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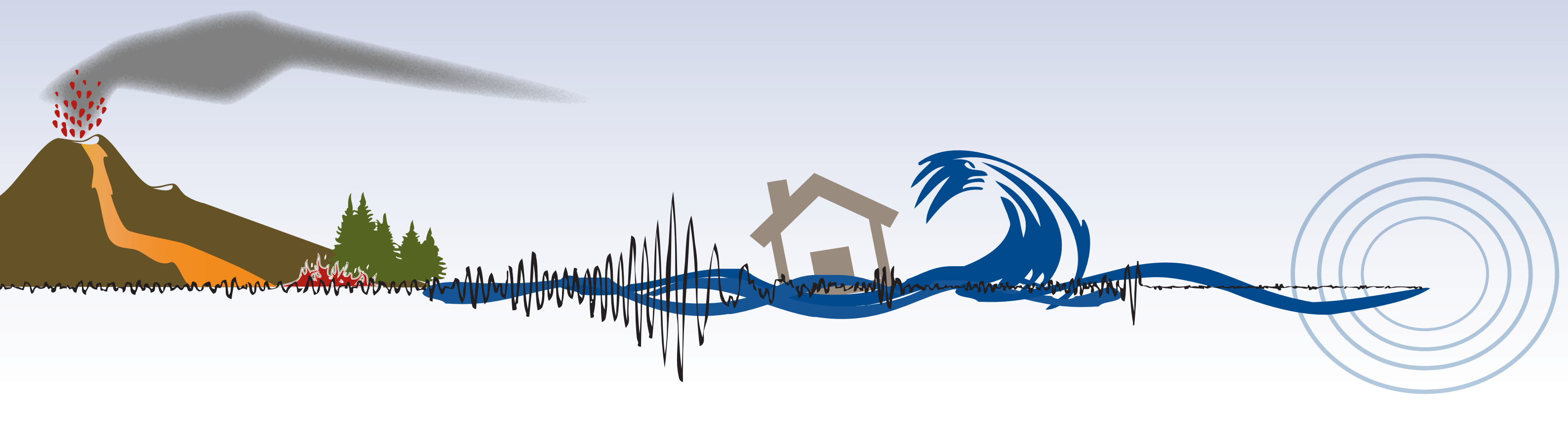

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Editorial

Special Issue Papers

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Introduction to the Special Issue on Information Systems for Crisis Response and Management in the Asia Pacific Region

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Abstract

The current special issue was arranged by Information Systems for Crisis Response and Management, during a point of the COVID-19 pandemic when many contingency plans were being made. It is a collection of the papers with the most positive reviews submitted to a conference organised by the Asia Pacific chapter of this organisation but which needed to be postponed by one calendar year. This special issue includes research papers ranging from the electronic provision of social work services and the adoption of e-learning by university students during the pandemic to relevant challenges faced by tourism supply chains around the world. Other special issue papers cover broader issues such as emergency response capacities and information systems for emergency medical care. Papers on the digitalisation of health care and a framework for studying supply chain resilience take a more conceptual approach to enduring issues, while papers on rescue coordination and traffic accident modelling look at issues affecting our everyday lives. As a whole, this special issue represents a panorama of important research and research-related activity that was being carried out as the pandemic progressed. We are proud to have seen the current set of papers through to publication during such a challenging period.

Keywords: *Special issue, Editorial, COVID-19, Information Systems*

In the middle of 2021, the Information Systems for Crisis Response and Management (ISCRAM) Asia Pacific chapter was planning to follow up its very successful 2018 conference in Wellington, New Zealand, with an even more high-profile event in Melbourne, Australia. Among other institutions, they had partnered with the Commonwealth Scientific and Industrial Research Organisation (CSIRO) which is based in Melbourne and hoped to run a hybrid conference that would include a main conference hub in the city, with smaller hubs in Auckland, New Zealand and Zhuhai, China.

The conference was scheduled for the end of 2021, but pandemic-related complications meant that it would be very risky to host the conference in Melbourne at that time. It seems timely to highlight that the conference theme was Planning for the Unexpected, at a time when not-so-pleasant surprises had become the norm. The conference was postponed by one year, and the authors of several accepted papers were invited to submit their papers to the current special issue rather than waiting for conference proceedings that would take more than another year to come together.

The publication of this special issue gave us the opportunity to publish leading research on information systems that would still be timely enough to inform responses to and recovery from the COVID-19 pandemic. At this stage, the challenges posed by new variants and vaccine availability mean we cannot guarantee that the virus will be brought under control in every affected part of the world (McIntyre, 2022). We are far from recovering from the aftermath of the virus and perhaps even further away from learning from many mistakes, despite best efforts, made at many points of our response.

Special Issue Content

As the Guest Editors, we are proud to present a set of special issue papers that can help us learn from the first genuinely pan-lateral emergency faced in the information age. The resulting special issue includes a study into the factors predicting whether students would continue studying online, while cut off from their university campuses (Huggins et al., 2022). Mundane as this may seem, we are beginning to witness the impacts of educational discontinuity around the world, and the toll this has taken on developing minds in most corners of the globe. The next paper, by Wong et al. (2022) also looked at disruptions and challenges caused by the COVID-19 pandemic, in terms of the way Chinese social workers reconfigured the support provided to residents of Wuhan, China, in the very early stages of the pandemic. Their paper outlines the crucial role played by technological devices and connectivity at a time when physical mobility was so limited.

Other research, by Umar et al. (2022a), broaches COVID-19-related interruptions to tourism supply chains, at a time when the international tourism sector was facing its biggest challenge to date. The next paper by this author (Umar et al., 2022b) provides a framework for identifying potential remedies, for promoting the resilience of supply chains extending well beyond any one industry. It presents the adaption of a model originally created for analysing elements of road safety. This, together with the wide-ranging scope of Umar's framework, reminds us that the challenges posed by the COVID-19 pandemic did not eliminate pre-existing perils such as traffic accidents. The next special issue paper, by Zhang et al. (2022), focuses on traffic accident modelling and highlights the fact that a wide range of emergency management research continued well into and during the pandemic. Their research provides a validated model for calculating the disruptions caused by motor vehicle accidents.

The subsequent papers outline new technologies for crisis response and management that being developed and piloted at the time of writing. Tijerino et al. (2022) outline their pilot research into innovative incident management software. Their paper finishes with important insights around end users´ perceptions of usability. Morand and Rizza (2022) present some of the gains and obstacles encountered while piloting a first aid application designed for the general public. Ongoing development of the same application will include a more detailed analysis of usability and other adoption factors.

The special issue concludes by taking a slightly wider view of the more obvious theme of the day, healthcare. The penultimate paper by Madanian et al. (2022) outlines a new approach to information system architecture, that can be used to help ensure that hospitals, and other medical facilities can continue functioning during a wide range of crises. The importance of these information system architectures cannot be overstated, especially when they help ensure that medical services are not jeopardised at the very time when they are needed most. The final paper, by Magutshwa (2022), critically analyses and discusses the digitalised healthcare approaches that became much more common during the COVID-19 pandemic. This paper concludes with an agenda for further research that will respond to both recent, and previous, lessons learned.

Conclusion

We are grateful to each author who contributed to the current special issue. Their patience and perseverance has not only contributed to the continuity of our universities, research and development institutions, government departments, and private and third sector initiatives. Their constructive focus has also helped to make sure we have this short compendium of information systems research, being conducted during the COVID-19 pandemic. We are sure that many readers will appreciate that there is a lot to hope and strive for, even among the more technical milieu of information systems for crisis response and management.

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Online learning adoption by Chinese university students during the Covid-19 pandemic

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Abstract

The 2019 Novel Coronavirus Pandemic has severely challenged the continuity of post-secondary education around the world. Online learning platforms have been put to the test, in a context where student engagement will not occur as a simple matter of course. To identify the factors supporting online learning under pandemic conditions, a questionnaire based on the Unified Theory of Acceptance and Use of Technology was adapted and administered to a sample of 704 Chinese university students. Structural equation modelling was applied to the resulting data, to identify the most relevant theoretical components. Effort expectancy, social influence, and information quality all significantly predicted both students' performance expectancies and the overall adoption of their university's Moodle-based system. Performance expectancy mediated the effects of effort expectancy, social influence, and information quality on symbolic adoption. Internet speed and reliability had no clear impact on adoption, and neither did gender. The direct impact of information quality on symbolic adoption represents a particularly robust and relatively novel result; one that is not usually examined by comparable research. As outlined, this is one of three key factors that have predicted online learning engagement, and the viability of educational continuity, during the Coronavirus pandemic. The same factors can be leveraged through user-focused development and implementation, to help ensure tertiary education continuity during a range of crises.

Keywords: *Online learning, technology adoption, business continuity, pandemic.*

Introduction

At the time of writing, the 2019 Novel Coronavirus (COVID-19) pandemic continues to present substantial challenges to the world's universities. Although the current pandemic's progression has caught many institutions by surprise, smaller-scale antecedents have included the severe acute respiratory syndrome (SARS-CoV) of 2003 and the H1N1 pandemic of 2009. The global scale of the COVID-19 pandemic came foreshadowed by the 1918-1919 Spanish Influenza, which killed between 24.7 and 50 million people around the globe (Johnson & Mueller, 2002; Oxford et al., 2002). This pandemic also left many millions of students studying by distance (Ammond, 2001; Lilley et al., 2020; Mamelund, 2017; Rosner, 2010), in a sudden departure from normal student life.

