really low*".

Implementation & Post Crisis Adjustments and Development

Following the initial rush, COVID-19 patient numbers were not so high in the first wave (March – June 2020). The solution was not immediately deployed for use in the health services. The informants describe this period as a brief intermission, which allowed them an opportunity to take pause for reflection. The time allowed for extensive assessment of the system, with in depth consultation of experts. The project lead recalls: "I *had some discussions with some friends in a pretty big international network, some out of Italy and out of Asia, US region, to see how they are doing it, application user managers and designers, I needed to get some feedback*." Rather than simply being a summarization of past activity, the feedback informed a learning process at this stage that was used in further refinement of the system. The team demonstrated a keen sense of awareness and willingness to remain alert to the changing environment and the possibility of expansion. An imagination of the possibilities and additional services that the system could provide was also evident. In reference to the onset of the second wave of COVID-19 infections, one of the informants said: *"I thought about how it should have contributed, contributed to the security of several other patients than just COVID…we have seen now as this society is in a new lockdown, depression rises, loneliness rises, and suicide was so high. And I think if society was more mature, to just give this solution to anyone that just needed a health worker to be on the other side, then I think we would gain much more than we ever can anticipate."* Interestingly, the project team members are ready to consider the long-term integration and benefits that can be realised from a wider scope of usage for the system. There are unanticipated issues in the integration of the service into existing health systems and the general practitioner's (GPs) clinical practice. A mixed reaction to the solution is unsurprising, the health service is widely known to be 'conservative' and required to follow strict procedures and policies even in crisis. One interviewee stressed: "*work changes in routines are difficult to implement in the system. It is conservative… They know their existing routines. And they get insecure when it's new way of working.*" It is understandable that clinicians would be concerned about the extent to which the information furnished by the system could be trusted. In contrast, a GP that had been part of the development process and implemented the system in their practice was optimistic. He stated: "we *had to be quite strict, with those questions (algorithm), and they had to be in a way that was true with our clinical practice… it has to be a solution that is quite convenient into the main practice. It must not disturb the practice."* The project team's reflection activities emphasize the immediate revision of prior knowledge in the face of emergent trends, shaping and influencing an operational environment that responds to the trends. Collaboration, adaptation, innovation, novel thoughts, and rapid idea development are highlighted as critical factors leading to the successful radical improvisation process.

Data Analysis

As mentioned in the Data Analysis section, the analysis is conducted in three phases as set out by Gioia (2013). This was an iterative process comprising multiple rounds of coding into the first and second orders. Fig.4 is a snapshot of the process, detailing the progression from data to theory, giving examples of how first order themes are subsequently linked to crisis management theory.

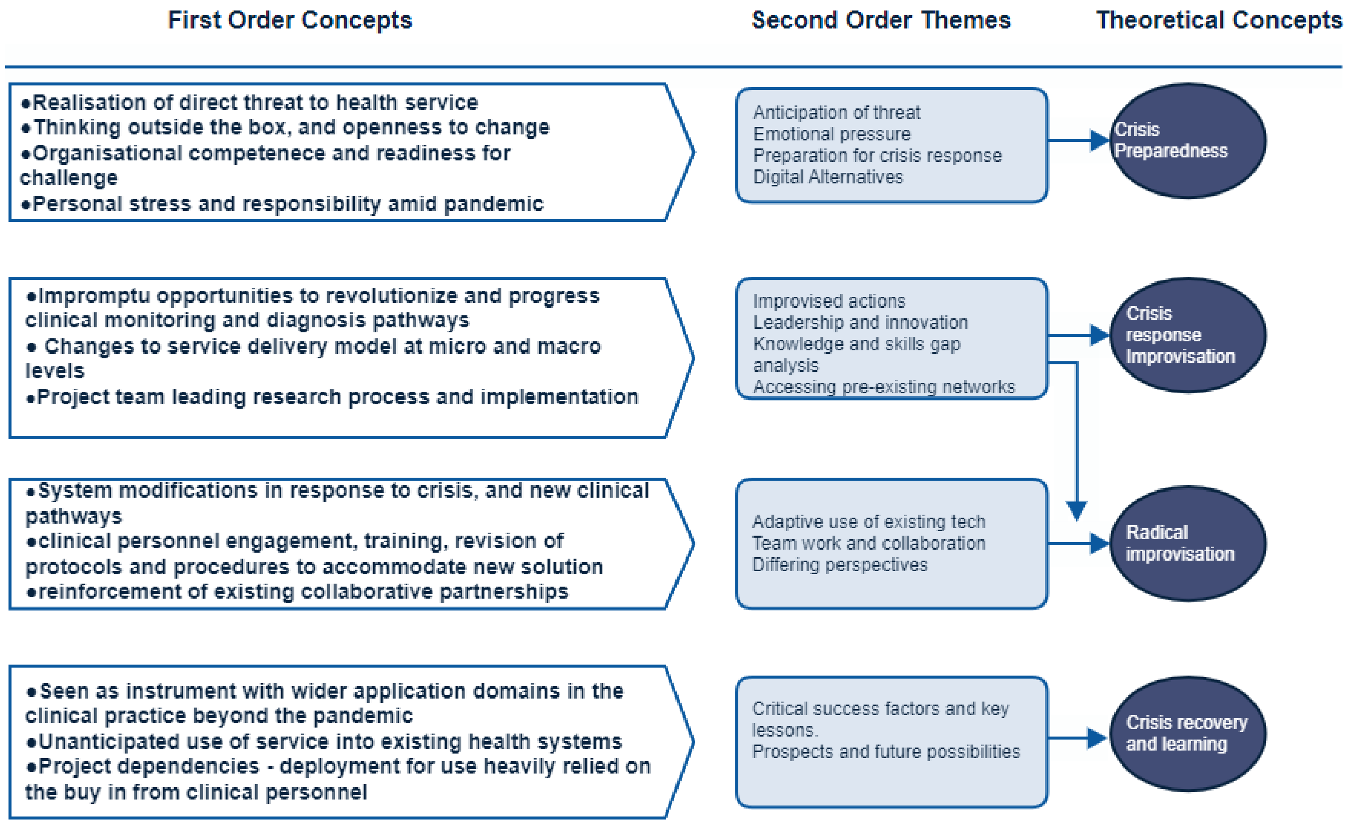
In the following section, a discussion of how radical improvisation of health technology occurs and logical insight into the subprocesses that structure it are proposed.

Discussion

The empirical case provides the opportunity to investigate how health technologies are included as resources and contribute to crisis response efforts in a health organisation. A key assumption in the analysis of the data is the consideration of radical improvisation as an innovation process of technological adaptation and optimization due to crisis (Weick, 2017). This approach makes it possible to factor in established practise, structures, routines, and resources that contribute to crisis response efforts (Suarez & Montes, 2019). The findings in the previous section described how the emergence of the COVID-19 pandemic led to the improvised use of digital-follow-up. A sequence of steps that reveal the radical improvisation of technology to be a process comprising various subprocesses is deduced. The sequence of these steps is illustrated in timeline format as seen in Fig. 5, overleaf.

The key steps and processes identified in Fig. 5 provide an overview of the organisation's operations as it transitioned from one phase of the project to the next. Nine milestones are identified in the project progression. The subprocesses identified were Perception and Mitigation of threat; Application Development and Continuous Refinement; and Implementation and Consultation-based Adjustments. These subprocesses were corroborated using crisis management and improvisation literature (Pan et al., 2012; Pearson & Clair, 1998; Suarez & Montes, 2019). This was to check that they were verified processes and steps in documented studies. A novelty was how the technology developers emphasized the need to 'rethink' the software

Figure 4
Snapshot of Analytical Process Following Gioia Methodology



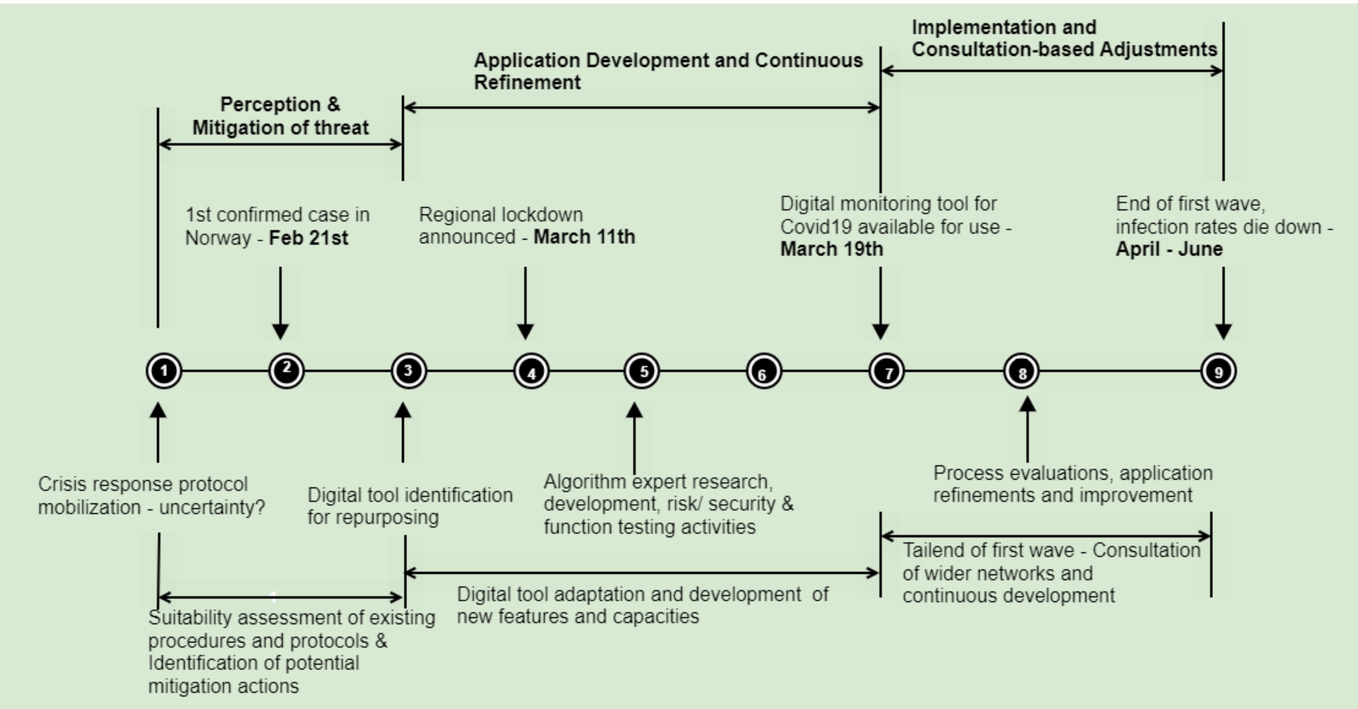
development procedure and make concessions, for instance- when Org-X undertakes to design the web user interface (a service they ordinarily do not provide at all) out of necessity. Therefore, additional scrutiny was applied to identify changes in pattern, enactment, and ordering of the known and novel processes (Suarez & Montes, 2019; Weick, 2017; Whitelaw et al., 2020).

The technical team's ability to respond to the rapidly evolving user requirements efficiently, and effectively while facing situational stress and time pressure is a demonstration of flexibility and agility. Based on the timeline and the processes and steps identified in Fig. 4, it is possible to logically arrange the identified subprocesses and steps and map them into a conceptual process model. A key observation in the data, is the participants emphasis on continuous learning – during and after the crisis highlighted in the Continuous Refinement, and the Consultation-based Adjustments subprocesses identified in Fig.4. Learning during the crisis is characterised by rapid intra-crisis learning and gradual inter-crisis learning. Intra-crisis learning aims to improve response as a single crisis unfolds while inter-crisis learning thrives to prepare and anticipate for probable future crises and improve general operations(Pursiainen, 2017). COVID-19 presents as an interesting scenario, as most countries experienced it in 'waves of infection', and in our analysis we characterise each wave as a new crisis cycle. The different learning points and scenarios experienced in the case are detailed in the table below. According to our interpretation, rapid intra-crisis learning is experienced during an active infection wave, and slow inter-crisis learning is enacted in between infections waves.

Table 2 provides insight into the practical implications on crisis triggered learning and is one of the novel contributions of the study. It is arranged in classifications that reflect the processes detailed in the Results section: illumination Knowledge building, Preventability, Management, Technical, and Decision-making aspects of learning. Knowledge Building describes matters related to skills gaps or capacity related necessities and the mitigatory actions taken to fill them now and in the future. Preventability and Anticipation describe the thinking concerning future pandemics and other disasters. Management/Coordination and decision-making focuses on the managerial implications while Infrastructure and Technical risk contemplates the technological elements and their handling. This is ideal, as it accounts for not only technical requirements of the digital technology, but the organisational and social system contributions.

Recall that the research question is: How does the radical improvisation of health technologies emerge and develop during a health crisis? The discussion so far provides an explanation for the emergence of radical improvisation providing a logical basis to determine the practical

Figure 5
A Logical Sequence of Key Steps and Processes



implications of the study. A theoretical conceptualisation will provide insight on how it develops.

Fig. 6 is a process model derived from the steps and subprocesses identified in Fig. 5. It highlights the relational aspect of radical improvisation subprocesses to the established structure and routines in the health organisation. This conceptual process model is novel because it factors in a combination of empirical evidence and literature to provide a coherent representation of the sub-processes that structure the radical improvisation of a health technology. As a convenient starting point and to illuminate the connection to the crisis management cycle, the processes in Fig. 6 are mapped against the first two phases of the crisis management life cycle – preparedness and response (Pearson & Clair, 1998; Pursiainen, 2017). Milestones 1-7 from Fig. 5 are classified under 'Preparedness' in the process model, and the remaining milestones classified as 'Response'.