There have been important changes to the scale and nature of education since the latter antecedent to the current pandemic. University level studies have become much more commonplace since the beginning of the twentieth century. In 1900, there were approximately 500,000 university enrolments throughout the world, growing to over 100 million by the year 2000 (Schofer & Meyer, 2005). The same shift has been even more recent for Chinese universities, which experienced an increase of almost 40 million tertiary students from 1950 to 2019. By 2019, total university enrolments reached 34,205 times the number of students enrolled as at 1949 (China Ministry of Education, 2020).

Even more recent decades have seen many universities and other education providers develop online platforms to deliver tertiary level courses, and course-related content (OECD, 2005; Allen & Seaman, 2013). Among other capabilities, this has enabled universities to deliver blended learning, combining both online and offline activities into the same set of courses. Rasheed et al. (2020) identified a wide range of relevant shifts towards a blend of place-based and online learning, with respective challenges for students, teachers, and institutions. Studies by Shea and Bidjerano (2014) and by Shi et al. (2020) have shown how students nonetheless tend to benefit from this blended mode of learning, in terms of improved learning outcomes and even increased college graduation rates. This has meant that millions of university students have been able to continue their studies online, using portable devices such as cell phones and laptops during the COVID-19 pandemic (Huang et al., 2020), rather than waiting for paper-based courses to be delivered by mail. This switch to online education during a pandemic also follows antecedents. Similar situations were experienced by institutions in many countries, who prepared online modes of education in response to the H1N1 pandemic. This included an estimated 67 % of universities in the USA, who made plans to switch to online education delivery in response to the pandemic (Allen & Seaman, 2010) .

In the decade separating the H1N1 pandemic from the COVID-19 pandemic, online education became part of business as usual in universities around the world. A range of graduate and postgraduate material was already taught online before COVID-19, and many courses included online learning alongside classroom-based teaching. This trend has extended to parts of the world that have traditionally been described as *developing* countries. For example, online education was already being developed by many Chinese educational institutions well before the COVID-19 pandemic (Zhu, 2010). By 2014, the Chinese Ministry had already run 24 different massive open online courses within the Chinese mainland (Qiu, 2014). The current paper focuses on this developing educational context, which has advanced rapidly but which has also tended to be under-researched and under-reported in the English language.

Technological advances in China and around the world have created many opportunities for delivering education by distance in the contemporary world. Internet capable devices have become much cheaper, and more accessible to a wider range of students (Cronje, 2016). Online courses are also becoming more accessible, with most designed to be compatible with a wide of range of hardware including desktop, laptop and mobile devices (Lambert, 2020). Internet speeds have also substantially improved over the last decade. Internet speed from a regular internet service provider is now ten times faster, delivering hundreds of megabits per second compared, to the tens of megabits per second delivered only ten years ago (Feamster & Livingood, 2019). These advances are particularly relevant for the relatively wealthy context studied in the current paper, characterized by a high level of student hardware and communications infrastructure. Over the same period, server capacities have become a key component of universities' IT infrastructure. These capacities have dramatically increased to host learning management systems (LMSs) and in turn, to ensure successful e-learning delivery (Alsabawy, 2013; Asalla, 2017). To enhance the clarity of the current paper, the resulting LMSs are referred to as online learning platforms.

Despite the potentials outlined above, universities that heavily invested in online learning platforms can run the risk of widening a pre-existing digital divide: between those that can and cannot make good use of online technologies (Warschauer, 2003). This concept of a divide helps to highlight how online learning does not occur as a matter of course. Even a very basic online course has several costly requirements, including: a rapid and stable internet connection; a sizeable internet data allowance, to accommodate video content; a screen that is big enough for extended viewing; and a functioning keyboard, for even minimal interactions. As highlighted by Warschauer (2003), technology users also need certain technological skills, to take full advantage of these kinds of technological tools and associated software.

Even when students have reliable access to online learning platforms, the COVID-19 pandemic has put those platforms under largely unprecedented demands. Rather than being an optional or complementary mode of delivery, they have become the only way for many institutions to continue functioning (Huang et al., 2020). Students' adoption of online learning platforms has therefore become even more important than blended and online learning options provided during business as usual. The importance of online learning platforms has been particularly tangible in populous countries such as China, where a governmental, open education platform received 8 million clicks within the first day of operation in February 2020 (Huang et al., 2020). Towards improving university student engagement during the current pandemic and future crises, the current research aimed to identify technology and user characteristics predicting Chinese university students' adoption of a specific online learning platform. As outlined below, decades of prior research into predicting LMS adoption has been adapted to help meet challenges presented by the COVID-19 pandemic.

Prior Research

The current research focuses on student engagement with an LMS called iSpace. This LMS had been developed and implemented at a liberal arts university in the South of China over a period of more than five years. However, the platform had not yet been used to teach exclusively online. To reflect challenges posed by exclusively online teaching during the COVID-19 pandemic, the iSpace system is the online learning platform of interest for the remainder of the current paper. It is based on the generic Modular Object-Oriented Dynamic Learning Environment (Moodle) platform, which was "designed to provide educators, administrators and learners with a single robust, secure and integrated system to create personalized learning environments" (Moodle HQ, 2020, para 1). As at June 2020, there were over 213 million Moodle users throughout the world, making it the world's most widely used online learning platform (Moodle HQ, 2020). Generic Moodle capabilities are maintained by an expansive community of programmers and contributors throughout the world, coordinated by a group of 80 Moodle Partner service companies (Moodle HQ, 2020). The basic Moodle platform has also been customized by universities around the world, for delivering online educational content and activities as part of tertiary level courses. The basic Moodle platform is nonetheless non-proprietary and open source. This means that universities who have not yet fully leveraged its potential can do at minimal cost and inconvenience.

Like many other technologies, students' adoption of Moodle-based online learning platforms can be explained and studied using the unified theory of acceptance and use of technology (UTAUT) (McKeown & Anderson, 2016; Raman et al., 2014). Before outlining several examples of relevant research in the following Section 1.2, a brief introduction to the UTAUT theoretical model helps to explain why it suits research into online education engagement. The UTAUT framework emanated from the need to unify competing theoretical models, including the theories of reasoned action (TRA) (Ajzen & Fishbein, 1980) and of planned behavior (TPB) (Ajzen & Madden, 1986), and the technology acceptance model (TAM) (Davis, 1986, 1989). These theoretical antecedents had previously provided robust explanations of users' engagement with a range of technologies, by defining a very wide range of aspects and relevant concepts. The UTAUT model (Venkatesh et al., 2003) synthesized a more concise set of key concepts by combining these pre-existing models, to define the main factors leading to active technology adoption. The first of these key concepts is effort expectancy, which is "the degree of ease associated with the use of the system" (Venkatesh, 2003, p. 450). This concept is sometimes referred to as perceived ease of use and may be particularly important for students studying under relatively improvised and distressful conditions. This is because those students may not be able to concentrate on novel, and unnecessarily complicated, technological demands.

Facilitating conditions are another key aspect of the UTAUT model. This concept refers to "the degree to which an individual believes that an organizational and technical infrastructure exists to support use of the system" (Venkatesh, 2003, p. 453). As outlined in Section 1.0, it cannot be assumed that all students have equal access to online learning. A persistent digital divide between students may have seen many of them attempting to study online without rudimentary requirements such as a reliable internet connection.

Social influence is another key aspect of the UTAUT model. This concept addresses "how strongly an end user perceives that others believe that he or she should use the new system" (Prasanna & Huggins, 2016, p. 171). This aspect of online learning has been particularly important during the COVID-19 pandemic, for Chinese students forced to study back in their family apartments or other family home environments. Although the students may have become relatively independent, the current crisis may have returned them to considerable pressure from their parents and other family members. This temporary context for social influence is distinct from, and perhaps more salient than, more rudimentary contexts studied by prior LMS adoption research.

Relatively recent adaptations to the UTAUT model highlight how information technologies can be effectively redundant unless they provide useful information. Information quality generally addresses "whether a system is free of errors, whether it provides the information needed for the user to complete their work at the time they need it, and whether information is provided in a format which is easy to read" (Prasanna & Huggins, 2016, p. 171). Although this factor has not traditionally been addressed by LMS adoption research, it was particularly relevant for the current study. The concept of information quality creates unique challenges for a broad range of organizations (Jayawardene, 2016, Jayawardene et al., 2021). It is particularly relevant and challenging for educational institutions tasked with delivering robust and engaging learning materials through online platforms (Hansen & Gissel, 2017). These learning materials can include: videos, additional readings, forum prompts, and glossaries. This is why information quality makes an intuitive addition to more standard applications of the UTAUT model, because the quality of LMS content is just as important as the quality of learning content delivered through any given mode of instruction. Ideally, any learning content will be delivered in a way that leverages student attention spans (Bradbury, 2016; Hartley & Davies, 1978) to good effect, and promotes learning that extends well beyond the most basic level of simply remembering the course material (Anderson, 2001).

The UTAUT model treats each of the preceding concepts as a technology characteristic that will either lead to, or undermine, performance expectancy: "the degree to which an individual believes that using the system will help him or her to attain gains in… . performance" (Venkatesh, 2003, p. 447). Within the UTAUT model, performance expectancy mediates how each of the preceding technology characteristics affect technology adoption (Venkatesh, 2003; Prasanna & Huggins, 2016). The resulting level of adoption is typically gauged in terms of symbolic adoption: "an end-user's mental acceptance of a new system" Prasanna & Huggins, 2016, p. 171). As discussed in further detail below, symbolic adoption is often used as a proxy for adoptive behaviors, due to a consistently close correlation with the latter (Prasanna & Huggins, 2016).