Radical Improvisation begins in the preparation phase, both technical and organisational aspects are reflected. Resource and Policy fortification describes the early attempts made in the health organisation to reinforce and strengthen the system for shock from the pandemic. Resources reference human and digital elements that are assembled and reallocated to fortify existing structures. Mitigation and Capacity Building are necessitated by the information and skills gap created by the COVID-19 pandemic's novelty. Implementation and Refinement are the culmination of preparatory activities but are not closed ended subprocesses. All three subprocesses linked to Preparedness are connected by 'two-way' arrows to reflect the iterative nature of the processes, which also includes a learning loop. The learning loop in the Preparedness phase is representative of the inter-crisis learning activities, and steps taken to ensure reduced susceptibility to any future crisis. The Response phase comprises three subprocesses, the system is under implementation in the crisis Adapted/ Modified protocol and the radically improvised technology must be evaluated. Interestingly, the long-term applicability of the system and possibility of integration into legacy systems must be considered at the response phase as well. Another learning loop is reflected in this phase, representative of intra-crisis learning, however, as seen in the process model, both learning loops feed into

Figure 6
A Conceptual Process Model for Radical Improvisation of Digital Health Technology

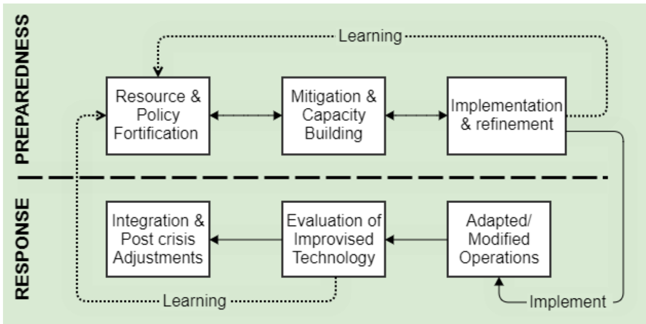


Table 2
Intra-Crisis and Inter-Crisis Learning Outcomes

	Rapid intra-crisis learning	Slow inter-crisis learning
Knowledge Building	• Capacity building to facilitate digital solution development. • Shift towards and heightened interest in digital technology supported solutions. • Digital solution design documentation. • Personnel training for nurses etc.	• Improved attitudes to digital technology and increased usage. • Change in risk perception, more trial-and-error based learning. • Continuous iterative learning and development strategies.
Preventability & Anticipation (future pandemics or other disasters)	• Notable waning 'alertness' as the pandemic went on longer. • Use of first wave of pandemic as a fire drill exercise.	• Planning for expected health care worker shortages in the next 20 – 30 years. • Digital solution use by mobile health care workers, mental health patients etc.
Management	• Presence of trust and enabling preconditions for successful improvisation. • Openness to 'outsider' innovation, using a less incremental and more radical approach.	• Creating incentives for the development of business models for technology deployment in the health sector. • Developing an affordable health care model. • Long term planning for project-based learning.
Infrastructure & Technical Risk Analysis	• Changing patient demographic, possibly a good and terrible thing. • Robust security testing. • Patient autonomy and increased independence.	• Integration of user experience focused design, and systems integration. • Heightened security models that consider the social aspects of the modern health systems.
Coordination and decision-making	• Mindfulness – harmonisation of all the moving parts that are required for the system to work. • Decentralised emergency decision making structures.	• Possibility to deepen partnerships and collaboration at various levels within the organisation. • Maintain the digital work format – proved efficient and effective.

overall resource and Policy Fortification processes. The subprocesses are in the response phase are linked by unidirectional arrows, with focus on organisational refinements and policy updates. The process model provides novel insight into the embedded subprocesses of the radical improvisation of digital health technologies. It gives insight into the technical and non-technical compositions and how they interact to generate adequate crisis response and influence future decision making and policy formulation. The next section focuses on discussing the theoretical implications of this study.

Radical Niche Construction: Crisis as Opportunity and Calamity

The traditional theoretical understanding of crisis and crisis management captures the calamity and challenges that the occurrence of crisis may create in an organization. However, this study has highlighted the possibility of opportunity arising from untoward conditions (Gkeredakis et al., 2021) and existing literature does not fully account for this possibility. The operational environment in this case if defined by the technical and non-technical constituents of the health organisation. The COVID-19 pandemic poses an undeniable existential threat to health organisations and prompts a 'natural selection' of the most efficient means of survival (Whitelaw et al., 2020). In this case, actors in health organisations (knowingly or otherwise) have made a series of decisions and taken actions that lead to the modification of the local operational environment (Laland et al., 2007). The observed adaptations in technology, health services protocols, and institutional logics in response efforts to the pandemic are a representation of the environmental modification that eventually opens the door to the possibility of deepened use of the technology. An example of such expansion is the decision to use the digital health technology to gather data on the novel virus, going beyond simple adaptation through the exaptation of previously unused secondary features (Magutshwa & Radianti, 2022). This observation is not only consistent with technology evolution but affirms niche construction literature by illuminating the growth spurt within the health organisation prompted by decisions and actions taken during a calamitous event. The COVID-19 crisis created an abundant 'demand' for digital alternatives, forcing the hand of an otherwise highly conservative health sector. Telemedicine and other digital health technologies have thrived during the pandemic, with improved attitudes to technology and increased appetite for health service models that are not centred on human contact. This is the construction of an operational-environment niche for digital health technologies. Radical improvisation, adaptation, and exapted innovations are crisis response processes that resulted in a pro-digital health technology trajectory that accelerates the technology evolution dynamics and yields the possibility of agile evolution pathways within health organisations (Fischer & Baskerville, 2022). This resonates with technological evolution that thrives on the availability of an assortment of radical innovative technologies that can be easily recombined and innovatively reconfigured (Odling-Smee et al., 2013).

The emergence of a new niche is often accompanied by the exploration of the form and process of radical improvisation is nuanced by the operational-environment niche carved by the COVID-19 pandemic. While the radical improvisations, technology adjustments, adaptations, and exaptation are slotted into pre-existing health organisation operations and prove useful steps in the short term, they also invent and construct the new operational-environment niche in the long term. This raises the possibility of health organisations and digital health technology growing and evolving in unanticipated directions. Participants in the study affirm this thinking when they describe a 'forced digitalization' that resulted in them making countless leaps and bounds in the wider adoption of the digital health technology. This notion alludes to radical niche construction theory, which states that "new technology markets cannot emerge and evolve without societal application of new technologies" (Andriani & Cohen, 2013). That adaptation, innovative processes, and exaptation explain the gradual progression of a niche from one into the next. This is evident in how the digital-follow-up solution is introduced to the health services system of the Fundi region as a welfare technology but swiftly changes due to a change in operational environment niche. Existing modules are co-opted for a new function through radical improvisations, adaptation and exapted innovations and while there is technological continuity, there is a functional discontinuity. The niche construction perspective emphasizes the opportunistic aspects of crisis environments and resolves the matter of the emergence of new technological capabilities in crisis situations (Cattani, 2008). It also highlights a new ideology on technological change and evolution. In this paper, we have contributed to crisis management and information systems literature by developing a conceptual process model that describes a crisis innovation process. Therefore, we introduce six embedded processes of radical improvisation. On a macro level we also propose a novel theoretical interpretation of the development of digital health technology in crisis conditions that is based on a multilevel understanding of technological change through use of an evolution framework. The theoretical analysis investigates the role of crisis as a trigger of the niche construction process and highlights how recurrent innovative spurts can create avenues for future technological evolution. We map the structural and process sequences through which radical improvisation contributes to the development and emergence of a new niche. The use of NCT is novel and the proposed understanding of a co-constructed environment niche that blends parallel learning forms, including social, technical, and physical elements. The contributions of our paper provide deepened understanding of the evolutionary processes and functions of complex health organisations.

Conclusion and Limitations

The work in this paper has focused on the radical improvisation of ICT in crisis response, an under-developed area of research in crisis management and information systems literature. The empirical study clarifies how existing digital technologies in health organisations can be repurposed in times of crisis to meet changintg operational needs and generate a response to crisis. The main contribution of the paper is the Radical Improvisation of digital health technology process model which enhances the unidirectional type of incremental improvisation widely discussed in extant literature. It outlines a continuous, iterative radical improvisation process comprising interpretation, response, and learning from the operational environment to inform the parallel technology development process.

Despite this contribution, the findings must be considered within their limitations, and these are twofold. Firstly, this paper is based on a solitary case study conducted in the period July 2020 – January 2021, it is possible there have been further changes that are not within the scope of this study. Secondly, the findings focus on the processes outlining the development of a health technology and neglect to discuss the core attributes of the technology that facilitate the improvisation process. These are potential future research directions that other researchers may consider in future.

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BEYOND CRISIS RESPONSE: LEVERAGING SOCIOTECH-NICAL TRANSFORMABILITY

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Research paper

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Abstract

We investigate the organizational capacities required to leverage digital infrastructures both (1) in response to crisis and external threats, and (2) in realizing the transformative potential associated with the digital infrastructures. Thus, our research question is: What is required for organizations to be able to transform in the face of disruptions and breakdowns? We report from an empirical study of a digital infrastructure innovation process in the context of the COVID-19 pandemic, which involved extensions and novel development of both the technology and the former service model. While the literature on organizational resilience offers us a conceptual framework to identify organizational capabilities, we lean on literature that foregrounds transformability as a crucial aspect of resilience. We discuss organizational capacities which are considered vital in realizing the potential for transformative crisis learning in sociotechnical systems that builds adaptive capacity and influences the enactment of future organisational routines.

Keywords: organizational resilience, transformability, COVID-19 pandemic, digital infrastructure.

1 Introduction

In these times we experience that the foundations we believed were stable and dependable can change abruptly. For instance, when pandemics, disruptive weather events, or socio-political unrest upset routine operations, the inherent fragility of the technological and societal infrastructures we took for granted is revealed (Paton & Buergelt, 2019). Facing future uncertainties, the ability of humans to improvise, adapt and learn will be a crucial part of future skill sets (see Durugbo et al., 2021; Toft et al., 2005). We need “to acquire dynamic capabilities to adapt and learn in the face of rapidly changing environments” (OECD, 2021; Lampel et al., 2009). These issues represent the ulterior motivation for our focus on the capabilities required to meet such an uncertain future.

Future-oriented methods have already been introduced in various design- and policy-oriented discourses: Foresight studies may employ horizon scanning, forecasting, or scenario planning in attempts to include the possible futures into decision making – either through extending the horizons for thinking into longer-term timelines or through deliberate envisioning of alternative futures. Future studies encompass a host of various theories of change at micro-, meso-, and macro-levels (Minkkinen, 2020). UNESCO points to the capability of Future Literacy as “an essential competency for the 21st century”, “a universally accessible skill that builds on the innate human capacity to imagine the future” (UNESCO, n.d.), where its value lies in countering the poverty of the imagination. Within technology-oriented design discourses, we can find applications of anticipatory design (Clèries & Morrison, 2020; Morrison et al., 2020), design fiction, speculative design (Auger, 2013), and transformative service design (Alkire et al., 2020). Within the information Systems field, there is acknowledgement of how unstable environments increasingly yield fast-changing technologies and scholars posit that a mindset shift to embrace the ‘unstable’ is needed (Fischer & Baskerville, 2022). There is a dearth of analysis of what such future-oriented organizational capabilities look like in reality, with limited attention to future oriented study forms, with some exceptions, (Chiasson et al., 2011; Hovorka & Peter, 2021),

It is pertinent for organisations operating in the current climate to develop insight into the capabilities required to meet a future characterized by non-reducible uncertainty, vulnerability, and emergence. Often such capabilities are denoted as *resilience*, a term originally coined to characterize the capacity of socioecological system to recover from a crisis (Holling, 1973; Walker et al., 2004). In the organisational context, resilience is characterised as "the maintenance of positive adjustment under challenging conditions such that the organisation emerges strengthened and more resourceful" (Vogus & Sutcliffe, 2007). Our interest lies in the notion of positive post-crisis outcomes, that strengthen the current entity and future entities. We will build on this organisational resilience literature, which we review in the next section, and specifically target the capacity of transformability.

The research question we address in this paper is: ***What is required for organizations to be able to transform in the face of disruptions and breakdowns?*** More specifically, we examine what it takes to mobilize digital infrastructures in a crisis response situation and which capabilities are required to not only respond but to realize (some of) the transformative potential associated with digital infrastructures. We report from an empirical study of a process where a pre-existing digital infrastructure was repurposed as a crisis response measure. A group of healthcare innovators deployed a digital solution for following up on patients with a confirmed COVID-19 infection at home. Beyond repurposing, this also involved extensions, deepened usage, and novel development of both the technology and the service model. Thus, we argue that this goes beyond just a crisis response to also constitute an innovative expansion of the health services.

In the following section, we review related literature on resilience, while section 3 presents the background for the empirical study and the research approach. Section 4 provides our analysis of the presence and absence of resilience capabilities in the case. The discussion follows in section 5 before we conclude the paper in section 6.

2 Resilience in sociotechnical systems and organizations

2.1 Resilience in socioecological and sociotechnical systems

Following on from Holling's (1973) seminal work on resilience that focused on the 'resistance and stability of ecological systems', the term has migrated to other scientific fields such as socioecology (e.g., Walker et al., 2004), systems theory, and sociotechnical systems research (e.g., Heeks & Ospina, 2019; Rehak et al., 2018). The latter research domains have developed insights into a systems' ability to respond to external stressors where resilience is reflected in a system's preparedness for, absorption, recovery from, and adaptation to a disruptive event. Rehak et al. (2018) draw distinctions the authors deem necessary for the assessment of resilience in sociotechnical systems – highlighting that there are technical (robustness, recoverability) and social/organizational (adaptability) aspects to resilience that must be assessed simultaneously. The authors unpack adaptability to comprise innovation processes, education and development processes, and risk management. However, this dichotomous representation of technical and organizational resilience by Rehak et al. (2018) does not consider the interconnectedness of elements in sociotechnical systems. Similarly, Walker et al. (2004, p.3) define resilience in the context of large disturbances as "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks." The authors emphasize that resilience is only one out of three main attributes necessary to explain system dynamics, the other two being adaptability and transformability. While in Holling's (1973) early work the emphasis is placed on a restoration to a known state, later studies in socioecological and sociotechnical studies are oriented towards the continuous retention and carrying forward of necessary lessons learned during a disturbance, i.e., adaptability and transformability (Amir & Kant, 2018; Walker et al., 2004)

In this paper, we are especially interested in transformability, which is required at points when "it may prove necessary to configure an entirely new stability landscape" (ibid., p. 6). The capacity of transformability is defined as "the capacity to create untried beginnings from which to evolve a new way of living when existing ecological, economic, or social structures become untenable" (ibid., p. 6). In focusing on transformability, we follow Amir and Kant (2018) who transpose the discussion from socio-ecological systems where it emerged (Walker et al., 2004), to sociotechnical systems. They argue that sociotechnical systems tend to have smaller scales than socioecological systems, and that intentional, actor-driven change is more significant in sociotechnical systems. Therefore, the capability of *transformability* will be more significant in these contexts and therefore they argue for an understanding of sociotechnical resilience that foregrounds transformability.