Many studies have used and/or adapted the UTAUT model for researching online education engagement. For example, a recent study by Mehta et al. (2019) found that an adapted version of the UTAUT model predicted online learning adoption, among adults studying in Gambia and the United Kingdom. This followed research by Amornkitpinya and Wannapiroon (2015), Arteaga Sanchez and Duarte Hueros (2010), Raman et al. (2014), Lahkal et al. (2013), and by Lee and Mendlinger (2011), which demonstrated how the UTAUT, or the antecedent technology adoption model (TAM), reliably predict online learning engagement in a wide range of settings.

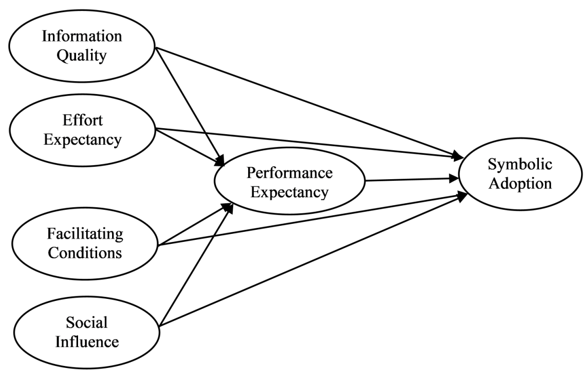
The prior research by Amornkitpinya and Wannapiroon (2015) and by Lee and Mendlinger (2011) also gauged self-efficacy, a student's belief in their own likelihood of success, as an additional factor predicting online education adoption. Their approach was consistent with Bandura's definition of self-efficacy: "beliefs in one's capabilities to organize and execute the courses of action required to produce given attainment" (Bandura, 1997, p.3). In practical terms, this approach to predicting adoption places a distinct onus on improving the self-confidence of students needing to study online. However, crisis situations such as the COVID-19 pandemic may not afford this luxury, before the crisis triggers a rapid switch to online learning. Students with a lack of relevant mastery experiences may not have established self-efficacy (Bandura, 1977). This is likely to limit their e-learning performance, and meaning there are benefits from supporting students who lack experience in technology-enabled, active learning environments (Shi et al., 2020). For the current study, this support is addressed through the concept of facilitating conditions, which normally include technical support for less confident users. The current research therefore takes a more technology-centric approach to online education adoption, where certain aspects of technology design and provision will improve effort expectancy, or perceived ease of use, for users with a wide range of personal characteristics and different degrees of technological familiarity.

Current Theoretical Model

To expand on research conducted in non-pandemic contexts, the current research used a specific UTAUT-based theoretical model developed and validated by Prasanna and Huggins (2016), for mandatory technologies used within a crisis context. This model was originally designed to address the adoption of emergency management software, among trained professionals. It nonetheless also aligns very closely with UTAUT iterations outlined above, which have successfully predicted online learning engagement.

Results reported by Prasanna and Huggins (2016) showed that even mandatory technologies, such as obligatory online education, are adopted to widely varying degrees. According to their results and analysis, the adoption of software mandated by users' employers

Figure 1.
Theoretical model of hypothetical relationships between factors



varied as systematically as did the adoption of non-mandated technology. These results led to the validation of the UTAUT iteration shown in Fig. 1, above. As outlined by Prasanna and Huggins (2016), the level of commitment involved in the symbolic adoption of mandated technologies entailed more system usage. It also led to more effective system usage, through familiarity and well-rehearsed human-computer interactions. Considering this high degree of relevance to the current research context, the theoretical model shown in Fig. 1 was used to structure the current research. For this purpose, it included the following constituent hypotheses:

1) That performance expectancy would be predicted by effort expectancy, facilitating conditions, social influence, and information quality.
2) That symbolic adoption would be directly predicted by effort expectancy, facilitating conditions, social influence, and information quality.
3) That symbolic adoption would also be indirectly predicted by effort expectancy, facilitating conditions, social influence, and information quality – mediated by performance expectancy.

Methods

Scale items were adapted from prior technology adoption research by Arteaga Sanchez & Duerte Hueros (2010), Lahkal et al. (2013), Lee & Mendlinger (2011), and by Prasanna and Huggins (2016). Adaptations were minimal and primarily aimed to address the current online learning platform, instead of prior wording that addressed other platforms and technologies. Participants were asked to answer the resulting question items using a Likert scale, running from: 1 – “Strongly Disagree”; 3 – “Neutral”; to 5 – “Strongly Agree”.

Adapted scale items were complemented by demographic questions, concerning gender and major enrolment. The complete questionnaire was administered using the Typeform (Version 2, 2020) online survey platform, following piloting and adjustment with the same group of five students who had previously used the same Moodle-based online learning platform, but had not used it during the COVID-19 pandemic.

All students who had used the Moodle-based online learning platform between February and July 2020 were then invited to participate. At this time, no student or teacher were allowed on the university campus, meaning that all students and teachers were restricted to on-line classes. They were emailed an invitation complete with the Typeform URL, via university administrators. Their invitation included the offer to enter a 20 RMB prize draw in compensation for their time, with one prize for every ten entries. Before granting informed consent on the first page of the survey, participants were assured that their participation and any personally identifiable data would remain confidential, and that it would be anonymized during data collation and analysis.

The questionnaire was attempted by 742 out of approximately 5,400 online learning platform users, studying at the university in question. 711 survey responses were completed without obvious response sets or associated problems with response variability. Some of these responses were not accompanied by voluntary, demographic information. The final sample of participants nonetheless numbered 503 females, 201 males, 4 students who declined to name their gender, and 3 students who identified as an “Other” gender. Students who named their program of studies were studying business management (39%), science and technology (34%) humanities and social sciences (11%), or arts (9%). A sub-total of 361 (49%) respondents were first year students, meaning that the overall sample was evenly split between participants who had previously used iSpace and those that had not.

Analysis

The initial set of questionnaire items was refined and validated through parallel factor analysis, to ensure the validity and reliability of each model factor. The remainder of analysis used structural equation modelling to validate factors and test whether the relationships between them matched the theoretical model shown in Fig. 1 of Section 1.2. This analysis used the IBM Statistical Package for the Social Science (SPSS) version 25 and Analysis of Moment Structures (AMOS) version 25 software to perform a two-stage structural equation modelling process. The first stage of this process involved measurement model assessment through combined parallel and exploratory factor analysis (EFA), before conducting confirmatory factor analysis (CFA). The second stage involved structural model assessment, which was used to evaluate the causal relationships between factors.

Combined parallel and exploratory factor analysis followed the iterative process conducted by Wood et al. (2015). The current parallel analysis used the O’Connor (2000) rawpar.sps script, which produces eigenvalues from the raw data and compares them with eigenvalues resulting from Monte Carlo simulations, using randomly generated data. Parallel analysis for the current study used 5,000 simulations to produce the randomly generated eigenvalues, with a 95th percentile cutoff.

Multiple iterations of this process were used to identify the optimal number of factors for the overall model. Each iteration was followed by an assessment of identified factors using EFA using maximum likelihood extraction with oblique rotation. The EFA involved generating pattern matrices based on the number of factors determined in the parallel analysis; pursuing solutions with factor loadings above the thresholds set by Hair et al. (2014) and reliability thresholds from Fornell and Larcker (1981). This resulted in distinct groupings of variables with strong correlations, confirming that the previously theorized number of factors could be adequately determined.

After determining the number of factors through the combination of parallel analysis and EFA, CFA was conducted using AMOS software. This involved reviewing modification indices to find a model fitting Hu and Bentler's (1999) criteria for fit. Reliability and both convergent and divergent validity of the measurement model were also assessed. Reliability was assessed against Hair et al.'s (2014) suggested threshold. Convergent validity was confirmed by an average variance extracted (AVE) for all factors higher than thresholds defined by Hair et al. (2014). Following Hair et al. (2014), discriminant validity was assessed by a square root of AVE for factors that was higher than the absolute value of between-factor correlations. This CFA process was used to confirm whether analysis had arrived at a stable measurement model, with retained items that could adequately measure the theorized constructs. The resulting measurement model was then subjected to structural analysis. As outlined below, this involved using the same AMOS software to evaluate causal relationships between the validated factors.

Results

The parallel factor analysis of all survey responses led to the retention of 17 of 25 items, excluding: effort expectancy (EE) item 3; facilitating condition (FC) items 1, 4 and 5; information quality (IQ) item 1; social influence (SI) items 3 and 4; and symbolic adoption (SA) item 4. All performance expectancy (PE) items were retained, along with all other retained items shown in Table 1. Each resulting factor met standards for composite reliability (CR), from Kline (2000) and Kline et al. (2012), and for AVE, from Hair et al. (2014). The latter standards were also applied to the square root of AVE for each factor, marked in bold in Table 1. The remainder of Table 1 shows correlations between each factor, which were consistently less than unitary values of CR and AVE for each individual factor. The full set of retained questionnaire items are marked with an "*" in Appendix A.

Table 1.
Analytical summary for refined factors

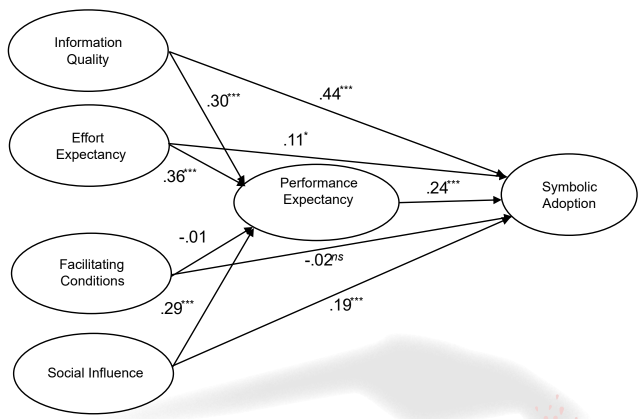
Factor	CR	AVE	SA	PE	IQ	EE	FC	SI
Symbolic Adoption	0.84	0.63	**0.79**					
Performance Expectancy	0.90	0.70	0.72	**0.84**				
Information Quality	0.83	0.62	0.77	0.68	**0.79**			
Effort Expectancy	0.82	0.61	0.61	0.66	0.62	**0.78**		
Facilitating Conditions	0.85	0.75	0.31	0.33	0.33	0.44	**0.86**	
Social Influence	0.71	0.55	0.61	0.59	0.54	0.40	0.30	**0.74**

Note: CR = Composite Reliability, AVE = Average Variance Extracted, SA = Symbolic Adoption,

PE = Performance Expectancy, IQ = Information Quality, EE = Effort Expectancy, FC = Facilitating Conditions, SI = Social Influence. The square root of AVE for each factor is presented in bold, on the diagonal.

All constituent factors could be retained, meaning that the original theoretical model from Fig. 1 was then retained for structural equation modelling. The statistical significance of predicted correlations is displayed in Fig. 2, providing strong if partial support for the current theoretical model. The current results indicate that both performance expectancy and symbolic adoption were directly predicted by information quality, effort expectancy, and by social influence, but not by facilitating conditions.

Figure 2.
Empirical relationships between components of the current theoretical model



n = 711
* $p < .05$; ** $p < .01$; *** $p < .001$

Table 2 shows mediated effects for information quality, effort expectancy, and social influence, on symbolic adoption. This indicates that the effects of information quality, effort expectancy, and social influence on symbolic adoption, were all mediated by performance expectancy. These results supported the majority of hypothesis 3: That symbolic adoption would also be predicted by effort expectancy, facilitating conditions, social influence, and information quality – as mediated by performance expectancy. Although responses to five-point Likert scales for facilitating conditions had the highest level of variance (*SD* = 1.13) of any items, this data had no clear relationship with performance expectancy or symbolic adoption.

Table 2.
Summary of indirect effects on symbolic adoption

Pathway	Estimate	95% Confidence Interval	
		Lower Limit	Upper Limit
IQ → PE → SA	.08**	.03	.14
EE → PE → SA	.10**	.05	.16
SI → PE → SA	.05**	.02	.10

n = 711
** *p* < .01
IQ = Information Quality, PE = Performance Expectancy, SA = Symbolic Adoption, EE = Effort Expectancy, SI = Social Influence

Discussion

Each of the following hypotheses were partially supported by the current results, to a large extent: 1. That performance expectancy would be predicted by effort expectancy, facilitating conditions, social influence, and information quality; 2. That symbolic adoption would be directly predicted by effort expectancy, facilitating conditions, social influence, and information quality, and; 3. That symbolic adoption would also be indirectly predicted by effort expectancy, facilitating conditions, social influence, and information quality – mediated by performance expectancy. All but one of the predictive factors included in the UTAUT model from Prasanna and Huggins (2016) were found to be a valid part of these hypotheses. This also reflected the majority of results from prior research by Mehta et al. 2019), Amornkitpinya and Wannapiroon (2015), Arteaga Sanchez and Duarte Hueros (2010), Raman et al. (2014), Lahkal et al. (2013), and by Lee and Mendlinger (2011).

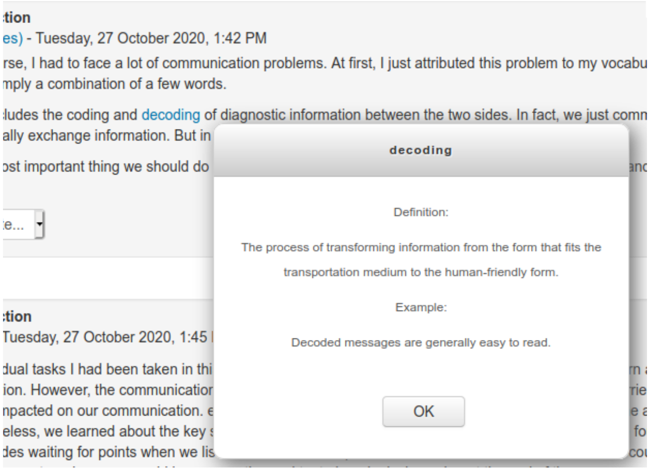
Effort expectancy was the predominant predictor of performance expectancy. The extent of this relationship replicates results from Arteaga Sanchez and Duarte Hueros (2010), who researched e-learning adoption under non-crisis conditions. It is also intuitively relevant for the current research, where students facing the demands and emotional strains posed by the COVID-19 pandemic were less likely to adopt learning that required even more effort.

It is most important to note that the direct relationship between information quality and symbolic adoption (*r* = .44, *p* < .001) was twice as strong as the relationship identified by Prasanna and Huggins (2016). There was also a statistically robust pathway running from information quality to performance expectancy and then symbolic adoption. This mediated pathway had an estimated upper limit exceeding .1 and was statistically significant at the level of *p* < .01. As outlined in the introduction, information quality had been included in the current theoretical model to reflect the importance of user confidence in the information being provided under crisis conditions. As identified by Prasanna and Huggins (2016), users' perceptions of information quality are a key driver of whether the same users will actively engage with that information during a crisis scenario. The importance of information quality during crises is also reflected in a growing body of research, concerning a wide range of decision-making scenarios (Jayawardene, 2016; Jayawardene, 2021). For the current research, it can be assumed that students would simply select other information available on the internet, when quality information was not being provided through the online learning platform. Vice versa, high quality information appears to have led students to return to the online learning platform in pursuit of further high quality information.

The importance of results concerning information quality is illustrated by the example of an online glossary of terms. Any Moodle-based course can include a simple glossary of terms, relating to a particular course or to an overall topic. Teachers and university administration can take certain steps to optimize the quality of glossary information, in terms of: "whether a system is free of errors, whether it provides the information needed for the user to complete their work at the time they need it, and whether information is provided in a format which is easy to read" (Prasanna & Huggins, 2016, p. 171).

Student-generated glossaries can be particularly useful, because student entries directly identify and address the technical terms and associated concepts which they find most interesting. Students are also free to select the terms they find most difficult to understand and apply. In sum, their contributions help ensure that the glossary contains only the most necessary information, i.e. "the information needed". Teachers can help ensure that

Figure 3.
Clicking a highlighted glossary term opens up the approved glossary entry



a student-generated glossary is "free from errors" by making sure that individual student entries are checked and approved before being added.

Accessible and timely access to the glossary, i.e. "at the time they need it" can be provided in many ways. As shown in Fig. 3, direct lookup access to the glossary will give students a chance to correct any misunderstandings while making their own forum contributions. Automatically detecting and linking of all glossary terms, used in student forum entries, allows their fellow students to use highlighted and linked glossary terms to check their own knowledge, when reading and responding to the same forum post. Pop-up information and other interface characteristics help ensure that the glossary information is provided "in a format that is easy to read". These approaches to Moodle-based glossaries illustrate how online education can use dynamic and integrated information, to support the application of course content, in addition to basic remembering and subsequent levels of revised Bloom's taxonomy (Krathwohl, 2002). Once these levels of learning are attained, students will be much more prepared to advance towards analysis, evaluation and creativity (Krathwohl, 2002). At the tertiary level of education, they will be supported to become a more engaged and capable learner.

On the other hand, facilitating conditions did not predict either performance expectancy or symbolic adoption. A broader range of facilitating conditions items had been eliminated during factor analysis, meaning that this factor was effectively limited to internet speed and reliability. The lack of a statistical relationship between these items and adoptive factors could have been due to the temporary nature of iSpace usage during COVID-19. At the time of data collection, the pandemic appeared to be under control throughout most of China and most students would have been confident about returning to studying on campus in the following semester. Any temporary issues with internet connectivity were likely to be resolved in the relatively near future, while symbolic adoption tends to gauge technology adoption over a longer timeframe. Furthermore, many interruptions to connectivity were likely to be minor, due to the advanced state of internet infrastructure across the majority of the Chinese Mainland. While expectations for connectivity may have been high, it is unlikely that the participants faced the kind of critical and ongoing issues with connectivity faced by students in many other parts of the world.

Practical Implications

The practical implications of robust results concerning both effort expectancy and social influence are relatively straight-forward. For example, it appears that online learning platforms need to be user-friendly to optimize effort expectancy. This implication extends to ensuring that Moodle-based platforms are developed towards student user needs, rather than primarily focusing on teachers´ preferences and wider institutional objectives. In terms of Sowa and Zachman (1992), this would leverage the impact of user-focused development, on end-user engagement and resulting performance (Prasanna & Huggins, 2016). According to Huggins and Prasanna (2020) and Yang et al. (2014), this approach to development is exemplified when technology development focuses on end-user tasks and associated information needs (Huggins & Prasanna, 2020; Yang et al., 2014).

Social influence is a little different, but no less straight-forward. The positive impact of this factor can be leveraged by ensuring that LMS activities involve a students' wider network of peers and other influences. The current results concerning social influence suggest that performance expectancy and overall engagement will improve when members of these peers and other networks are both aware, and supportive, of online learning platform capabilities. This may result in other benefits for the host institutions, who are more likely to gain further enrolments due to positive perceptions of their online learning delivery.