A fundamental aspect of this transformability discussed by Amir and Kant (2018) alludes to sociotechnical change. Sociotechnical change is characterised by systemic adjustment/ updates to routines, processes, and practice (Sarker et al., 2019). Based on the premise that change is central to sociotechnical systems dynamics, we should aim to design not only resilient systems that can "bounce back" but should also consider "how quickly and robustly a sociotechnical system transforms from one state to another" (ibid., p. 11). This is further supported by recent literature in sociotechnical change theory, that asserts the temporary nature of 'stability' in modern sociotechnical systems that are now seen to be characterised by being prolonged states of 'unstable equilibrium'. In such configurations, the surface-structures are continuously unstable while the deep structures maintain stability (Harder Fischer & Baskerville, 2018) . This thinking is consistent with recent studies that highlight the possibility of 'bounce forward' resilience (e.g., Russpatrick et al., 2021) where learning, from either positive or negative experiences, is a prerequisite for system viability and secures future safety. Any learnings are incorporated into future system configurations and arrangements (Lundberg & Johansson, 2015). Extant literature is rich in theoretical conceptualizations highlighting that disruption can create opportunities for learning, adaptability, and transformability through a sociotechnical resilience process (Russpatrick et al., 2021; Sakurai & Chughtai, 2020). If we acknowledge that modern sociotechnical systems are in unstable equilibrium, it is implied that the surface social and technical structures in the systems are fluid, providing possibilities for continuous reconfiguration, i.e., dynamical stabilization seen in transformability. We understand that the future favours sociotechnical system models that promote this dynamic interplay between resilience and change. There is a call for practice-oriented studies that provide an understanding of the nature, and the requirements for transformability to occur in real-world contexts (Amir & Kant, 2018) and to develop sociotechnical change models reflecting a balance between flexibility and stability (Fischer & Baskerville, 2022). In this paper, we wish to examine the nature of transformability in contexts of even smaller scale (sector-level sociotechnical systems) than what Amir and Kant (2018) discussed, such as transportation, electricity supply, etc.

2.2 Resilience in organizations

In organization-focused research, resilience is conceptualized and studied as a meta-capability comprising a combination of organizational capabilities and routines (e.g., in Lengnick-Hall et al., 2011) with the potential to capitalize on a perceived disruption through a positive adjustment (Vogus & Sutcliffe, 2007). We are interested in capabilities at the organizational level, and while there exists a significant research stream on such organizational capabilities, they are, however, usually defined related to resilience during crisis rather than specifically as capacities for transformability. Transformability can be used to introduce positive routines and actions that promote resilience (Kayes & Yoon, 2020). Based on Teece et al.'s (1997) notion of dynamic capabilities, resilient organizations are often seen to possess capabilities that enable them to respond to changing conditions through adapting, integrating, and reconfiguring internal and external resources and competencies (Teece et al., 1997).

Some researchers also incorporate notions related to anticipation. For instance, Stephanie Duchek (2020) identifies three successive resilience stages – anticipation, coping, and adaptation – and assigns important organizational capabilities to each of these stages (Duchek, 2020). She defines "organizational resilience as an organization's ability to anticipate potential threats, to cope effectively with adverse events, and to adapt to changing conditions." (ibid., p. 220). To **anticipate** potential threats and critical development, she lists three specific capabilities: (1) the ability to observe internal and external developments, (2) the ability to identify critical developments and potential threats, and (3) to prepare for unexpected events. This anticipation yields a resilience potential that is not presently evident or realized, only latent. In the **coping** stage, the capability of (1) accepting, (2) developing solutions, and (3) implementing solutions are key. For this, improvisation in the form of recombination of actions already in the organization's repertoire is crucial, as shown by (Weick & Roberts, 1993). It is worth noting that the ability to develop solutions not only means idea generation, but also coordination, and that actually implementing solutions that have been developed may be challenging. Finally, the **adaptation** stage indicates the ability to learn and/or transform after critical situations have occurred. This ability refers to adjustments following crises and is directed toward organizational advancement long-term learning. Adaptation includes two types of capabilities: (1) reflection and learning and (2) organizational change capabilities. Duchek's model supports the stages of resilience, highlighting how resilience precipitates a crisis, prevents escalation. The adaptation stage sparks the central consideration in this paper of transformability.

2.3 From resilience to transformability

While Duchek's three stages of resilience and the associated organizational capabilities give us a starting point, we wish to focus on transformability rather than generally on resilience, we return to Amir and Kant (2018). They define three core aspects of the organizational and/or institutional reconfiguration associated with transformation - informational relations, sociomaterial structures, and anticipatory practices. Informational relations can strengthen resilience through "designing effective informational networks, implementing cross-scale information couplers, regulating the flow of information, and making information available to the targeted audience proactively during crisis." (ibid., p. 12). Regarding the sociomaterial structures, Amir and Kant ask "how flexible is the sociomaterial structured and is it designed such that it will allow the sociotechnical system to undergo transformation to avert disaster and to metamorphose in the aftermath of disaster? "(ibid, p. 12). Moreover, they remind us that "these structures enable certain practices while curtailing others" and that "a notable aspect of these sociomaterial structures is their interpretive flexibility due to interaction with various groups and subgroups" (ibid, p.13). The ability for technologies to be used in different situations by different user groups "is both supported and limited by the technical constitutions of the artifacts". (ibid., p. 13). Finally, anticipatory practices refer to "the construction of regular activities aimed at anticipating possibilities of what would occur in the future" (ibid., p. 13). This does not only focus on bouncing back to become fully operational again, "but also the possibilities of averting disasters and extending the horizon for safe functioning of the system" (ibid., p.13).

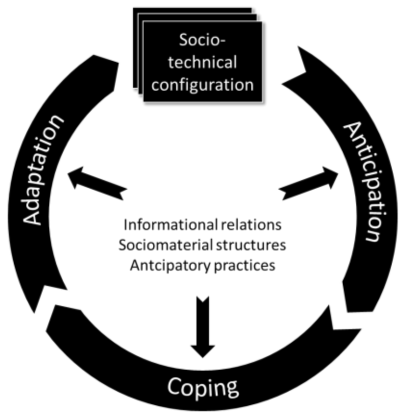

Figure 1. Sociotechnical transformability

The combination of Duchek's (2020) process model of resilience and Amir and Kant's (2018) facets of transformability constitutes our analytic framework of *sociotechnical transformability*. In Figure 1 we fuse Amir and Kant's three core aspects of transformability and show how they feed into each phase of the resilience process as modelled by Duchek. It is our understanding that the sequence of events is best structured and understood through the Duchek model, however, to acquire in depth understanding of the reconfiguration, underlying processes, routines, and practise, we infuse the concepts of informational relations, sociomaterial structures, and anticipatory practices into the analytic model and apply them in combination. The relevance of this approach is exemplified in the adaptation stage of resilience which anchors processes of reflection and change that transform lessons into sociotechnical configurations and capabilities that influence future organisational routines and build adaptive capacity. This sociotechnical perspective on the resilience process provides deepened insight into the requirements that enable organisations to pivot into transformation in the face of breakdown/ disruption. The following section provides details related to the background for empirical study and our approach.

3 Case background and research approach

3.1 Case: digital home monitoring of patients

The Agder region in the south of Norway has a population of slightly above 300 000 inhabitants, spread over 8 towns and 25 municipal districts. The municipalities are responsible for the primary health and social care services, which are predominantly public. The Hospital of Southern Norway has branches in three of the towns and employs over 7000 staff. Different electronic health record systems are in use: the hospital uses an Electronic Health Record (EHR) system made for the specialist health services, the municipalities used different EHR systems for their nursing homes and home care services (three different products across the region) and the General Practitioners use other systems (four different products). To facilitate interaction in the fragmented ICT landscape, a shared national broadband infrastructure (the Norwegian Health Network) and a messaging standard allow the exchange of structured digital messages between these different systems, such as referrals, lab requests, discharge reports, etc. Sharing of information among multiple health care actors is highly relevant in the care of patients with complex chronic conditions who often suffer from more than one disease because this patient group is frequently in contact with both primary and specialist health services. This is the reason for the region's long-standing efforts (dating back to 2013) to establish an innovative digital infrastructure that can support the ongoing shared care for this patient group. The targeted demographic was older persons with chronic conditions (e.g., diabetes, heart disease, or chronic-obstructive pulmonary disorder).

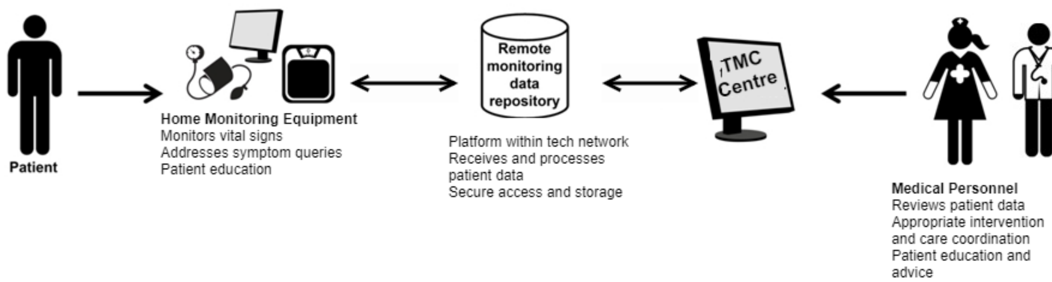

Figure 2. Service concept for patient facing infrastructure

The initial deployment of the solution (as depicted in Figure 1) comprised a combination of technical and organizational infrastructure. A patient-facing frontend was based on tablets with blue-tooth-connected devices, and a health personnel backend that showed data from all patients was installed in a response centre (called a telemedicine central or TMC) which was staffed by health personnel. There were established agreements with hospitals and general practitioners (GPs), who had access to the same platform and data. At the time of the start of the pandemic, these services were provided in the context of a region-wide project. This pre-existing solution is the focus of our case study.

In the time leading up to the COVID-19 outbreak being officially declared a pandemic by the World Health Organization on March 11, 2020, the regional leadership had mobilized crisis response protocols in the region. Early media reports of unfolding events in other countries (e.g., Italy) created anticipation of similar infection trends locally, which drove efforts for crisis preparation and mitigation. As a direct result of these initial efforts, a decision was made to repurpose the digital infrastructure that was used for patients with chronic diseases. It was updated and deployed already on March 19th, 2020. In Figure 3 we offer a timeline highlighting the key phases in the process during 2020.

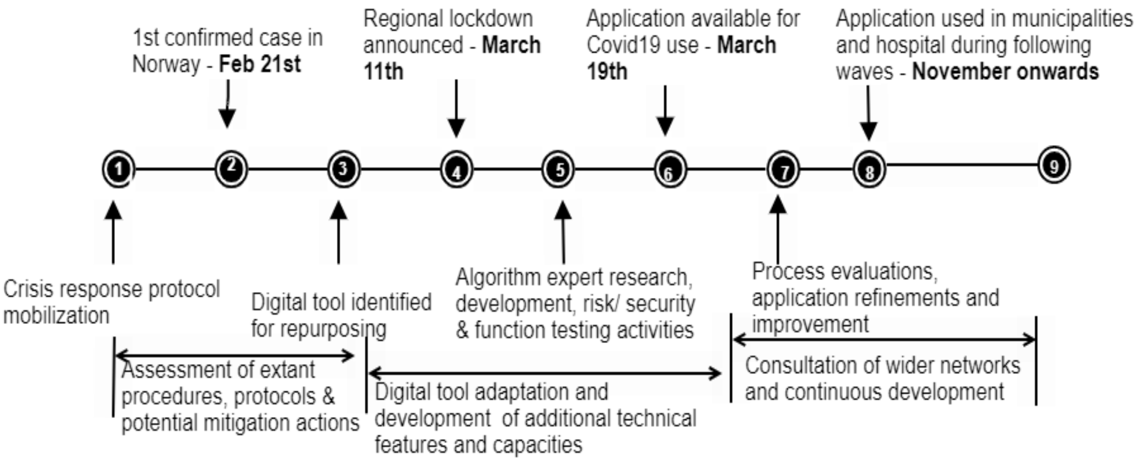

Figure 3. Case chronology

3.2 Research approach and data gathering

We have conducted a qualitative case study with the aim to characterize organizational behaviour during the anticipation, coping, and adaption stages of the pandemic. The case encompasses the involved healthcare actors within the region, centred around the project team behind the patient-facing infrastructure (hereafter called PFI). The PFI project team worked under an overall, regional project organization that comprised all regional municipalities in a formal structure created to support the implementation of digital solutions. In our material, three different healthcare organizations are salient, one large and one small municipality, as well as a hospital. The backdrop for this research is a long-term (~10 yrs.) research collaboration between the University and healthcare actors on establishing a patient-facing infrastructure (PFI) for remote monitoring of patients with chronic diseases. More specifically, since March 2020 there has been ongoing contact with frequent update interviews, and a formal project-based collaboration since July 2020.

The data collection has been based on these frequent update meetings, informal discussions, and formal interviews with involved staff in both the municipal team and the hospital. A series of 16 formal interviews totalling 30 hours in duration, over a 2-year period were conducted and transcribed. Interview subjects included the PFI project team (4 persons), Org-X (the technology vendor; 2 persons), clinical personnel, and crisis managers from the municipalities (3 persons) and the hospital (2 persons) in which the solution was implemented. The interviews were conducted in either Norwegian or English with a blended format of digital (on Zoom) and physical meetings when possible. Analyses of policy documents, guidelines, and reports produced during the project period (2020 - 2021) which describe the solution and the experiences during the development, implementation, and use phases are also included.

÷	**Position (number of interviews)**	**Organization**
Inf-1	Head of Digital and Enterprise Services (1)	Org-X
Inf-2	Digital Solution Lead (1)	Org-X
Inf-3	Head of Research & Medical Doctor (2)	Fjord Municipality
Inf-4	PFI Project Program Manager & ex Rescue Medic (2)	PFI project team
Inf-5	eHealth Research Innovation Manager (2)	Fjord Municipality
Inf-6	eHealth Advisor (2)	Yaro Hospital
Inf-7	Nurse (1)	Yaro Hospital
Inf-8	PFI Design Lead & ex Nurse (1)	PFI project team
Inf-9	General Practitioner (1)	PFI Project team
Inf-10	PFI Security Lead (1)	PFI project team
Inf-11	PFI Distribution Lead (2)	PFI Project team

Table 1: Study informant profiles

3.3 Data analysis

Due to our familiarity with the case and contextual dynamics in the region, the emphasis of our research focused on the interrogation of the research data to extract practical consequences. This pragmatic approach in organisational processes facilitates the exploration and understanding of the relations between theoretical knowledge and practical actions in context. (Kelly & Cordeiro, 2020). The study explores the project's progression with a specific focus on the capabilities, and organizational skills required in the adaptation and implementation of the patient-facing infrastructure.

The analysis was theory-driven, conducted in two stages, drawing from the sociotechnical resilience analytic framework described in Figure 1. To guide the coding and thematic analysis, we employ Duchek's (2020) three phases of anticipation, coping, and adaptation to structure the empirical material, and identify the underlying organisational processes, capabilities, and functions. This is detailed in the case insights section of the paper. Thereafter, we identify the role of informational relations, sociomaterial structures, and anticipatory practices. We searched for salient actions and decisions at each of the stages, then discuss and unpack the required capabilities from a pragmatic stance in the discussion section. The following section details the key insights from the empirical study.

4 Case Insights: resilience as transformability

Our study followed the design and development of functionality and procedures of the patient-facing infrastructure which was coordinated by the regional PFI project team. In addition, different municipalities and the hospital would follow different trajectories in the implementation of the solution, based on different needs, internal structures, and processes. We here present our analysis according to the three stages of anticipation, coping, and adaptation.