The relationship between information quality and both performance expectancy and symbolic adoption may be even more important than other results from the current research. This is a more recent addition to the UTAUT model which appears to be particularly valuable in crisis situations (Prasanna & Huggins, 2016). The example of Moodle-based glossaries outlined in Section 4.0 helps to illustrate how information quality is not accomplished as a matter of course. Many teachers making a rapid switch to e-learning will not have the skills required to implement this more technical, approach to Moodle-based glossaries or other learning content. Efficient professional development will be required, rather than waiting for teaching staff to develop a specific set of technology-related skills. As recommended by Prasanna and Huggins (2016), personnel will ideally be familiar with an Moodle-based LMS, long before the onset of a crisis requiring off-campus study. To achieve this level of familiarity, relevant professional development needs to be provided under non-crisis conditions, as a kind of business as usual. This approach to longer-term professional development can also promote the blend of online and offline learning that, according to Shea and Bidjerano (2014) and Shi et al. (2020), has improved student learning outcomes and even graduation rates in a range of contexts.

Further Research

The current results also have implications for further research, including opportunities to expand on methodological constraints that are relatively characteristic of technology adoption research. There is an ongoing opportunity to analyze a wider range of text and image-based qualitative data, in additional to Likert scale responses. Ongoing research can also be carried to consider actual use data, concerning how many clicks were made by respective participants, during the weeks following questionnaire completion. Most of the current participants explicitly consented to the use of this type data during the actual research protocol, permitting a re-assessment of the common assumption that symbolic adoption equates to adoptive behaviors.

Conclusion

The current research examined students' engagement with online learning during the COVID-19 pandemic; at a time when there was no alternative to continuing their university level studies by distance. This global health emergency had meant that online learning platforms were becoming an essential component of business continuity for universities around the world. Data was gathered from over 700 university students studying at a Chinese university during the COVID-19 pandemic, querying their perceptions and usage of a specific online learning platform. The students were asked to complete a questionnaire that included a number of adapted scales, reflecting the UTAUT model of technology adoption. The resulting data was subjected to factor analysis, which enabled the robust selection of questionnaire scales, for the purposes of SEM analysis.

This SEM analysis produced results in support of all but one aspect of the current theoretical model. In brief, students' symbolic adoption of the online learning platform was predicted by their associated levels of effort expectancy, social influence and perceived information quality. The same factors also predicted students' performance expectations, which in turn predicted symbolic adoption. In theoretical terms, these results have highlighted the validity of an adapted UTAUT model, for a Chinese population which may have therefore been neglected by prior technology adoption research.

Results of conducting the current research with participants with a Chinese ethnic background nonetheless reflect factors observed in many other parts of the world, including the results of research conducted in many developed western cultural contexts. Facilitating conditions were the only exception. Despite a high degree of variability, this factor did not predict student engagement with the LMS. This result may mark a unique characteristic of Chinese populations when engaging in online learning during a crisis. Further research with comparable samples may help strengthen this conclusion, in addition to research using a broader range of participant responses and actual usage statistics.

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Practice Update – Social-psychological emergency response during Wuhan lockdown: Internet-based crisis intervention

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Abstract

Wuhan was completely locked down in 2020 because of the COVID-19 pandemic. Its residents were isolated, depressed. They were badly in need of information, advice, and psychological support. However, social and psychological services could only be provided by distance. The Social Workers Across Borders trained and supervised more than 120 volunteers to offer e-counselling services through WeChat platforms. The digital environment was very different from real life or even hotline settings. Wechat platforms, similar to that of WhatsApp, enabled multi-players, multi-media, and multi-directional exchanges for as many as 500 participants. They could raise questions, share information and offer opinions. Volunteers, composed of medical students, psychological counsellors, social workers, community workers, and lay community volunteers, were understandably not ready for the challenge. The teams found that traditional crisis intervention skills training, designed for face-to-face emotional support, was no longer sufficient to ensure satisfactory results in the digital environments. The current study, based on the analysis of the supervision records of the volunteers, discussed the hindering factors in providing Social Psychological e-services and proposed their respective solutions. A new mode of Social Psychological Emergency Response has emerged and our traditional training for respective responders needs to be revolutionized.

Keywords: *E-counselling, COVID-19, social work*

Introduction

The City of Wuhan, with a population of over 11 million, was locked down on January 23, 2020, due to the outbreak of a novel coronavirus, later named the COVID-19 by World Health Organization (WHO, 2021). Up to April 17, 2020, the total number of confirmed cases in Wuhan alone was recorded at 50,333, and the number of deaths reached 3,869, (XinhuaNet, 2020). Facing life-threatening risks, infected persons rushed for emergency care, leading to serious hospital cross-infection.

The Social Workers Across Borders (SWAB) trained and supervised more than 120 volunteers to provide Social Psychological e-counselling (SoPsy e-services) through WeChat group platforms from early January to April 2020. These teams attended a minimum of two and up to a maximum of eleven sessions. Some eager-to-learn volunteers hopped from one supervision session to another whenever they were available (Wong, 2020). In supervision, some members preferred to arrange the sessions within the same professional background, while others opted to maintain the composition of their original interdisciplinary team.

All supervisions were properly recorded by assigned secretaries mainly social work students. As supervisions were highly frequent, brief summaries were recorded instead of verbatim. There were altogether 38 sessions and the average length of supervision records counted up to 2,500 Chinese characters. Assistants were trained to identify Hindering Conditions and Unsatisfactory Effects, deriving from 38 supervision recordings with a total of 75,000 Chinese characters.

During supervisions, volunteers reported tremendous difficulties encountered at different stages of emergency response to this public health crisis. The nature of these difficulties was identified through analysing supervision records.

Social Psychological Emergency Response

Early studies on social psychological emergency response

The development of modern technologies has made it possible to study natural disasters in a global context since the 1980s (Seroka et al., 1986; Dufka, 1988; Banerjee & Gillespie, 1994). Early studies on disasters focused mainly on the roles and functions of the rescue aspects. The Kobe earthquake occurred on Jan 17, 1995, and the Chi-chi earthquake in Taiwan occurred on September 21, 1999, sparked more studies on the roles and functions social and psychological workers played in restoring survivors' mental health. In 2001, the United States 911 Terrorist Attack further exposed the need to develop a more systematic set of mental health guidelines to handle future catastrophes.

Iravani and Ghojavand (2005) identified, through the Iran earthquake experience, techniques social workers can apply in disaster settings. Situational supporting, hopefulness making, consoling, assuring, concentrating, and solution developing were ranked high on his list.

Table 1.
Albert Robert's ACT Model

A (Assessment):
1. Assessment/Appraisal of Immediate Medical Needs, Threats to public safety, and property damage
2. Triage Assessment, Crisis Assessment, Trauma Assessment and
3. Biopsychosocial and Cultural Assessment
C (Crisis response):
1. Connecting to support groups, the Delivery of Disaster Relief and Social Services,
2. Critical Incident Stress Debriefing (verly & Mitchell, 1999)
3. Crisis Intervention (Albert Roberts' Seven-Stage Model) Implemented,
4. Through Strengths Perspective and Coping Attempts Bolstered
T (Treatment):
1. Traumatic Stress Reaction, Sequelue, Posttraumatic Stress Disorders (PTSD);
2. Ten Step Acute Trauma and Stress Management Protocol (Lerner & Shelton);
3. Trauma Treatment Plan and Recovery Strategies Implemented;
4. Traumatic Stress Reaction, Sequelue, Posttraumatic Stress Disorders (PTSD);
5. Ten Step Acute Trauma and Stress Management Protocol (Lerner & Shelton);
6. Trauma Treatment Plan and Recovery Strategies Implemented;

Social work educators and practitioners in Asia, by developing the Disaster Actions Guidebook, stressed the importance of all disaster management stages from rescue to reconstruction. Chou et al. (2001) highlight the social workers' roles in her three stages of disaster social work: emergency response, recovery response, and preparedness response. Feng (2000) also stressed the significant functions social workers can perform in disaster work such as management of resources, planning, and advocacy, support to rescue workers, assessing clients' needs, and providing case management. These studies helped social workers to better master their roles when responding to disasters.

Albert R. Roberts, after experiencing the 911 Incident, presented an intervention framework superbly in his article: Assessment, Crisis intervention, and Trauma Treatment: the Integrative ACT Intervention Model. Robert's (2005, p150) ACT Model can be summarized in terms of the following components (See Table 1):

There are seven stages according to Roberts' technique of Crisis Intervention (CI), namely, assess lethality, establish rapport, identify problems, deal with emotions, explore alternatives, develop an action plan (including signing a contract for safety), and follow up. The ACT Model is an expansion of crisis intervention (CI), so to speak, and CI remains the core technique in the Model (Roberts & Everly, 2006).

Another technique listed in the ACT Model of Albert Robert was Critical Incident Stress Debriefing. In fact, George Everly and Jeffrey Mitchell (1999), by integrating knowledge from military psychology, have developed a full package of intervention tools—the Critical Incident Stress Management (CISM). Notably, the Crisis Management Briefing (CMB), among other tools is very useful in SoPsy e-services. CMB composes of 3 major steps: Introduction, Information, and Education. *Information* refers to the latest development of the incident and *Education* is about effective coping to mitigate stressful reactions. As CMB can be repeated and conducted through writing, voice messages, or video clips, it is particularly adaptable to the digital environment.

Procedure: Developing Digital SoPsy E-Services for Wuhan

SWAB provided supervision to a group of volunteers, using the ACT Crisis Intervention Model from Roberts (2000). The volunteers included community workers, medical students, psychological counsellors, and professional social workers. They were recruited by a number of social work educators in Wuhan under the initiation of the China Association of Social Work Education. Later, they named themselves The Good Companion Team (Yuo, 2020).

The situation in Wuhan City lockdown posed significant restrictions to disaster response as all services needed to be migrated online with minimal support on the ground. There were also knowledge and training gaps for offering consultation and counselling in a digital environment. The resulting SoPsy e-services taken by SWAB and the volunteer teams are listed in Table 2.

Actions began with training

From January 23rd of 2020, citizens were not supposed to leave Wuhan without special reason by land, water, and air. This comprehensive and strict control over personnel outflow for the whole Hubei province was intended to contain the flow of the coronavirus. The city lockdownt marked the impact stage of the epidemic and SWAB was immediately drawn into action.

Formation of Interdisciplinary Teams

In organizing those information and counselling WeChat groups, social work educators and leaders in Wuhan realized that it was necessary to involve different areas of expertise. As this is a new coronavirus and we have little knowledge of its path and characteristics of infections. In the end, a *4+1 Structure* was adopted for these WeChat service teams (Yuo, 2020). There were four types of volunteers: one medical or nursing practitioner, one social worker normally as a team leader, one psychological counsellor, one social work assistant who took care of logistics plus one lay volunteer from the community who can help to provide material assistance on grounds (Yuo, 2020). Altogether, 120 volunteer counsellors were divided into 10 teams, and 38 supervision sessions were offered to these teams.

Table 2.
Training and supervision arranged by SWAB from January to April 2020

Date (2020)	Actions
Jan 22	*On-line Advocacy* SWAB published on the website The Appeal to Social Workers Action in response to the Novel Corona Virus 2019. It was advocated that social workers must rise to meet the challenges of this epidemic to protect and help the vulnerable groups.
Jan 25	*Online Volunteer Training* The training session was provided to the first batch of professional volunteers including medical students, social workers, and psychological counselors, with the theme of Conducting Crisis Interventions through web-based platforms.
Jan 28	*Recruiting Online Crisis intervention Supervisors* Around 20 experienced social workers, with CISM Basic Certificates in Assisting individuals and Group Crisis Intervention, were recruited to serve as supervisors, also on a voluntary basis. The supervision approach emphasizing "emotional support function" and the use of defusing techniques to lead supervision sessions was reiterated in supervisors' training.
Jan 29	*Online Training on Community Crisis Intervention* Second web-based training was provided for professional volunteers of Wuhan on the theme of Community based Crisis Intervention.
Jan 30	*Onsite Material Support* With the support of a Hong Kong Charitable Fund, SWAB was able to donate 120 Life Support Respirators and delivered them to 13 hospitals in Wuhan. Some medical protection supplies like hats and shoes wraps were also sent to these hospitals timely.
Feb 8	*Online Educational Resources* Two series of online courses on Crisis Intervention, one for social work educators and the other for healthcare social workers, were released through East China Institute of Technology Publishers. The series was commissioned by the China Association of Social Work Education. Each series is composed of 5 one-hour lectures.
Feb 15	*Online Community Resilience Training* Online training on Community Resilience was delivered to social workers and community workers serving on the ground in Wuhan. A Model of Community Emergency Response (AtCER) was formally introduced. Positive psychology programs (PPP) were also introduced and experiences were shared on how these programs could be organized to promote community recovery in Wuhan.
Feb 19 - 20	*Extended Online Social-Psychological Services* Social and psychological support was provided to 6 groups of Hong Kong residents in Hubei. Twenty-three social workers who had Hong Kong experience were recruited to help. Hong Kong residents had a lot of anxiety these days as they also experienced difficulties in getting daily supplies like milk powder, masks, and the prescribed medicine.
Feb 7 to Mar 15	*Online Supervisions* Supervision services were provided to professional volunteers groups including members of medical students, social workers, and psychological counselors. Up to March 15, more than 38 sessions of group supervision, averaging one hour per session, were conducted. Over 120 volunteers participated in the supervision sessions.

Hybrid Mode of Services

The primary aims of crisis intervention in the Wuhan single case were to connect medical care, save lives, provide shelters, maintain social distancing, provide food and restore a sense of security. These objectives could not be met by services entirely online. A hybrid model combing e-services and volunteers on the ground was adopted.

Both CMB and defusing techniques were used to develop helping relationships, through reference to Everly & Mitchell (1999). Ehrenreich and McQuaide (2001) suggested was targetting vulnerable groups such as women, children, and the elderly in disasters. There were 21.46% of Wuhan residents aged 60 (hb.qq.com, 2020). The SoPsy e-services targeted the older people in the community by forming special WeChat rooms for them.

Life-Saving Services and Subsistence Supplies

The response was developed primarily for the purpose to save lives and provide personal safety. The most pressing need belonged to medical care. To connect availability of hospital beds and solicit supplies of medical equipment were urgently demanded. In the meantime, quarantine enforcement had imposed tremendous strains on the city's capacity to assist vulnerable groups. Older people living by themselves, families with disabled persons, single parents who needed to look after their children when schools were closed, and people suffering from chronic diseases who could not go to regular hospital visits, all needed assistance. There were problems with getting food and daily supplies.

Connecting People and People and Psychological Comforting

Social-psychological services emphasized, first, social measures like linking resources, connecting people, particularly family members, friends and relatives, and bridging public and private capitals. People were under extreme stress. Quarantined people were uncertain about when normal life could be resumed, waiting patients were uncertain whether a hospital bed would be available and those hospitalized had good reasons to worry about whether they would die or recover.

Cultural Sensitive Modifications, Triage and Follow-Up

Another factor related to social and cultural assessment was the resistance to help-seeking. Wuhan people were proud of their history and considered help receiving as losing face. The SoPsy e-services tried to include volunteers who could speak the local dialects in order to break the cultural barriers. Crisis intervention put a lot of emphasis on assessments. A pressing task social workers had was to identify those who needed psycho-social support most. Eventually a non-structured, interactive mode of the general health questionnaire (GHQ12) was adopted to detect psychosomatic symptoms. The oriental culture found questions related to physical health easier to respond to and share with strangers. The SoPsy e-services were carried out from mid-January to the end of April when the city lockdown was lifted.

Observations: Difficulties in providing SoPsy e-services

There were many barriers reported by the volunteers for SoPsy e-services. Some clients did not have a stable network and many were multi-tasking while listening to the group chats. The WeChat group members were heterogeneous in the background and did not know each other. Lack of social trust among group members and towards volunteers made interventions even more difficult.

It was mentioned that the counsellors were not used to intervening online. Moreover, they were facing the clients not individually but in a big group setting. To man the online services, volunteer teams worked almost around the clock. The problems volunteers met in SoPsy e-services, the reasons for these problems, and the intended outcomes of the volunteers are discussed below.

Hindering Conditions

Hindering conditions refers to certain digital environments that inhibit e-services of either social and psychological nature. A list of derived from the analysis is shown in Table 3.

Unsatisfactory Effects

Unsatisfactory effects are the kind of social and psychological services the volunteers intended to do but were unable to deliver. More importantly, the volunteers reported the unsatisfactory effects of the digital environment that hinder their interventions. The above conditions provided definitions for research assistants to code the types of intended interventions reflected in the recordings. The resulting set of unsatisfactory effects are listed in Table 4.

Table 3.
Hindering Conditions in digital environments for SoPsy e-services

	Hindering Conditions
1	Group members did not have a stable network;
2	Group members did not know how to use their i-phones or applications efficiently, for example, the digital map;
3	Group members came and left the group chat without notifying the volunteers;
4	Group members who wanted to be anonymous did not even show their faces;
5	Some group members spoke dialects and it was impolite to ask them to repeat or ask others to interpret;
6	Group members did not show their social and economic background;
7	Group members did not want to start a dialogue;
8	Some group members did not show emotions through voice tunes;
9	Group members often kept silent at the volunteers' comments;
10	Group members, though living or working in Wuhan, did not know how to access public resources online;
11	Some group members did not trust the volunteers and showed help-shopping behaviors such as hopping from one to another WeChat group;

Table 4.
Unsatisfactory effects in digital environments for SoPsy e-services

	Unsatisfactory Effects
1	Could not fully understand the emotional state of the clients;
2	Difficult to conduct the cognitive and emotional assessment;
3	Difficult to build trust;
4	Difficult to express empathy;
5	Could not protect clients' privacy and confidentiality;
6	When group members quarreled and were in conflict, it was not possible to stop them by non-verbal means or other IT means;
7	Difficult to organize condolence services with proper symbolic logistics;
8	Difficult to provide grief counseling;
9	Difficult to work together as an interdisciplinary team without non-verbal interactions among the volunteers;
10	Difficult to follow up on individual needs etc.

Personal Privacy Concerns

Last but not least, in order to respect personal privacy, it was not possible to conduct grief counselling and assessment of Post Traumatic Stress Disorder (PTSD). This was regarded as the greatest handicap by psychological volunteers. Death is taboo in many cultures. In Chinese culture, it is also inappropriate to ask people to talk about the deaths of their loved ones. Culturally acceptable condolences, therefore, were important for emotional ventilation. Encouraging family members of the deceased patients to ventilate their emotions, under appropriate conditions, was not an easy task.

One of the ways to show condolences was to deliver concern messages under the umbrella of community information through the WeChat groups. Education on coping with grief was also provided in the form of written CMB. In case group members were facing emotional turmoil, volunteers would invite them for individual chatting. The use of individual counselling online increased in time after March 2020.

Nature of Difficulties

Although the teams provided SoPsy e-services as professionally as possible, numerous difficulties were reported by the volunteers when it was brought online. From Table 2, several hindering conditions could be categorized into the following areas:

1) Technical, relating to network and efficient use of digital devices;
2) Social, the social barriers created by digital devices for relationship building; and
3) Cultural, relating to the unwillingness to express emotions in public and the digital distance created greater social distance, particularly if they could be identified by other members of the group.