4.1 Anticipation: latent resilience

The three specific capabilities that Duchek (2020) associates with anticipation were: the ability to observe internal and external developments, the ability to identify critical developments and potential threats, and the ability to prepare for unexpected events. Here we describe our observations concerning these aspects. These anticipatory capabilities appear to have been reasonably well supported in the organization. *Inf-3* recalled: "*for those of us who have a background in medicine, and epidemiology, the potential of a possible pandemic was obvious quite soon...we had a plan, the pandemic response plan was not that old, it was used as a basis for the risk assessments on the sector*". This risk assessment involved analysis of the level of exposure the region would likely suffer due to COVID-19 infections and to what extent there were available resources to meet the demands of coping with the crisis. Short-term measures were required to protect crisis management personnel from infection because their good health and availability were critical to the overall outcome of the health service. *Inf-5* recalled: "*We established a crisis organization, and let many persons work from home office… the municipality found resource persons to take part in the work of risk assessments and develop plans to cope with the possible challenges that might come due to infections, especially regarding locking down parts of normal activities".* Responding to the need for social distancing and protecting health personnel by removing them from face-to-face service could lead to unforeseen cascading effects and complications. *Inf-3* recalled: *"other very important things we did was make continuation plans, there was also the dilemma of the consequences of closing - about defining what groups of employees had critical functions. So, it was not clear when the pandemic started."* The existing pandemic response plan was made for an influenza type of pandemic rather than for a respiratory disease that COVID-19 initially was understood to be, implying the plan had deficits, and needed to be revised.

The anticipated rise in infection was of great concern to the health services, but at the same time, there was little knowledge about the disease and little preparation for specific needs such as personal protective equipment (PPE). Thus, the existing capabilities to observe development and identify threats could leverage the preparations that had been made earlier. However, the preparations were not sufficient to encounter this novel threat. In the words of *inf-6*: "*within the healthcare sector, we were not prepared to cope with this kind of the contagious disease like COVID-19…there was also a lack of the PPE, and that underscored the importance of being able to be in contact with the vulnerable groups and to provide online and digital follow up"*. Another concern was related to the projected number of patients, reflected by *inf-4*: "*Thinking how we can help infected patients with COVID-19 to help them stay home as long as they possibly can, without seeking medical attention"*. As an outcome of mobilizing the latent resilience capabilities and assessing them, gaps were detected and spurred the mobilization of innovative coping capabilities.

4.2 Coping: innovation as crisis response

The anticipation capabilities had ensured that the coping response was underway well before the region went into lockdown. *Inf-1* and *inf-2,* personnel from Org-X recall: "*the whole organization actually changed focus within weeks to prepare for the worst-case scenario together with the municipalities*". Following Duchek's (2020) model, after accepting and recognizing the crisis, the capability to develop and implement solutions are key aspects of coping capabilities. This requires improvisation or bricolage, and Weick (1993) argues that novel recombination of actions already in the organization's repertoire is crucial. The importance of such recombination of both informational and sociomaterial relations was evident in this case. At a general level, we see such an improvisation in the choice to repurpose the existing digital infrastructure for the novel needs. The existing patient-facing infrastructure (PFI) was in use for the vulnerable group of older patients with chronic conditions, and recruitment was ongoing for a randomized controlled trial addressing the clinical outcomes of this mode of follow-up. *Inf-4* said: "*We were kind of in the middle of the inclusion of other patients into our PFI study. […] a lot of our patients that we want to include in our study are in the risk groups…my thought was that if we could use our technology and our network … also, because we have a telemedicine central. So, I thought we could just […] take this system and scale it".* Although the system had been in use for a while, the digital platform was not ideal for scaling to cater for the projected COVID-19 patient numbers. Also, the functionality of vitals and symptom reporting had not been designed specifically for the COVID-19 symptoms. Thus, several revisions and changes needed to be considered. This required further development and mobilization of resources, both in terms of clinical and technical expertise and resources.

4.2.1 Latent network relations enable emergent response teams

While the digital PFI solution had been used for both patients with diabetes, heart disease, and chronic obstructive pulmonary disease (COPD), none of the screening algorithms in use was appropriate for

COVID-19 patients. The development of a custom patient screening algorithm was thus a key step in developing a solution. For this, an ad hoc team of medical doctors was summoned. This drew on informal networks within the region and included a pulmonary specialist who had participated in developing the COPD algorithm earlier, as well as GPs with experience in digital patient follow-up. Throughout a few days, this team (meeting only virtually) iterated on the pre-existing COPD algorithm, taking away some symptom measures and adding others. All the time the team would consider the emerging knowledge on e.g., symptoms and progression from official sources such as the World Health Organisation, and the National Directorate of Health. This is an example of a coping capacity that depends on "knowledgeable people self-organize into ad hoc networks to provide expert problem solving" (Weick et al. 1999, p. 100). This was not a formalized network, only a latent resource based on personal knowledge and previous collaboration experience. It could be mobilized in this situation and then be dissolved again. Such organizational forms are also described as emergent response groups (Majchrzak et al. 2007).

4.2.2 Flexible and modular technology enables swift innovation

However, defining the clinical algorithm for follow-up was only one initial part of the solution. The pre-existing deployment model was based on a "patient kit" comprising a tablet and select medical biosensors that was physically delivered to the patients' homes. This was not considered to be a scalable model in the face of the existing uncertainties. *Inf-8* shared: "*we didn't know at that moment if we are going to have 10 patients or 10,000 […] So, we needed to jump from that rigorous system to a more scalable system, so an application with bring your own device – BYOD – but also with two-factor authenticated login."* The existing digital solution was delivered by a large international vendor of healthcare technology (Org-X), who quickly developed a web interface. Using this interface, patients at home could enter data – i.e., symptoms and measurements, using their own equipment such as thermometers. A couple of weeks later also a downloadable application (app) was available. The patients who were enrolled would get an SMS with a web link and could download the app and start registering their symptoms. Thus, this BYOD model guaranteed dramatically wider accessibility to the service, with an equally dramatic reduction of logistics and device costs associated with offering it.

Expedited user testing was conducted with test subjects recruited informally within the organizations' employee pool, their family, and friends. Any feedback required from this phase was incorporated into the prototype. However, it was considered that the move to a BYOD model required more proper security testing. While the pre-existing system was used by an older adult demographic, this would change with COVID-19 patients, and this might have other security-related implications. Two-factor user authentication was introduced, and further steps were taken. *Inf-10* shared: "*it's completely different stuff when you're on your own device on iOS, Android, and it's also because we were working with older people, so the chance of old Ole trying to hack the system was low. Going public with another prototype was different".* In addition to the security testing conducted by Org-X as a part of system development, a security task force was put together at the regional level. Following the recommendations of the security task force, independent consultants were engaged to conduct two rounds of penetration testing. The flexibility and modularity of the underlying technical platform were crucial for this development to succeed.

4.2.3 Mobilizing pre-existing skills and structures

The follow-up was conducted by the same telemedicine central as the pre-existing follow-up of patients with chronic diseases. The COVID-19 extension was running on the same technical platform as was already in use here, and which the existing staff was already familiar with. Furthermore, the staff was used to remote follow-up of patients, which included making judgments of whether an intervention would be required. The pre-existing service was not intended to respond to emergencies and was operational only in the daytime on weekdays. Including COVID-19 patients represented a different task and novel clinical risks. *Inf-8* recalled: "*Another risk was non-responsive patients, being at home, and the risk of the application not catching deteriorating patients because we see a trend where on day five,* *some patients would have a sudden dip".* To counteract the possibility of missing out on deterioration, patient were required to submit measurements twice daily, not once as other patient groups. Also, the monitoring staff would make mandatory calls to patients on day five, to confirm the patients' condition. This could be done via the integrated video and messaging functionality. This was a decision made based on recommendations from clinical personnel to ensure patients received optimal care.

The regional PFI project team had initiated the decision to develop the COVID-19 module together with the technology vendor. However, the choice to implement would be made by the health service provider at the municipal level or at the hospital. *Inf-11* recalled: *"We contacted the municipalities that we already had a collaboration with, to see if they could test it out on patients and some of them did and some of them didn't".* Following the March lockdown, the infection curve flattened, and things somewhat stabilized soon after that as society headed into the summer with very low case numbers. Three of the health care providers we studied made very different choices – the Yaro hospital, the River municipality, and the Fjord municipality, which had all participated in the ongoing PFI project using the pre-existing system for patient follow-up. The hospital decided to use the PFI infrastructure and offer home follow-up to allow the earlier discharge of COVID-19 patients. Due to low infection numbers in the region, the hospital had received a 'manageable' number of patients and decided to continue with the kit-based deployment protocol.

Fjord municipality is a large municipality with a central role in the ongoing PFI project. Employees from Fjord municipality were central resources in the team that developed the solution initially and spend a lot of resources on developing version 2 (which we describe in the next section). Despite this, Fjord municipality decided in September 2020 to not deploy the COVID-19 module. Also, when later waves of infection hit harder than at the start, the inhabitants of the city did not get an offer of home follow-up when they were ill with COVID-19. River municipality is a relatively small municipality that experienced an unexpected outbreak in November 2020 with relatively high numbers of infections in a short period of time. The municipality chose to implement the COVID-19 module and throughout this outbreak wave, 62 patients used the application to log their symptoms. The general practitioners were involved, and based on individual patient needs, made recommendations for the extra provision of e.g., sensors to measure oxygen saturation for specific patients. The service received favourable reviews from both healthcare staff and patients, highlighting the ease of use and effectiveness of the service provision.

4.3 Adaptation – learning and transformation

Duchek's (2020) third stage – adaptation – points to the ability to adapt, adjust and use change for the organization's own purposes in a form of long-term learning. In her model, adaptation includes two types of capabilities: (1) reflection and learning and (2) organizational change capabilities. The long-term results of the changes made in the coping phase depend on the attitude towards the future. Amir and Kant (2018) point to transformability as crucial, consisting of "intentional activities, focusing on the ability of sociotechnical systems to shift from one form to another in the aftermath of shock and disturbance". This is a specific form of learning and change, one that deliberately attempts to change its form. This is a quite vaguely defined, but crucial capability for the future. In this section, we will recount the elements of the case story that points towards the presence or absence of such capability to reconfigure its structure and operations in the light of the future.

4.3.1 Preference for short-term coping strategies

Despite successful implementations at River municipality and Yaro hospital, the PFI team struggled to get most municipalities to take up their innovative new solution. They were in dialogue with both the cross-municipality regional coordination group and individual municipalities. The team preferred that the system be tested in live environments before the second wave of infections. *Inf-4* recalled: *"it was difficult to get municipalities (decision-makers) to try it out. Because I tried to communicate to the big municipalities that if we could test it and take the steps to further develop, then you can have a more robust system when numbers take off".* One interviewee from Fjord recalled: *"we didn't have the need for it".* The onset of the second wave presented another round of opportunity for the project team to see the system in live action on COVID-19 patients, but also this was not smooth sailing. *Inf-11* recalled: *"When COVID-19 started to come back for the second wave we tried to contact the municipalities again and it was difficult to get a response. It was – 'We don't know, we want more information, or we don't know the benefits'"*. In the face of extremely high demand for the municipal healthcare service, the pandemic was not perceived as a conducive situation for experimentation, and the municipalities were only using the solution when the novel service model overlapped with the perceived immediate needs. The more long-term perspective, seeing the potential of transformative change afforded by taking up the COVID-19 module, was primarily held by the PFI team.

4.3.2 Innovation in preparation for change

When the Fjord municipality was reluctant to initiate a new service, one of the arguments was that the responsibility for patients who do not already receive municipal, or hospital healthcare services resides with the general practitioners (GPs). The staff at the telemedicine central was the municipal staff that cared for the patients in the PFI project. *Inf-5* from Fjord said: *"the responsibility for patients with COVID-19 belongs to the GPs. So, they would always be the first to follow up patients. So, it was important for us not to go outside the established responsibilities"*. In response to this sentiment, the PFI project team and the vendors initiated another development process and came up with a version of the app that did not require follow-up from the telemedicine central. This version rather had automated screening where the patient would receive feedback according to the same "traffic light model" that the telemedicine central solution used – with a red, yellow, and green light indicating the criticality. If the measurements and responses triggered a red alarm, the patient would then get a message advising him or her to contact healthcare personnel. However, the implementation of this version stalled, as no one was willing to take on the extra costs of setting it up or integrating it to the GPs electronic health record (EHR) systems. The need for separate login details to access patient data was flagged as an 'inconvenience' by the doctors. Another major reason was that the independent GPs were not organized in a way that they could collectively make decisions or take on responsibility for such a solution. When asked whether the work put into the system had made a difference, *inf-4* in reflection shared: *"making that application speeded up the change from kits with tablets to the BYOD format. So, we take the work we did for COVID-19 into making our other patients' lives better, we can jump multiple steps in improvements"*. The learning from this development was thus fed into the work of the PFI team, but the opportunity to gather hands-on experience with using a GP-oriented follow-up solution was missed.

4.3.3 Spreading of the innovative service model

Other actors displayed processes of learning and organizational change that carried through to the actual implementation of novel models into routine service provision. The deployment of digital home follow-up in the Yaro hospital had happened somehow disconnected from the municipal processes. The initial utilization of the PFI solution that allowed for early discharge of COVID-19 patients supported by digital home monitoring was noted by other employees in the hospital. When the adapted PFI solution was presented at the Yaro hospital, managers from other clinical areas saw the usefulness of the solution for their clinical domains. This led to further adaptations of the PFI in areas such as early discharged newborns in need of extra monitoring and increased self-management of HIV infections for reduced hospitalization. These examples demonstrate how both the flexibility of the technology and the mobilization of the informational network, were crucial in the diffusion and adaptation of the FPI solution. This was supported by the interviewees who stated the importance of communicating ideas and solutions in the early stages of the pandemic.

The diffusion of the FPI was not limited to the Yaro hospital. Through the hospital's participation in international research projects focusing on digital follow-up, the same PFI for COVID-19 patients was adopted in other Scandinavian hospitals. This research participation also stimulated the development of additional models for home hospitals. An example of such a spinoff included the idea of using digital technology in ward visits to maintain social distancing. By equipping an assistant with a wearable camera, clinical personnel could attend the ward visits remotely, e.g., from offices or from home. This idea was developed at the Yaro hospital and was further tested and implemented in one of the collaborating Scandinavian hospitals. For the diffusion of innovative service models to happen, interviewees stated the importance of communicating ideas and solutions in the early stages of the pandemic.