The list of *Unsatisfactory Effects* from Table 4 was also informative. They could be categorized also into the following areas:

1) Assessment: enabling the volunteers to understand the cognitive and emotional states of the group members;
2) Social supports: providing material resources or appropriate information;
3) Psychological comforting: to show empathy, condolences, emotionally supporting and comforting, etc.
4) Problem-solving: setting priorities and discussing alternatives.

Recommendations to Overcome Digital Barriers

Summary of Digital Barriers

As reported in Tables 3 and 4, there were three types of conditions and four types of unsatisfactory effects identified. Among hindering conditions, 1) technical, 2) social, and 3) cultural conditions appeared to be

Table 5
Barriers in digital environments for SoPsy e-services

Hindering Conditions	• Technical problems with the internet; • Language barriers and Social distances; • Amplified Cultural gaps between volunteers and service recipients
Undesirable Effects	• Inaccurate assessment; • Unabled social support; • Weakened psychological confronting; • Incomplete problem-solving discussion

prominent. A range of unsatisfactory effects, on the other hand, happened in 1) assessment, 2) social support, 3) psychological comforting, and 4) problem-solving.

To summarize both the hindering conditions and undesirable effects, obstacles facing Social and Psychological e-services could be categorized into three major areas. Consequently, solutions can be targeted at technical obstacles, social and cultural obstacles, and competence obstacles, as outlined below.

Technical Solutions

Purposefully designed e-Counselling Platform and Tools

To overcome technical hindrances to social psychological services, advancement of technologies and better education can help to eliminate the digital divide between populations different degrees of readiness for digital services. For example, the popularization of 5G technologies and the development of user-friendly mobile applications, definitely help. Technology is a road of no return and e-counselling must catch up with innovations.

Victims of disaster always wish to find their relatives and friends (Leung & Wong, 2005). Digital devices could facilitate the efficiency of connecting people other than resources. The WeChat platform appears to have strengthened bonding, bridging, and linking social capital for residents of Wuhan. As numerous medical professionals went online to provide free advice to Wuhan residents, proper branding through a reputable and professional digital platform would enhance social trust and facilitate their contribution.

Volunteers in the Wuhan e-service relied heavily on the WeChat platform. However, the social media platform was designed only for daily use. For e-services, it should include functions of individual chats and chat control like those of an online meeting room. Social workers could express their needs to platforms managers and promote the platform. To solve the problems of case follow-up, a kind of continuous chat could also be included. To facilitate assessment the social work platform could include certain tools of psychological tests. In short, there is much room for improvements in digital social work.

Digital Disaster Social Services

One major issue suggested by the findings of this single case study was the lagging behind and slow development of digital social work. In all disaster responses, the most important task at the impact stage is to allocate extremely scarce resources to the people who needed them most. Medical treatment, health information, and quarantine shelters are the most important needs among the residents of Wuhan, as reflected in this study. However, volunteers serving online had no access to information about the availability of these resources. An effective GIS platform showing a map of medical resources definitely helps. The GIS map could also allow people in need to input their demands for resources.

Social and Cultural Solutions

Local and external volunteers partnership

This concerns the need for partnership between local and non-local volunteers. Regional, national and international volunteers must collaborate with local NGOs and volunteers. Obviously, external social and psychological agencies will be more experienced in emergency responses. However, their weaknesses lie in the lack of local knowledge. They may need more time to tune in to the local contexts. Local volunteers, on the other hand, may have little experience in an emergency. They may not know how to intervene. Therefore, as early as the impact stage, advocacy for local and external intervention partnerships is required.

Formation of SoPsy Emergency Response Network

A long-term solution for overcoming social and cultural barriers requires the development of a standing volunteer network designed especially for social and psychological responses. Through regular conferences and other forms of exchange, mutual understanding can be enhanced for local culture and sub-cultures.

Competency Solutions

Special Training in online counselling skills

There is abundant literature on the effectiveness of e-counselling (Anderson et al., 2005; Vernmark et al., 2010). Reduction of resistance to professional counselling online can be achieved by sharpening e-communication skills among counsellors through proper training offered by counsellors with similar experiences.

Online courses on internet-based counselling skills

In the long run, specially designed courses on internet-based counselling can also be offered online. Recognition of these courses by professional bodies in the social work and counselling fields should be attained through proper accreditation.

Conclusion

In addition to practical measures outlined in the current paper, SoPsy e-service is also an emerging field for future research. Ann Wolbert Burgess, in her foreword for the Crisis Intervention Handbook 3rd edition (Roberts, 2005, p. vii) wrote: “But all mental health practitioners and graduate students have an overriding concern over community-wide disasters especially massive terrorist attacks and how to assess and provide crisis intervention services.” In the same handbook, Dziegielewski and Powers highlighted the importance of evaluating crisis interventions and explains how to design respective research. Without a doubt, the COVID-19 outbreak was a massive community crisis in which innovative and pragmatic community crisis interventions were required. Post-disaster SoPsy e-service integrating medicine, digital technologies, sociology, psychology social work, and media technologies has established a new approach to emergency response in the digital society. Findings from the current study point to the need for further research in relevant areas of community crisis intervention.

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Tourism supply chains: Issues and resilience strategies during the global pandemic

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Abstract

Covid-19 related border restrictions and national lockdowns have challenged the overall resilience of hotel supply chains in New Zealand due to the industry's over-reliance on international tourists. Using case study research methodology, this study interviewed 13 hotel managers in Akaroa, a famous tourist destination located near Banks Peninsula in the South Island of New Zealand. This study has revealed that the major objectives for these supply chains were related to surviving and maintaining breakeven during the lockdown periods (March 2020 and August 2021). Significantly, during these restrictions, most of the interviewed hotels streamlined their internal operations and focused on building better relationships with their network partners. Having an extensive network structure, and the help of key government organisations like Tourism NZ (who shared information and created targeted marketing campaigns focused on attracting domestic tourists), enabled these supply chains to bounce back relatively quickly. While managers faced many challenges but the key challenge was demand management as the relationship with online suppliers (booking.com) was deteriorating. Suppliers and other service providers for these hotels also found themselves in a difficult position (due to Covid-19 related restrictions) that further worsened the situation. By modifying their products and services, adjusting their prices, utilising local suppliers, diversifying their customer bases, and coordinating with tour operators in the region, these hotel supply chains were able to quickly recover and today, show further signs of improvement.

Keywords: *Hotel supply chains, supply chain resilience, tourism, Covid-19 Pandemic.*

The inbound tourism sector has always been a significant contributor to the New Zealand (NZ) economy. In late 2019, international tourists traveling to NZ peaked at slightly over 3.9 million. This figure was almost double the number that visited the country in late 2001, with most coming from Asia and Australia. Several factors have contributed to the growth in international tourist numbers, including the rise of a financially independent middle-class in Asia, increased flight connectivity, and the global tourism boom (Statistics NZ, 2017). However, on the 19th of March 2020, to stop the spread of Covid-19, the New Zealand government closed the country's borders to everyone except for New Zealand citizens, and the nation went into lockdown. This move resulted in the total halt of inbound tourism in New Zealand and the end of travel within the country. Tourism is a vulnerable industry, sensitive to risks originating from external factors, including economic crises, natural or man-made disasters, and, in this case, global pandemics (Ritchie & Jiang, 2019). Not only was the Covid-19 outbreak sudden, but it was also global. Radical measures to control the spread of the deadly virus implemented by governments around the world proved devastating for many businesses in this industry.

The fragmented and interdependent nature of tourism products forces businesses to coordinate with each other for their customers' benefit. Tourism supply chains include a variety of actors such as suppliers, distributors, the government, and competitors. Due to the highly interdependent nature of these firms, a shock in one organisation can impact the whole supply chain or produce ripple effects (iLibrary, 2020). The impact of the Covid-19 pandemic on the travel and tourism sector has been disastrous and due to its ongoing nature and the emergence of different variants, continues to affect these businesses even today. Around the globe, airlines are struggling and have drastically reduced their operations. Likewise, tour operators have also stopped or downgraded their offerings. The hotel sector, particularly in New Zealand, is struggling, especially in areas dependent upon international tourists. Due to the lockdowns, there have been extremely low occupancy rates, and many have had to close their facilities. In New Zealand, a country which depends on tourism, more than 70% of hotels have temporarily closed, and revenue has declined by 90% (TourismNZ, 2020). While there has been some improvement to occupancy rates due to domestic travel, IATA (2020) predicted that global passenger numbers are not likely to top pre-Covid-19 levels until 2023 as airlines' capacity has significantly reduced, and the cost of travel has increased. So, although domestic tourism has provided some relief to the hotel industry, many small and medium hotel supply chains are still struggling.

This study investigates the challenges and resilience of New Zealand hotel supply chains during the Covid-19 pandemic. Hotels are important nodes within the larger tourism network as they provide tourists with accommodation and link them with numerous other services within the sector. Here, we focus solely on the hotel supply chains or the network of organisations involved in delivering different hotel services to customers. This supply chain relies on the flow of information (bookings), monetary transactions (payments) and physical items (rooms, food and drinks) (Al-Aomar & Hussain, 2017). Many small communities in New Zealand rely heavily on tourism for their economic base. Unlike big cities where visitors can be accommodated relatively easily because tourism represents only a small percentage of their economy, small cities and towns struggle even with small declines in visitor numbers. Akaroa is an example of such a town. It is located near Christchurch, NZ and depends heavily on international tourism. Its hotel industry is struggling with the big dip in the number of international tourists traveling to the area. This paper empirically examines the resilience of small hotel supply chains in Akaroa, NZ and the challenges they have faced as a result of the ongoing global pandemic. The paper answers the following questions:

1) What are the major supply chain coordination issues in hotel supply chains?
2) How are hotel supply chains responding to, and recovering from, the global pandemic-related disruptions?