5 Discussion

Decision-makers and clinical personnel had to find innovative solutions to cope with the pandemic, which implied implementing novel patient care models. The case is an instance of crisis-driven innovation that depended crucially on repurposing the existing patient-facing infrastructure. We are interested in the organisational capacities required for this. As previously mentioned, our approach has been pragmatic, seeking to examine the practical consequences of the organisational activities in crisis response efforts, and what the implications for the future (if any) can be. In this section, we discuss the links to practice through the reflexive and critical analysis of how the processes, and steps evolved in the case study. We sought to understand what it takes for the lessons learnt during a crisis to trigger transformative thinking, i.e., for the novel approaches to influence the enactment of future routines and adaptive capacity of the sociotechnical system. This focus is consistent with what Amir and Kant (2018) denote as transformability – the ability of sociotechnical systems to shift from one form to another in the aftermath of shock and disturbance, for which relations, structures, and practices are crucial.

5.1 Capabilities required for innovative response and transformability

The existing **informational relations** among the PFI team, the municipalities, the hospital, and the vendors were central when mobilizing the ad hoc expert team to develop the COVID-19 solution. However, the existing relations also encompassed the cross-municipality regional coordination group, for whom the PFI team worked. The PFI team reports that they did not manage to engage or mobilize this group to support the implementation of the novel COVID-19 module, and negotiations related to the PFI option had to happen with each municipality. In these discussions, the outcome depended on the situation in the municipality, perception of need at the time, and contingent factors. Most likely, implementation success would have been strengthened if the capability to make joint, strategic decisions on crisis response had been present. We also saw missing relations in relation to the GP-oriented solution (version 2) that was not implemented as there was no collective representation of the various GP to negotiate and coordinate with.

In terms of the **sociomaterial structure**, the flexibility of the digital infrastructure was central. Specific system capabilities connected to the pre-existing patient-facing infrastructure were leveraged in the repurposing of the digital technology: 1) the flexibility of the solution to design a novel algorithm to collect other data; 2) to incorporate new measurement devices; 3) to build a downloadable software application with a self-registration system to replace manual enrolment by health personnel; 4) develop a novel BYOD service; 5) to develop a prototype for use without TMC follow-up; 6) and the availability of physical and organizational call-centres with healthcare personnel. These qualities of the sociometrical structures enabled the creation of novel and highly scalable services, with lower operational costs and simplified logistics. Some desired and potentially useful features were not realized, such as integration into the GP's electronic health records (EHR) systems and integration of third-party technologies, such as a decision-support system, which would further reduce the work burden and increase capacity in the health service. Going a step further would be to consider a differentiated feedback model which would be useful in the automated categorization of patients according to preference and disease severity. The interviewees are unanimous about the need for technical flexibility in the light of future pandemics with unknown factors regarding mechanisms of contagion, symptoms, risk factors, and progress of the disease. Knowledge will continue to develop along with the pandemic and will need to be fed back to shape the response - this implies that ongoing flexibility and adaptation are a necessity.

In terms of organizational **anticipatory practices**, firstly, we observed that the predefined pandemic crisis response strategies were inadequate and needed improvised adaptation. When the organizations adapted their existing health services they seemed to cater for a worst-case scenario, focused on limiting exposure and minimizing the overall impact of the crisis. This response mindset seems to have factored out recognition of the potential viability of the COVID-19 module. The challenges in the implementation described by the project team indicate that some of the internal organizational structures lack sufficient anticipatory capacity. Different opinions and decisions are of course legitimate, and e.g., decisions not to use the system may be well founded and justified. We argue that this variation in approach demonstrates how the anticipatory practices unfold differently in respect to timing and strategy. While the municipalities and hospital are crisis oriented and maintain a propensity for a short-term coping solution to pandemic related constraints, in contrast, the PFI team stress how the short-term learnings from use of the system during the pandemic may sustain expanded use of the PFI in the future. And so, robust learning and feedback loops are central to securing the achievement of both short-term recovery and long-term innovation. Learning is distinguished from adaptation based on the environmental experience to predefined structures – learning forms new emergent structures that are previously unknown (Johnson & Gheorghe, 2013). This might have been better supported if some forms of anticipatory practices were deliberately cultivated and integrated into decision-making processes.

5.2 Implications for theory

While Duchek (2020) details organizational capabilities for organizational resilience, she does not specifically address transformability. Also, when Amir and Kant (2018) define sociotechnical resilience as transformability, they do not concretize this into what capabilities are required for the relations, structures, and practices to work. In our combination of these two lenses, we have attempted to draw out learnings related to capabilities for transformation in sociotechnical configurations. It is important to note that the notion of sociotechnical transformation captures the changes at multiple time scales – both changes due to repair and changes from adaptation to the new environment. This transformation, caused either by repair or adaptation, may involve organizational and institutional reconfiguration in terms of informational relations, sociomaterial structures, and anticipatory practices.

The qualities of information relations, sociomaterial structures, and anticipatory practices are confirmed to be central in our case study. In terms of the more concrete capabilities required for transformability, we contribute by reframing the role of the capability of anticipation. While Duchek's (2020) model positions anticipation as the initial stage (preparedness for a crisis), we argue that this is a crucial feature also in the final stage of her model – that of adaptation, reflection, and change. Anticipation of the next crisis should feed into the decisions made, and forward-looking considerations should inform which decisions are made about reconfiguring practices and structures. This 'reflective anticipation' that is partially observed in our case is a representation of how transformability is sustained beyond the immediate crisis recovery period, and shapes future entities. Another contribution concerns the sociotechnical or sociomaterial infrastructure, to which Duchek's (2020) model of organizational capabilities pays little attention. Our case demonstrated that the qualities of the pre-existing sociomaterial infrastructure, in particular its capability to flexibly be reconfigured and extended, were crucial for the innovative response. Also, in the further development during the crisis, flexibility in the form of optionality was built-in, an attribute of embedded flexibility that facilitates further innovative activities should the need arise.

Our analytic approach illuminates how the organisations deep structures maintain relative stability throughout the crisis, with much of the reconfiguration occurring within the surface structures. This shapes as a good lens to scrutinise sociotechnical change. The sociotechnical system experiences sustained instability over a period, and does not quite stabilise, instead, remaining in a quasi-equilibrium while the surface structures continuously shape and shift from the original configuration. It is difficult to imagine a scenario where things simply 'return to what they were' (equilibrium). We concur with Fischer and Baskerville who assert "the pursuit of agility and the accompanying prevalence of fast-changing technologies have led to increasingly unstable environments…and periods of relative equilibrium in IS have grown shorter, less frequent, and unreliable" (Fischer & Baskerville, 2022). The future seemingly demands modelling of sociotechnical systems where stability is nothing but a fleeting moment and rather embrace the dynamism of transforming only from quasi-equilibrium to unstable equilibrium, to deliver the necessary stability, flexibility, and adaptability (Empson & Alvehus, 2020).

Another conceptual frame in which to understand the case might have been the notion of antifragility, a notion that subscribes to living in a world surrounded by unknowns, and designing our technologies with an inclination to thrive under external threat (Abbas & Munoz, 2021; Gorgeon, 2015). Antifragility, an approach that is based on the possibility of positive outcomes following stressful events or hazards. It is essentially a system's expansion in capability to thrive because of stressors, shocks, noise, faults, attacks, or failures (Taleb, 2012). We see elements of antifragile behaviour of the various actors in the context of this crisis. Such antifragile behaviour is deemed necessary for innovation during a crisis, however, it not only yields positive results during the crisis but is retained in the organization's skill repository. Developing antifragility requires cultivating the organizational capability to learn from internal and external stressors (Taleb, 2012) and we see a synergy between this and our empirical study.

6 Concluding remarks

We conclude that the response of the healthcare system during the pandemic was characterized by a mix of actions: some reactive with a short-term and problem-solving orientation, others more proactive with a longer-term and preparedness orientation. Pre-existing informational relations were utilized, however, additional use of these to also make joint strategic decisions would have been necessary for a fuller implementation of the COVID-19 module. The flexible and reconfigurable sociomaterial structures of the pre-existing digital platform, service, and infrastructure were central in facilitating the crisis response in the first place. However, also here we see the sketched and desired possibilities (e.g., for better integration into the EHR systems in use, as well as the un-realized automated monitoring possible in version 2) as an indication of further, unrealized potential. In addition to the prerequisite of a flexible digital infrastructure, the deliberate application of anticipatory practices appears to be of utmost importance. These were found primarily in the PFI team but are indicative of capacities that have the potential to support wider sociotechnical transformability.

While our study presents relevant insights for understanding what is required for transformability of sociotechnical configurations, it also has limitations. Firstly, our study and analysis are limited to an outsider's view of the actions ongoing in one region, while the real developments emanating from continued usage and changes in pandemic strategy are much richer than we can account for. Secondly, although other aspects of health infrastructure such as pandemic surveillance, contact tracing, testing logistics, etc. are relevant, these are not within the scope of this study.

To study challenges and crisis response can help us address what the future skills sets required for facing uncertainties may look like. The ability of humans to improvise, adapt and learn will be crucial, however these improvisations, adaptations and learning happen within the sociotechnical systems in which we are embedded. Steve Jackson (2014) writes about "broken world thinking" and highlights how we exist in an "always-almost-falling-apart world". He asks: "what happens when we take erosion, breakdown, and decay, rather than novelty, growth, and progress, as our starting points" (ibid., p. 221)? and we find such a question valuable when considering the uncertain future. A mindset that understands and accepts that "the world is always breaking; it's in its nature to break" (ibid., p. 223) may facilitate smoother adaptation and transformative approaches to an always evolving world. This may come across as a pessimistic or defeatist perspective, but this is only the case if we overlook that there is also a responsive world that is constantly shifting, reinvented, reconfigured, and reassembled into new combinations and new possibilities. The capabilities for taking advantage of these possibilities are important to cultivate, and we have drawn attention to these in our study of a crisis response and transformation process.

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A Qualitative Risk Identification Framework for Cyber-Physical-Social Systems

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ABSTRACT

As information and communication technologies, real-world physical systems, and people become interconnected in critical infrastructure, attention has shifted to the operations of Cyber-Physical-Social Systems (CPSS). CPSS are progressively integrated in core critical infrastructure organisational processes to achieve a combination of benefits. However, the high degree of integration of technology into human society and mission-critical processes leads to an increase in complexity and introduces novel risks and vulnerabilities. These novel constraints extend beyond what is known from previous cyber-physical and critical infrastructure systems studies and prompt the need for revised risk perception and identification methodologies. This paper aims to develop a novel qualitative risk identification framework that is used in the identification of risk and vulnerability in CPSS ecosystems deployed in critical infrastructure or mission-critical organisational processes. The framework emphasizes interactions between humans and the system making it possible to identify and understand how non-technical risk impacts the CPSS ecosystem.

Keywords

Cyber physical systems, cyber-physical-social systems, social processes, risk, vulnerability, mission-critical.

INTRODUCTION

Advancement in the digitalization of most critical infrastructure (CI) sectors has created ecosystems comprising various critical operations. In the early developments, CI operations integrated cyber and physical elements into their rather complicated background processes, referred to as cyber-physical systems (CPS). CPS combined the capabilities of interacting computational components and networks of physical systems. These combinations are popularly adopted in industrial process control systems, national power grids and smart traffic control (Yilma et al., 2018). The introduction of CPS further complicated CI operations, making them complex two-layer architecture systems that existed in the cyber and physical terrain.

While human actors have always been central to CPS ecosystems, there is a shift in the management of these integrated systems – through the coordination of closely coupled human and machine actors. In such systems, people progressively work closely alongside sensor enabled smart devices, machines, control systems, and robots to complete processes and operations. Personalized healthcare, emergency response, traffic management, transport, and smart manufacturing are examples of sectors where we observe these changes (Dey et al., 2018). The end goal of adopting the smart systems into the foreground of 'social contexts' vary, ranging from introducing new functionalities, to technological advancements leading to efficiency, convenience, personalized service, improved quality of life for users (Wang & Rong, 2009). These smart systems, characterized by the engineered networking of human or social, computational, and physical components are known as Cyber-Physical-Social Systems (CPSS). Human actors are known to be prominent components in the CPS, however, in CPSS environments, they are particularly centralised in the management of CI operations introducing levels of dependence and uncertainty. This necessitates efforts in exploring and understanding how this close coupling of human-machine components may lead to novel risks and system exposure emanating from human behaviour.

Generally, CPSS can be considered a fusion of social systems with cyber-physical systems. Social systems play a prominent role in CPSS, often incorporating interaction with expert and non-expert users. CPSS are popularly embedded into CI sectors such as healthcare, transport, and emergency response., but are also deployed in other application domains, such as a business or organisational setting. Recently, CPSS are incorporated into the critical functions of an organisation such as in decision making, monitoring services, control of organisational processes, and supply chain management. Critical functions are core to achieve the objectives of the organisation. Therefore, any processes that are linked to the delivery of critical functions are 'mission-critical' processes (JTFTI, 2011).

CPSS do present a potential for varying degrees of heightened efficiency, sustainability, and scalability in core organisational processes. For this potential to be realized, customized technological developments, policy, control, and security methods need to be implemented (Frazzon et al., 2013). Unfortunately, due to their complexity and qualitative dissimilarity of the system components (social, physical, and computational), CPSS are widely affected by novel risk, vulnerability, and security threats (Wang & Rong, 2009). CPSS may face security breaches in cases where the people, processes, technology, and other components are compromised. In case of incident, an understanding of the human induced risks, organizational risks and the intertwined nature of the two risks types are important for efficient response to such failures associated with CI and CPSS environments. Questions often arise regarding the nature of the human-organisational relationships that may occur in a CPSS and how they may compound the risk and vulnerabilities that pose a threat to the CPSS.

In CPSS, risk identification is somewhat complicated by the qualitative dissimilarity of the system components, the challenges encountered in CPSS ecosystems are unique. However, existing research related to the risk in CPSS mainly considers CPSS as purely technical systems and provides abstractions from this perspective, focusing on the system architecture layer (Bou-Harb, 2016; Gharib et al., 2017). Therefore, the social system issues such as cognitive behaviour, and human error are often overlooked. Indeed, numerous works examine and propose human risk assessment frameworks (Cacciabue, 2000; Kirwan, 1998a, 1998b), especially in the safety engineering domain, or organizational risk frameworks, especially in the information security management domain (Sebescen & Vitak, 2017; Singh et al., 2014). However, studies that examine the human and organizational-wide risk frameworks in the context of CPSS in CI organisations are still rare. This will be the main contribution of this work.

Hence, the aim of this paper is threefold: First, to provide an overview, of how CPSS are gradually adopted and deployed in an organization´s 'mission-critical´ processes. Second, to understand the potential exposure to novel organization wide and human factor risks and the interactions between these two factors. Third, to propose a qualitative evaluation framework for use in the risk identification process to analyse CPSS ecosystems through the organization-wide risk approach. The ultimate goal is that this framework will fill existing gaps and facilitate the understanding of the CPSS ecosystem dynamics through the decomposition of CPSS into easily identifiable components that are essential from a security risk perspective and how they interact. This framework will serve as an enabler for anticipating and taking comprehensive corrective actions that minimize risk in the social, computational, and physical system layers of the CPSS. This paper is an exploratory attempt to apply the organizational processes into CPSS ecosystems. The research question is: **In what way can a qualitative organizational risk approach to CPSS analysis provide useful insights into CPSS risk assessment approaches?**

The methodological approach of the paper is conceptual, incorporating interrelated literature analyses and drawing further on empirical illustrations. The next section discusses the origins and understanding of CPSS. The 'Previous Studies' section follows where insights from existing works serve as basis for shaping the conceptual reflections in the paper. In later sections, a risk identification framework is developed and applied to empirical illustrations. This is done using secondary data sources through profiling of two cases of CI compromise related to the transportation, and health sectors. The scenarios show the potential and relevance of CPSS usage in mission-critical processes in CI sectors. The rest of the paper is a brief discussion on the Contributions and Limitations of this research work followed by the Conclusion and Future Research Section

ORIGINS, UNDERSTANDING, AND DEFINITION OF CPSS

The origins of CPSS can be traced back to cyber-physical systems (CPS). CPS are 4th industrial revolution smart systems that include the engineered networking of physical and computational components, i.e., information and communication technologies, software, hardware, and data. The physical elements may be any combination of machines, electronic devices, and industrial plants. CPS are characterized as a 'system of systems', often supporting cross domain applications (Lee, 2006; Wang & Rong, 2009).

Typically, CPS harvest data from the environments through use of interconnected devices such as sensors. They bear a potential impact on the physical world due to this connectedness and it is a common cause for concern on their trustworthiness (Gharib et al., 2017; Gunes et al., 2014). As mentioned earlier, CPSS emerges from the further integration of CPS into social systems. In social systems, CPS include interacting individuals that act as a part of the systems and have their own "cognition, preferences, motivation and behaviour" (Zhou et al., 2019). Zhu and Milanović (2020), define CPSS as "a system deployed with emphasis on humans, knowledge, society and culture in addition to cyber and physical space. It connects nature, cyber-space, and society with certain rules". Figure 1 is an illustration of the concept of CPSS seen through a three-layer architecture with two aspects of integration, the cyber-social and cyber-physical.

The concept of CPSS is somewhat new, and therefore in the literature, a variety of terms are used to describe the

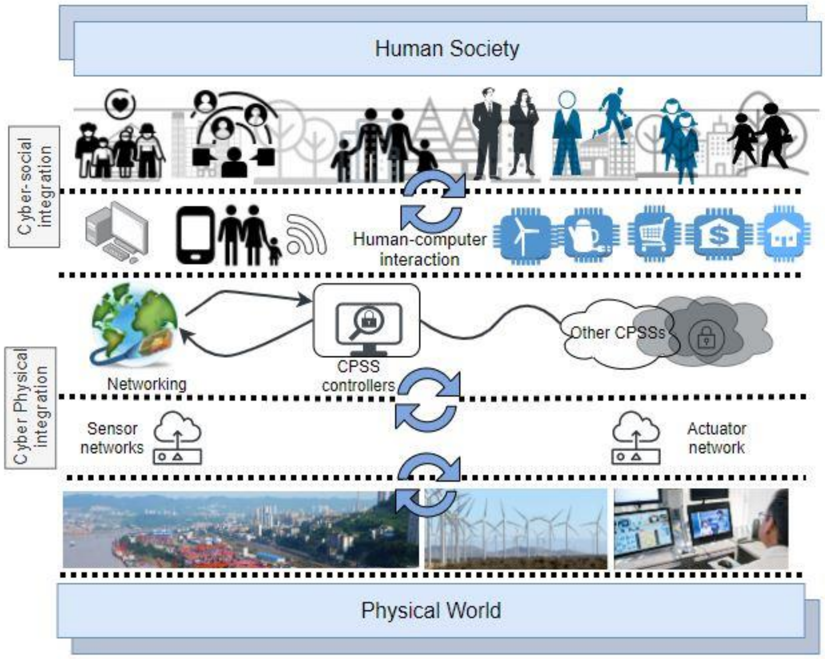

Figure 1: CPSS Architecture (adapted from Zhou, 2019)

integration of human aspects into CPS operations. Frazzon et al. (2013), propose "Socio-Cyber-Physical Systems", highlighting the social aspects of CPS and showing how context-dependent behavioural aspects bear impact on the system. Frazzon (2013) further describes that the technological elements are developed to provide support to the human actors in a production network CPS. "Cyber-physical Human System" is found the literature to describe systems of interconnected computers, cyber-physical devices, and people that allow other systems, people and data streams to connect and disconnect. It emphasizes the 'human connection' in the systems (Sowe et al. 2016; Kumar et al. 2017). In another term, "Social Cyber-Physical Systems", are described as complex socio-technical systems in which humans and technical aspects (CPS) are massively intertwined" (Xu et al, 2018).

The highlighted terms capture notions of CPSS in varying degrees, exploring different paradigms and abstractions of the influence of human aspects such as culture, motivation, and cognitive limitations based on the application domain of the system under study. The essence captured in the reviewed literature is the dependence on equal prominence of both cyber-social and cyber-physical integration elements in the smart environments (Zhou et al., 2019). A common trend across the various application domains is that CPSS require stability, robustness, security, reliability, and efficiency. Additionally, CPSS demand the cognitive interaction of humans with technological and industrial systems in the execution of organizational tasks and processes. This interaction introduces 'human behaviour', a rather complex dynamic aspect compared to the traditionally fully automated domain of CPS. Unlike machines, humans are prone to individuality and may not always follow rules that do not match their logic, needs or capabilities (Yilma et al., 2018). The quality of collaboration, linking the technical, physical, and social prospects determines the overall performance of the system (Frazzon et al., 2013).

The following subsection presents the different CPSS application domains as discussed in the literature. The essence captured in the reviewed literature is the dependence on equal prominence of both cyber-social and cyber-physical integration elements in the smart environments (Zhou et al., 2019).

PREVIOUS STUDIES

This section provides overview of two literatures, first, how CPSS are gradually adopted and deployed in an organization´s 'mission-critical´ processes, and second, on the potential exposure to novel organization-wide and human factor risks and the interactions between these two factors. The first literature selection is based on highly cited publications related to CPSS. It reveals the current discourse, application domains, and deployment of CPSS in engineering, computer science and information systems. The second analyses are based on a set of literature that discusses CPSS risk and threat identification or assessment methodologies from an organisational process viewpoint. It considers the associated risk perception and security recommendations. The aim is to uncover what the prevalent concerns are and potentially considering CPSS as a complex organisational process system in mission-critical

Extant literature on the CPSS paradigm describes it as an interdisciplinary subject area. The methods of investigation and interpretation tend to be aligned to the traditions of the research discipline under which the study is being conducted. This confinement to isolated research areas may be a limitation of sorts in different application fields due to the diversified nature of requirements and outcomes. Given the prominence of the human role, the majority of the studies assume user-centric views, yet in existing traditional design principles for CPSS the human aspect is not factored into the system architecture (Frazzon et al., 2013; Zhou et al., 2019). Much of the literature discussed in the first review reveals a bias to the technical aspects of CPSS, even when the human aspect is acknowledged. However, Frazzon et al. (2013) and Kirwan (1998a) provide compelling argument for research focusing on the 'human influence', highlighting that the efficiency of the resulting network depends on the capability to bridge technical differences and the culture induced behavioural differences among human actors. Given the prominence of the human role, it would be expected that the majority of the studies assume user-centric views, yet in existing traditional design principles for CPSS the human aspect is not factored into the system architecture (Frazzon et al., 2013; Zhou et al., 2019). Much of the literature discussed in the first review reveals a bias to the technical aspects of CPSS, even when the human aspect is acknowledged. However, Frazzon et al. (2013) and Zeng et al. (2020) provide compelling argument for research focusing on the 'human influence', highlighting that the efficiency of the resulting network depends on the capability to bridge technical differences and the culture induced behavioural differences among human actors.

CPSS in CI and Mission-critical Applications

As discussed in the introduction, CPSS has gradually been adopted in CI sectors and as a part of mission-critical organisational processes. *A mission-critical system or process* is "one in which a failure or interruption comes with intolerable operational or human cost. Examples of such costs may be information or research compromise, safety at risk, loss of data, and when critical business function is impacted (Skarin et al., 2018). CPSS is commonly integrated into transportation, energy, and healthcare. In health care, sensors have been deployed for clinical monitoring and rapid response in case of medical emergencies, which can be considered as a mission-critical process in order to deliver continuous health services to the public. Figure 2 shows a CPSS applied in remote patient monitoring, as an illustration of the CPSS in mission-critical application.

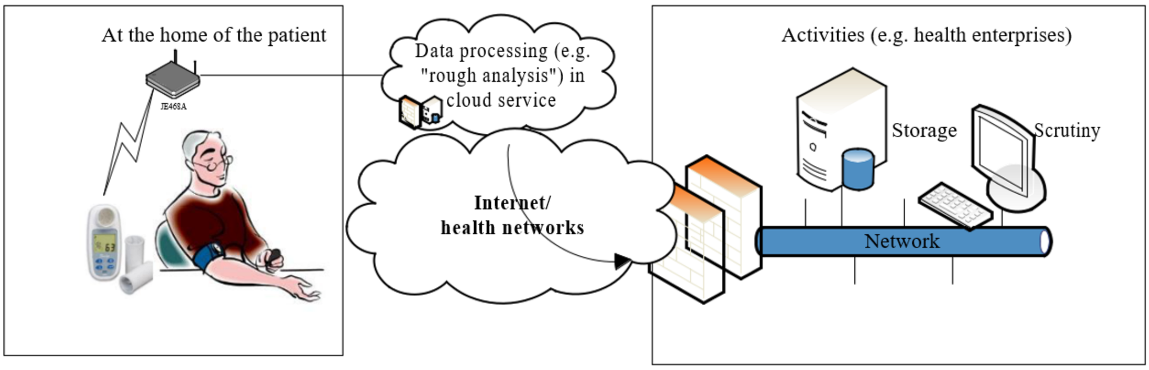

Figure 2: CPSS remote patient monitoring via cloud service (normen.no)

Such remote deployment of e-health services can induce more unknown threats and risks, triggered by a combination of vulnerabilities inherited in the technology and infrastructure itself, new ways of using it, and unpredicted behaviors of the patients when exposed to a new electronic service. This example highlights even more, why studies examining various aspects of human-induced risks in the CPSS system are becoming pressing needs, and motivate us to conduct this research.

The malfunctioning of the cyber elements (e.g., wearable health sensors) may lead to remote therapy disruption or even loss of life. In transport, vehicle-to-vehicle, and car-to-road communications to ensure safer automatic driving have become prevalent. They are mission-critical, because any malfunctioning sensors leas to a lack of situational awareness of road traffic, possibly leading to accidents. In energy, electricity grids and smart devices have been mounted on the grids to monitor power distribution, acquiring customer data and power consumption.

These are among mission-critical processes in electricity sectors. Of interest across the respective application domains revealed in literature is the "new relationships between physical and cyber components that entail new architectural models" (Dey 2018, Zhou 2019). Basically, a certain level of reliability, predictability and safety are required for the use of CPSS in CI sectors. Most discussions centre around the dynamic, decentralised, and changing ecosystem that CPSS create. The systems are repeatedly identified as complex socio-technical environments. It is argued that due to these CI sector applications, CPSS have acquired additional characteristics over ordinary CPS such as the awareness of users in social contexts. CPSS also possess an adaptability towards 'optimal collaboration' and accomplish the high levels of dependability (Dey et al., 2018; Frazzon et al., 2013).

The major challenges of CPSS are mainly related to security, safety, and reliability of the systems. It is repeatedly mentioned that to attain these goals and fully understand the CPSS ecosystem, improvements need to be made to computing abstractions, software development and physical processes. Further, research models need to be developed to reflect the revised properties of interest in CPSS (Bou-Harb, 2016; Dey et al., 2018; Gharib et al., 2017). Authors engage the system architecture (Yilma et al., 2018), application contexts, and resource management. Surprisingly, even though CPSS ecosystems are repeatedly identified as a part of critical function, little mention is made of the possibility to analyse CPSS from a process-oriented view, with a focus on mission-critical processes (Bou-Harb, 2016).

Risk Identification Perspectives, Frameworks, and Guidelines for CPSS

There are widely used and accepted risk management guidelines such as ISO 31000, IEC 31010, and NIST frameworks that outline suitable approaches to the different risk-related activities in CI and organisations. The NIST framework for improving CI cybersecurity (2018), emphasizes that there is no 'one size fits all' approach to managing cybersecurity risk in CI. There is need to customise practices described in a framework to reflect the unique needs of any CI operations. This implies that any framework should be flexible, and easily modifiable to suit different environments. The NIST framework provides a systematic approach to the identification, assessment, and management of security risk in CI. The framework also serves as a basis for novel security approaches, providing a basis for improved risk activities. In the case of CPSS in CI processes, the arrangement and organisation the elements are significant to risk related activities. A perspective of the system that reveals all the relationships for ensuring a comprehensive risk assessment outcome, with wide risk management approach can be seen in Figure 3, which stratifies the risk management process of any organisation into three tiers.

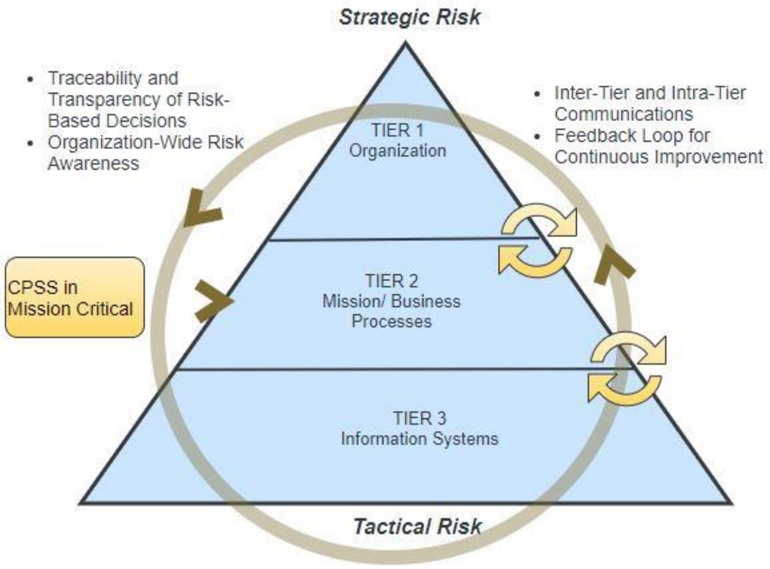

Figure 3: Multitiered organization-wide risk management (adapted from NIST, 2011)

While the layered architecture (Figure 1) provides a system level viewpoint, this is rather complex and provides no conceptualisation of the actual processes that the CPSS is part of. This makes it difficult to identify the novel risk or vulnerability posed through the implementation of the CPSS within the organisation or CI. A possibly simpler viewpoint is proposed in the multi-tiered organisation-risk related activities are applied across all three tiers making it possible to identify strategic and tactical risk, overlaps and dependencies. Of particular interest to this paper is Tier 2. The description of the interconnection that exists between the mission/business process and the underlying technology that is implemented to execute the processes (JTFTI, 2011). The translation of a CPSS ecosystem within this framework would provide a process level view that enables the identification of novel risk and vulnerability.

Research Gaps and Potential Contributions

Yoneda et al. (2015), propose the Risk Breakdown Structure (RBS) approach for use in the extraction and analysis of risk for CPS in 'office' environments. The emphasis of the work is on information and physical security. Notably, to begin with, in the risk extraction phase, 'risk factors' are identified and classified into either 'physical threats' or 'information security threats. Identified risks such as virus infection, spoofing, and illegal copying are weighted and classified based on a quantitative scale that they refer to as the 'risk matrix method'. Based on the matrix, control measures such as regular anti-virus updates, secure authentication systems and illegal copy check tools are then determined. This is a quantitative evaluation method, and the approach captures the essence of system performance which is ideal for CPS environments. However, the initial RBS classification of possible risk only into two streams – physical and information security, only makes it partially applicable to CPSS, focusing on the physical and cyber aspects of the system. Singh and Jain (2018) suggest purely technical measures by looking at vulnerabilities in hardware, software, technical, network, platform, and management vulnerabilities. Risk is interpreted as the various types of attacks that can be made to the network. This is once again a quantitative approach with a strong weight towards the cyber and physical components of the operational environment.

The prior sections highlight the prevalent use of CPSS in critical sectors such as personalized health care and emergency management lead to an increase in cyberattacks on CPSS. While cybersecurity continues to focus on the cyber and physical tiers of the systems the risk has evolved and this is no longer enough to protect the systems (Zhou et al., 2019). Different techniques have been used to introduce human actors in CPS. The use of smart devices and the tight coupling to their users has led to the possibility of 'human sensors', instances where humans are the primary source of information for the system. The need for revised methodology that factors in the social aspects of the CPS has also been highlighted in several studies (Lee, 2006; Zeng et al., 2020; Zhou et al., 2019). The revision of the risk and vulnerability identification process as a preliminary step to wider revisions in the risk-related activities of operations would lead to a balanced, comprehensive process. The risk identification process is used to establish other risk-based activities such as assessment, response, and monitoring. It is the identification of the "assumptions, constraints, risk tolerances and priorities/trade-offs", and establishes effective communications and feedback loops for continuous improvement in the risk-related activities of an organisation. The identification and appropriate classification of human induced risk in a CPSS is a key component to the development of comprehensive risk decision making, ensuring that all three layers (cyber, physical, social) are factored in.

While general risk identification has been suggested in different frameworks, there is very little information on how CPS or CPSS human induced security risks should be assessed. In the areas of CIs, twenty tools and frameworks have been identified targeting various users ranging from operators, asset managers, CI operators to policy makers (Giannopoulos et al., 2012). Typically, an additional step is required before identifying risk source, i.e., identifying CI assets. There is a need for adaptations of previous frameworks to address the organization wide CPSS risk identification processes and highlight the prominent role of human actors and how this leads to novel risk. In short, the authors observe the following gaps in the literature:

- Research on the security of the cyber and physical layers of CPSS has a bias to the technical components (Kumar et al 2020). In fact, the nature of risk has evolved in current systems. Thus, methodological changes that provide more holistic approaches to human-induced risk related activities of CPSS are required.
- Some authors, e.g., Yoneda et al. (2015), Singh and Jain (2018) propose different risk management approaches for CPS that operate in 'social settings. However, the suggested methodologies are quantitative, have a technical bias in the risk identification processes. The exploration of risks emanating from human activity would require primarily qualitative approaches.
- Majority of the proposed risk frameworks emphasize the identification of vulnerabilities and risk at a system level. They lack emphasis on the notion of interdependencies and the possibility of cascading effect/ risk.
- Existing works provided rarely consider CI operations from an organisational process-oriented perspective, and as a result provide limited insight into why research is now obliged to consider human actors as essential components in the management of critical infrastructure.

Hence, the proposed framework is intended to fill the highlighted gaps. The novelty in this work is to offer a customizable qualitative risk identification approach in CPSS ecosystems that provides the possibility of understanding the relationship among the social, cyber, and physical layers of a given CPSS. We propose and inclusive and balanced perspective using the multi-tiered organisation wide risk management approach. This is important to tailor the technical and non-technical aspects within mission-critical processes.

METHODOLOGY

To address our research goals, we used a combination of qualitative research techniques. For the first and second research goal, a literature analysis was conducted. This was done to support the previously mentioned problem statement and clarify how CPSS has evolved and come to use in critical infrastructure organisations. This was a non-exhaustive literature search targeting studies that focus on specifically CPSS or CPS in CI organisations. We selected recent, highly cited publications that identify the prevailing understanding of CPSS to reveal the degree to which it has been adopted and deployed in mission-critical organisation processes. The literature search also targeted studies that focus on the perception of security risk in CPS and CPSS, specifically risk identification and assessment methodologies. The activities and findings related to these two goals are detailed under 'Previous Works: Problem Statement and Potential Contributions' sections of this paper.

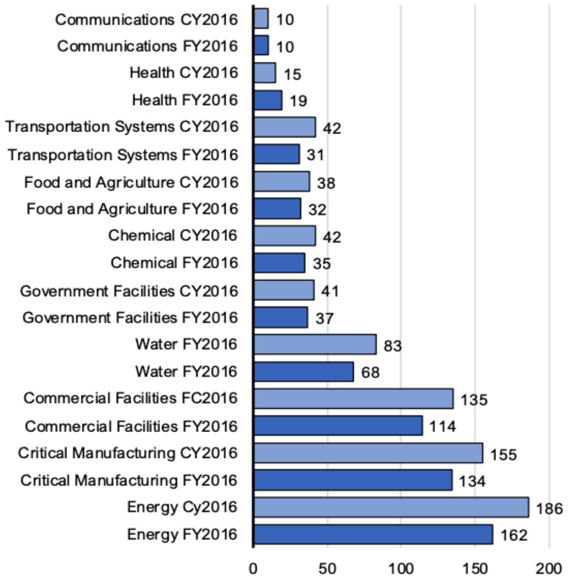

Figure 4: Vulnerabilities found in CI sectors 2016, with occurrences > 10

(Adapted from: ICS CERT Report, NCIC 2016)

To achieve the third research goal, the development of the so-called Qualitative Risk identification framework (Q-ID), the authors reviewed several models uncovered in the literature analyses that have been used by scholars to identify the risks and vulnerabilities in the CI and CPS systems and refined them to cover the various notions of risk in the CPSS, as a part of the mission-critical business processes (TIER2 as seen in Figure 3).

Furthermore, a qualitative evaluation is done to validate the proposed framework and demonstrate it can be applied satisfactorily to identify the novel risk and vulnerabilities of CPSS in mission-critical organisational processes. This is done through the identification of practical application scenarios and empirical illustrations, which have been selected, where the significance is supported through data. Over the years, CIs have been attractive targets for disempowering an organization or even a country. Figure 4 shows the vulnerabilities reported based on attacks occurred in Industrial Control System (ICS) in Fiscal Year (FY) and Calendar Year (CY) 2016, (NCCIC, 2016) as registered by the US ICS-CERT (Industrial Control System Computer Emergency Response Team), which is the core of cyber infrastructure. The statistical data shows that the vulnerabilities have been reported at least ten CI sectors, which include the transport and health sectors. Hence, we selected these two sectors for illustrating the applicability of Q-ID Framework, as two emerging sectors that recently are prompted by the prevalent use of CPS systems and sensor technologies for clinical management in the healthcare sector. The authors find this an interesting case of CPSS, that may provide greater insight due to the high degree of integration of the CPSS into human society (see Figure 1). ENISA Threat Landscape report on Main incidents in the EU and Worldwide has included Health Care attack as one of five the most targeted sectors (ENISA, 2020).

In brief, these two sectors - transport, and health are selected for further analysis and show the applicability of the risk identification framework from CPSS in mission-critical lens. The following section discusses the proposed framework, providing a justification for this qualitative risk identification framework and highlighting aspects in which the organisation-wide risk management approach leads to useful insights in CPSS risk analysis methodology.

RESULTS: PROPOSED FRAMEWORK

Prior sections in this paper discuss how CPSS has a layered architecture comprising of various components, which are at times interdependent. We have also discussed how this key attribute of CPSS generates novel risk and vulnerability that highlight the need for revised methodology to facilitate the interoperability and manage the emerging effects of these changing ecosystems (Dey et al 2018). Various frameworks to identify risks or vulnerabilities in CPSS or CPS environments have also been discussed. Many of the studies emphasize the cyber components or physical components, and rarely investigate the social components, or consider CPSS deployed in CI organisations for mission-critical processes. There is a gap between existing risk identification and assessment methodologies and the current trends in CPSS ecosystems. The proposed framework considers CPSS to be an organisational process, that is deployed at various levels of an organisation to collectively achieve a particular aim or objective. The framework emphasizes the existence of relationships among the composite actors, assets, and stresses how the dynamics that exist among these elements may result in dependencies. This may lead to novel risk and vulnerability. This logic coincides with context-driven risk assessment approaches such as the OCTAVE method that motivates for identifying risk relative to business goals and key business assets (ENISA, 2006; Tweneboah-Koduah & Buchanan, 2018).

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The proposed framework considers multiple existing frameworks, and the primary objective of the proposed framework is to further contribute to and optimize the existing frameworks. Beyond the identified frameworks in the Previous Studies Section adopted by the researchers, there are numerous frameworks and standards for risk assessment such as Operationally Critical Threat, Asset, and Vulnerability Evaluation (Octave) method, ISO standards such as ISO 27005 for information systems, ISO 31010 for IT Governance, and ISO 31000 for organizational wide (ENISA, 2006; Tweneboah-Koduah & Buchanan, 2018). Risk identification is a part of overall risk assessment process. Risk identification methodology can be done in several ways, including looking at the checklist, records, experience data and records. (ENISA, 2006) suggests that identification of risks can be related or characterized by the following steps outlined in Table 1, which is mostly focus on "cyber" domain. On the right column, we point out unaddressed issues when using this framework for organizational-wide context.

Table 1: Risk identification Methodology and examples of unaddressed aspects of organizational-wide context of CPSS

Risk Identification	Generic example (Enisa, 2006)	Unaddressed aspects of Human-induced risks in organization wide context of CPSS
It´s origin	Insider threats from adverse employees, competitor, governmental and non-governmental actors	Insecure ubiquitous connectivity, human-cyber interface, individual differences in CPS-based processing capacity and acting.
Certain activity, event, or incidents (threat)	Unauthorized disclosure of confidential data, competitor deploys a new marketing policy, new privacy law, power failures	Human-devices interplay, cognitive load when interpreting information from devices/sensors. Digital attacks causing inaccessibility of equipment (maintenance error and decision-making errors)
Its consequences, results, or impacts	Service downtime, loss or increase of markets, tighter or simpler competition	Lack of availability of mission critical services during infrastructure downtime; interrupted business continuity; increased workload
Specific reason for its occurrence	System design error, human intervention, prediction, or failure to predict competitor activity	System or user incorrect processing of data (idiosyncratic errors); unknown CPS abnormality are not covered in current organizational procedure
Protective mechanism and controls	Access control, policies, security training, market surveillance	Centralized control and monitoring in sensitive huma-CPS interaction points; CPS awareness training
Time and place of occurrence	During extreme environmental conditions such as flood in the computer room	Unavailability of shared infrastructure – e.g., internet for running mission critical, and acquire information from human part of CPS

CI organisations such as health, transport, energy, and water are known to be targets for malicious actors and face frequent cyber and physical attacks (Haque et al., 2014). The identification of technical and non-technical risks in mission-critical organisational processes is a prerequisite step to the assessment, and management of risks. The enhancement of existing frameworks, the novel components of the qualitative risk identification framework are:

Integration of the organisation-wide risk management model: The translation of the CPSS architecture into the organisation-wide risk management model is a means of attaining a greater level of visibility of the key processes and actors that comprise the system in the different tiers from an organisational perspective. This viewpoint provides an understanding of the security risks within the CPSS from each of the different layers – physical, cyber, and social. This approach allows for a smooth engagement of non-technical risks such as human behaviour during risk identification and may show how they are connected to or impact IT control gaps and vulnerability findings in the technical components of the system.

Identification and Classification of cross-functional risk from the organisational environment: in the qualitative risk identification framework the risk is understood to be cross-functional. Cross-functional risks are of a tactical and strategic nature (see Figure 3), this means they can present as technical risks – e.g., software, system complexity or non-technical risks – e.g., legal, environmental, or cognitive behaviour. People in the CPSS ecosystem work on different organizational processes that collectively generate a combination of strategic and tactical risks that affect the security and overall organisation objectives. The risk identification in the proposed framework comprises of a process tracing and risk mapping exercise. Unlike traditional risk identification frameworks, the proposed framework goes a step further in classifying the identified risk from the preceding step into human and technology induced risks. This approach provides improved appreciation for security or organisational objectives that are impacted by cross-functional risk or process-based vulnerability. An additional benefit of this exercise is the identification of mission-critical processes and the organisational resources (people or technology) that are tightly associated or linked to them.

Emphasis on the interaction between human and system alongside associated human risk in CPSS: the cyber-social integrations and human computer interactions highlighted earlier in Figure 1 give rise to novel vulnerabilities and threats. Among these being susceptibility to human error and the entailing risk. Examples of such human error are action execution errors, diagnostic/ decision making errors, and errors of commission (Kirwan, 1998a). The proposed framework provides a series of process tracing steps that make it possible to identify and understand how non-technical 'human risk' can affect the system.

A Qualitative Risk Identification Process Framework

The proposed framework is a useful addition to the risk assessment methodology of an organisation, preceding the actual risk assessment procedure. It is helpful for the identification, understanding, and communication of risk and vulnerability in a CPSS ecosystem, benefitting strategic risk identification mission-critical process researchers in an organisational or CI setting. Use of this framework provides clarity on the operational context, resources connected to critical function, and oversight on possible security risks. The framework considers CPSS as a multi-layer, organisation-wide system, this coincides with existing organisational risk methodologies that emphasize the need for equal tactical and strategic risk assessment. Figure 4 is a flow chart, outlining the objectives of each of the steps that are later incorporated into the proposed framework.

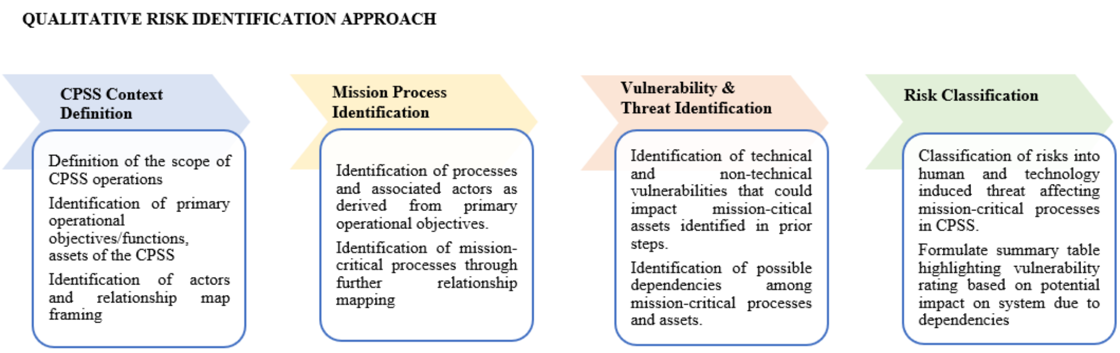

Figure 5: Analysis of CPSS and derivation of Qualitative Risk Identification Approach

Modelling Concepts for use in Relationship Mapping

An aspect of the proposed Q-ID approach is the relationship mapping exercise carried out alongside other activities in steps 1 -3 of Figure 5. The relationship map informs the risk classification activity in step 4. The relationship map includes select modelling concepts that are necessary to illustrate, understand, and express security risk in qualitative terms. An overview of the concepts used in the proposed framework is discussed below.

Actors: an actor within the CPSS is a representation of humans that exist within the ecosystem in their respective roles. Actors are a part of the system operations and they are integrated into the system loop. Every actor that exists within the CPSS ecosystem has a purpose, for instance – data acquisition, information retrieval, user feedback or general action (Zhou et al., 2019). Actors are also linked to goals, the operational objectives, and functions of a CI organisation; they carry out tasks that lead to their goal achievement and the CPSS's operational objectives.

Goals: goals are the overall activities associated with an actor that support and are derived from a selection of the CI's operational functions. Goals are generally reflected in the outcome of the processes in which an actor participates. An example of goals in a CPSS may be tasks/processes that relate to confidentiality, integrity, and availability of patient data in healthcare service. The goals are linked to and determined by the information security objectives of the CPSS operation.

Risks: risk as discussed in QID is perceived to be the possibility of the occurrence of undesired outcomes due to unintended incidents or events. Risk poses a threat in various forms towards the attainment of a CI's operational objectives. Risk in the proposed framework is classified under security as technical and non-technical. The risk identification is based on qualitative methods, combining process tracing and relationship mapping exercises. This will facilitate the identification of mission-critical processes, the risks and vulnerabilities that threaten them.

Assets: in QID, assets are understood to be tangible entities that are necessary and of value to the CPSS operational objectives. The identification of key assets and the relationship they share with actors and processes in the CPSS is an important part of the risk identification activity. An asset is described using two main features in the framework, criticality, and class. **Class** is the determination of sensitivity of an asset and the level of security required to protect it. **Criticality** is defined as a 'measure of the consequences associated with the degradation or loss of an asset. Criticality is ranked on a low, medium, or high scale and this ranking determines an asset's value to the CPSS operational objectives and mission.

Threats and Vulnerabilities: vulnerabilities are the potential weaknesses that exist within the CPSS operations that make it susceptible to external threats. In the framework, threats and vulnerabilities are then connected to assets, actors, and mission-critical processes that they are connected to.

Dependencies: threats affecting one component of the CPSS can propagate through the system, eventually affecting multiple parts of the CPSS (Wu et al., 2015b). A key consideration to understand the risks and vulnerabilities of a CPSS is through the examination of how the connections among computational, physical, and social dimensions interact in the system.

Table 2: Proposed qualitative risk identification (Q-ID) framework for CPSS

<table>
<tr><td rowspan="3">1. Mission definition
What is the purpose of the CPSS?</td><td rowspan="3">1.1 Define application domain of CPSS
In what context or sector is the CPSS in use?</td><td colspan="2">1.1.1 Functions
What mission functions is the CPSS connected to?</td></tr>
<tr><td colspan="2">1.1.2 Actors
Who are the key actors in the CPSS ecosystem?</td></tr>
<tr><td colspan="2">1.1.3 Assets
What are the assets linked to this CPSS?</td></tr>
<tr><td rowspan="5">2. Mission Process Identification
What steps are taken to achieve the goal of the CPSS?
Which CPSS steps are connected to mission-critical (MC) processes?</td><td rowspan="3">2.1 Process Description
How are the MC processes executed in the CPSS?</td><td colspan="2">2.1.1 Actors
Which actors participate in the different steps?</td></tr>
<tr><td rowspan="2">2.1.2 Process classification</td><td>Mission - critical
Which steps may lead to the failure of the CPSS?</td></tr>
<tr><td>Non-mission- critical
Which steps are considered necessary but optional to the CPSS operations?</td></tr>
<tr><td rowspan="2">2.2 Technical Systems Description</td><td>2.2.1 Assets
Which assets are linked to mission-critical processes?</td><td rowspan="2">Criticality & Class
Low, Medium, or High

What level of impact does the asset failure have on the CPSS?

What level of sensitivity and security does the asset require?</td></tr>
<tr><td>2.2.2 Asset classification</td></tr>
<tr><td rowspan="3">3. Vulnerable Components List
Which actors and assets are linked to mission critical processes?

In which layer (human, cyber, or physical) are they classified?</td><td colspan="2">3.1 Human Components
What are the vulnerable human components and which MC processes are they linked to?</td><td rowspan="2">Non-technical vulnerabilities list</td></tr>
<tr><td colspan="2">3.2 Cyber Components
What are the vulnerable computational components and which MC processes, and human components are they linked to?</td></tr>
<tr><td colspan="2">3.3 Physical Components
What are the vulnerable physical system components and which MC processes, and human components are they linked to?</td><td>Technical vulnerabilities list</td></tr>
<tr><td rowspan="2">4. Risk Classification</td><td colspan="2">4.1 Human induced risk
Which identified vulnerabilities emerge as a direct result of human related CPSS activity?</td><td rowspan="2">Cascade risk
What risk emerges because of a combination of human and technology induced incidents?</td></tr>
<tr><td colspan="2">4.2 Technology induced risk
Which identified vulnerabilities emerge as a direct result of the technical systems activity in the CPSS?</td></tr>
</table>

The identification and classification of risk and vulnerability in CPSS, is a complex, system-wide activity. It requires the analysis of risk "from a strategic to a tactical level, ensuring risk-based decision making is integrated into every aspect of the organization". The identification of risk in a CPSS is a first step before the implementation of controls and 'manage' the risk levels—which are beyond the scope of this work. Table 2 shows the proposed QID framework that considers the CPSS in mission-critical aspect. The colours in Table 1 correspond to Figure 5.

The aim of the mapping exercise is to reveal underlying connections and dependencies among the processes, assets, and actors. This step is helpful in the highlighting of the possibility of cascading risk. Cascading risk is an emergent behaviour of CPSS emanating from the multi-layer integrations in the systems (Wu et al., 2015a). The applicability of QID in CPSS mission-critical is discussed in empirical illustrations in the next section.

Q-ID FRAMEWORK EVALUATION

Rigour demands the evaluation of Q-ID framework as a demonstration to highlight how it facilitates CPSS risk identification in CPSS. The context definition of a CPSS is determined by the physical process in which it is embedded. We consider empirical illustrations highlighting CPSS linked to transport, and health.

Transport Infrastructure – Connected Vehicles

Vehicle manufacturers such as Audi, Mercedes Benz, and Tesla are examples of companies that are at the forefront of intelligent transport innovation. Vehicles come with a suite of on-board drive assist systems, with services such as lane control, emergency assist, and multi-collision brake assist. In this example, t*he vehicle and occupants are the CPSS*. The physical process that we will be analyzing is the emergency assist systems such as (Figure 6). This is considered a mission-critical process because the safety of human lives is at stake.

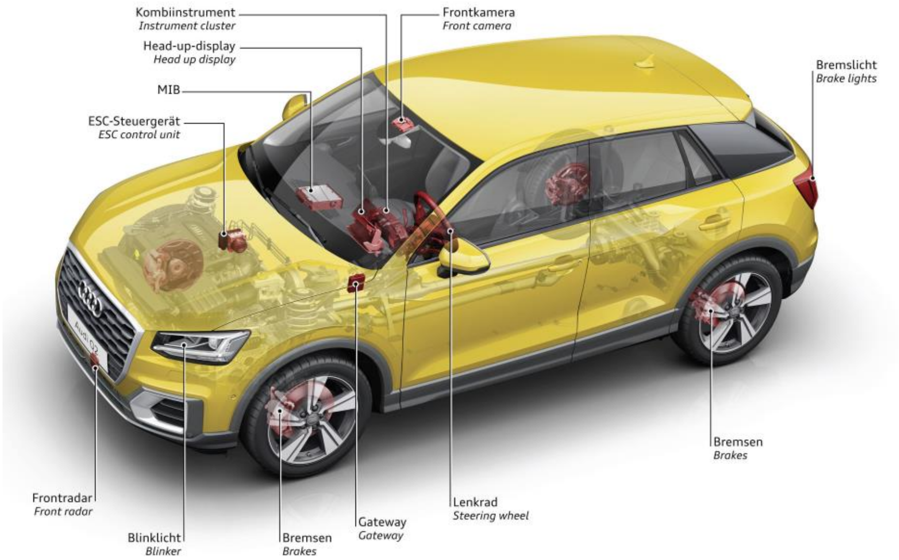

Figure 6: vehicle emergency assist sensor distribution (source Audi AG)

In Q-ID (**steps 1- 1.1.3**) the CPSS (Emergency-assist) delivers its goals (driver safety) in a series of planned steps (processes). Each step incorporating essential components, e.g. an actor (driver and passengers), asset (sensors, brakes, vehicle computer box) leading to successful delivery of a mission-critical process. Various emergency-assist related information is collected through use of intelligent sensors strategically placed in the vehicle (Figure 6) to achieve the CPSS goals. A series of processes follows (Q-ID **steps 2 – 2.1**). Based on the sensor data, emergency assist detects, within system limits when the driver is inactive. Should the driver be incapacitated, the system assumes control of the vehicle and automatically brake to a standstill in its own lane. Emergency assist is achieved through monitoring of the steering wheel movements and lane assist systems. When the driver appears unresponsive, the system, repeatedly prompts the driver, using a series of visual and audio cues and brake jolts (first brake jolt is at 80km/hour). The hazard lights are also activated to alert fellow motorists. The driver may deactivate the system by moving the steering wheel, disabling lane assist or cruise control, or pressing the brake, or accelerator pedals. Should the driver remain unresponsive following prompting, Emergency-assist brings the vehicle to a standstill and the parking brake is engaged. There are instances where the vehicle goes a step further and makes a call to emergency responders, providing vehicle location details through onboard GPS.

In the Q-ID (**steps 2.1.2 – 2.2.2**), the described processes would all be classified as 'mission-critical' - they have a direct influence on the overall safety of the driver. However, in the asset classification, the technical assets that participate in the process would be ranked differently on the criticality and class rankings, for instance, the car brakes would have a high criticality and class rating when compared to the brake lights. Interestingly, in Q-ID step 3 there is a duality to the vehicle driver, interpreted as an actor prior to an incident, and then a CPSS vulnerability in the case of incapacitation. This is due to the lack of predictability that emerges when something is wrong with the driver, yet they still convince the system otherwise. **In step 4**, it is shown that emergency-assist may be unable to complete its goal (driver safety) if the driver, moved the steering wheel or brake pedal (physical asset) or was otherwise intoxicated while operating the vehicle. The framework reveals a dependence between the cognitive state of the driver and emergency-assist that emerges as a 'human-induced risk', which leads to cascade risk such as road traffic accidents and fatality.

Health Infrastructure – Remote Patient Monitoring

The use of digital solutions in the health sector is an emerging trend. Various sensors and digital tools are used to capture biomedical and clinical data from patients living at home, allowing remote monitoring of chronic health conditions (see Figure 2). Digital health technologies have been integrated into and applied to processes such as contact tracing, clinical management, and infection screening. In this case, we analyze the use of a remote clinical monitoring application (see Figure 2) where data is uploaded to a cloud service from the patient, and the service includes the preprocessing of data in the cloud service.

Remote patient monitoring is primarily designed to allow patients to gain some independence while they continue to receive a reasonable level of care. Such applications generate a considerable amount of data, the possibility of loss of this sensitive data makes this a *mission-critical process*. In this example, the patient and all the infrastructure (see Figure 2) are the CPSS. In Q-ID (**steps 1 – 1.1.3**) a selection of biosensors (e.g., pulse-oximeter), are used to deliver a customised medical care plan (goal). The CPSS generates a lot of data – input, historic, and output data. When a patient (actor 1) makes a reading, input data is initially transmitted through a Wi-Fi connection to a cloud-based server, for pre-processing by clinicians (actors 2). They provide advice and feedback to the patient based on this data. Eventually, historic data is transferred via the internet or a secure health network into private storage. In Q-ID steps **2.1.2 – 2.2.2**, there are two main mission-critical processes that are identified – harvesting of patient data and the secure data transmission while ensuring its integrity. The criticality and class ranking for e.g., stable Wi-Fi connectivity and the biosensors is high within the patient monitoring process, and less so for secure data transmission.

In step 3, relationships between the actors (patients, clinicians), assets (e.g., biosensors, secure networks) and these processes are revealed. While the biosensors are seemingly passive, they require Wi-Fi connectivity to complete the CPSS goals. This connectivity has a direct impact on the patient privacy and data security in the cloud service and the wider network. While use of an identifiable Wi-Fi network allows flexibility and mobility for the patient, an unintended consequence is the 'surveillance' effect of such a system. This can compromise patient privacy that may carry safety, legal, or ethical implications. Further, should the patient opt to connect through an insecure network, this may compromise not only their individual data but that of other patients. The interpretation of the available information obtained from the CPSS/ sensors etc. further emphasizes the human-device interplay, highlighting how cognitive load could influence the overall quality of care the patient receives. **In step 4,** with further operational details, it is possible to deduce which aspects of the mission-critical processes are dependent on cognitive traits. Leading to an understanding of how a lapse in judgement by the patient or the clinician could compromise the CPSS ecosystem.

CONCLUSION & FUTURE RESEARCH

This paper is an exploratory attempt to apply the 'organisation-wide risk assessment methodology' to CPSS ecosystems in critical infrastructure sector applications. CPSS is understood to be a collective of resources, technological capabilities, and organisational processes. This understanding can be a starting point for further studies. The recommended alternative approach highlights the novel dynamics that are introduced through the integration of complex critical infrastructure systems into human society. The methodological approach is mainly conceptual incorporating empirical illustrations and the main contribution of this research work is a qualitative risk identification framework for CPSS analysis. The Q-ID framework serves as a building block for future research in the CPSS domain. However, the research results presented here require further elaboration, analysis and competing views. Further empirical and design-oriented studies are required to give deeper evaluations and go beyond the limited insights provided by the identified empirical illustrations.

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