Before explaining the study's methodology, it is first necessary to review the literature on hotel supply chains.

Literature Review

Supply chain disruptions have the potential to halt the economic activities of any region. This fact explains why the concept of the *supply chain* is now part of everyday conversations and is commonly discussed in the political arena and in Non-Governmental Organisations (NGOs) (Christopher & Peck, 2004). Supply chain management covers the planning and management of different sourcing, logistics, distribution, production, and retail activities. Similarly, the management, coordination, and collaboration with different suppliers, customers, and third-party logistics service providers are also included in supply chain management (Frankel et al., 2008).

The planning and execution of different supply chain activities across the boundaries of many different supply organisations is a difficult task. It is only possible through the efficient and effective coordination of informational, relational, and financial flows across the boundaries of a single organisation (Ponomarov, 2012). Through this well-coordinated effort, supply chains help produce and transport the right products in the right quantities, to the right place, at the right time, in a cost-effective manner. However, every step in the supply chain contains an inherent risk due to unforeseen disruptions. Disruptions due to natural or man-made disasters (such as damaged bridges or roads because of an earthquake or a flood), or border restrictions and lockdowns like the Covid-19 global pandemic, may affect an organisation's revenue and costs. In some instances, every part of a supply chain is exposed to severe damage due to a major disruption (Bradshaw, 2020; Ponomarov & Holcomb, 2009). Tourism supply chains are particularly sensitive to external factors and disruptions. As the New Zealand economy relies heavily on international tourism, it is critical to assess these supply chains, especially in the context of the ongoing global pandemic. Such an assessment would identify the key issues, and provide an opportunity to develop different methods to enhance and secure these critical activities (Berkes & Ross, 2013; Ritchie & Jiang, 2019).

The term tourism supply chains refers to a network of tourism related organisations engaged in range of different activities, from the supply of different tourism components (such as flights and accommodation), to the distribution and marketing of a specific tourism product (X. Zhang et al., 2009). Tapper and Font (2004) define it as a chain that consists of suppliers of different products and services that coordinate together to deliver tourism products to consumers. Within these supply chains, we particularly focus on hotel supply chains which we define as a network of organisations involved in delivering different hotel services to customers. Such supply chains work through the flow of information (bookings), monetary transactions (payments), and physical items (rooms, food and drinks) (Al-Aomar & Hussain, 2017; Fredendall & Hill, 2000). These hotel supply chain can be considered sub networks within the larger tourism supply network.

The tourism sector is distinct from other manufacturing and service industries because it is comprised of mobile customers who visit destination places to consume a service. Furthermore, the supply elements, such as the hotel itself, are often fixed, geographically speaking (Page, 2011). Tourism is also coordination intensive sector in which different products are often bundled together and sold as a package. In this sector, services like accommodation are considered to be *perishable* as they cannot be stored for other customers (Ujma, 2001). Also, many products which associated with tourism cannot be examined prior to their purchase; therefore, this industry relies heavily on the presentation and interpretation of products. The hotel sector is also an information intensive industry (X. Zhang et al., 2009). It is sensitive to minor disruptions and negative feedback. Part of the reason for these factors is the overall complex nature of these supply networks; most of the products in this industry are heterogenous and compound. Uncertainty around demand is common in hotel bookings as there are typically high levels of competition and the products are complex.

The identified characteristics of tourism supply chains give rise to number of issues that managers need to deal with in order to survive and thrive during a global pandemic. In order to survive and become resilient during a global pandemic, tourism supply chains must have clear objectives. While the ultimate objective for hotels and other operators is to satisfy tourists/customer satisfaction, reducing demand uncertainty and ensuring monetary value (revenue generation and cost reduction) are also vitally important during difficult times (Berkes, 2007; Gómez & Sinclair, 1991). So, while having a clear objective is crucial, a fundamental prerequisite for improved supply chain resilience is to have a clear understanding of the network that connects the hotel industry to its suppliers, its downstream customers, and all other industry actors (Christopher & Peck, 2004). X. Zhang et al. (2009) and Page (2011) have both noted that understanding how the tourism supply chain works is critical to ensure better management of it. Other scholars have suggested that key players should recognise the power relationships and business links (Belaya et al., 2009; Cox et al., 2001).

Next, management issues need to be identified and learned to ensure that key stakeholders can make well-informed decisions during disruptions. Considering the special characteristics of the tourism industry (such as perishability, inconsistency, people oriented), X. Zhang et al. (2009) have identified seven key management issues in tourism supply chains: supply chain coordination, supply management, two party relationships, information technology, demand management, inventory management, and product development. Of these seven elements, supply management, two party relationships and supply chain coordination can be considered supply chain relationship/collaboration management topics (Barratt, 2004). Demand management, inventory management, and information technology are logistic management topics (Murphy & Knemeyer, 2018). One must have a clear understanding of supply chain relationship-related and logistics management issues in order to ensure the resilience of the supply chain. These decisions may be strategic, tactical, or operational in nature and/or involve government taxation, wage subsidies, price setting, inventory levels, flexible timings, tour scheduling, advertising, and capital investment, components which may be adjusted to help a supply chain to bounce back. Each of these components are associated with different actors in the supply chain and changes to some or all of these may help these supply chains adapt to changing environment (Lee, 2004).

While the above mentioned components lead to effective performance measurement (Mittal & Sinha, 2021; X. Zhang et al., 2009), however, during a global pandemic, surviving and resilience obviously become top priorities for many supply chains (Ali et al., 2017; Bryce et al., 2020). Supply chain resilience seeks to reinstate and/or sustain supply chain operations in the event of a major disruptions (Abe & Ye, 2013; Ferris, 2016). Tourism firms, hotels included, must work together and create plan which outlines how they will provide sustained services in the face of any such event (Roy et al., 2016). In line with the existing literature, tourism supply chain resilience can be considered as the ability of a supply chain to find new ways of providing services to their customers, thus reducing the impact of any disruption (Mandal & Saravanan, 2019). As mentioned earlier, there has been a significant rise in uncertainty, especially after the spread of Covid-19, creating a severe risk to both manufacturing and service operations. As a result, firms have dedicated time to improving and creating better sustainability plans and risk mitigation strategies. As hotel supply chains have diverse structures, they must coordinate and plan for different possible contingencies. Simple risk management is inadequate as it focuses primarily on day-to-day, low impact, or frequently experienced disruptions. Supply chain resilience refers to a supply chain's capability to deal with such challenges (Ponis & Koronis, 2012; Sheffi & Rice Jr, 2005). Rightly so, Ponomarov and Holcomb (2009) and Christopher and Peck (2004) have defined resilience as a firm's adaptive capacity to meet demand despite disruptions. Resilience can be achieved by coordinating with each other and controlling operations.

Supply chain resilience literature has identified many different antecedents of resilience; for instance, supply chain agility, collaboration, having a culture of risk management, supply chain re-engineering, velocity, visibility, and flexibility (Jüttner & Maklan, 2011; Peck et al., 2003). Scholten and Schilder (2015) have shown that information sharing and coordinated efforts may improve resilience by having better visibility, velocity, and flexibility across the supply chain. As the extent of disruption, especially when its sudden and severe, also has a significant impact on the development of resilience in supply chains, businesses must acquire solid disruption knowledge as this information will enable them to configure useful resources needed to mitigate uncertainty (Umar et al., 2017). Hence, it is essential to determine what supply chain resilience looks like in the hotel industry. This research examines supply chain objectives structure, management issues, decision variables and supply chain resilience in order to provide insight and solutions for this vulnerable industry.

Methodology

Aligned with our goal to analyse supply chain issues and the resilience strategies in the New Zealand hotel supply chains during the Covid-19 pandemic, a multi case study approach was used. The key considerations were to explore and understand supply chain issues due to the Covid-19 pandemic, what measures were taken, and possible recovery strategies. This methodology is a recommended method for exploratory research where focus is to learn contemporary topics in real world settings. This method helps to find new insights and to better understand the complex issues (Halinen & Törnroos, 2005; Yin, 2014). We have adopted an abductive approach for this study where we utilized already reported constructs of supply chain resilience in the literature but also letting other constructs to emerge from the data analysis thus providing the more holistic picture of the phenomenon.

Case Selection

The research focused on regions which rely on hospitality businesses and international tourism with little diversification to other non tourism-related industries. For this study, we selected Akaroa, located in the South Island of New Zealand. The Covid 19 pandemic has had a significant affect on hotel supply chains in New Zealand, with a lack of tourists and migrant workers who are often employed to service these hotels. The broken supply chain of goods and services has generated other types of problems related to slow economic activity as the whole region depends on the tourism industry to survive. To ensure these supply chains remain functional in the future, there was a need to examine the devastating effect of these lockdowns and border restrictions. Hotel industry is the largest contributor to the economic activity of Akaroa (Christchurch City Council, 2021). We selected hotel industry network as our primary case within Akaroa region. Inside this hotel industry network, we have studied individual supply chains of different hotel as sub cases in order to get the best picture of issues faced and strategies adopted by these supply chains to survive the pandemic related disruptions.

Data Collection

Interviews were the primary method to collect data. An interview protocol was developed through a rigours process to bring the consistency in the asked questions. A group of supply chain experts (Senior faculty members in the Global Supply Chain Department of Lincoln University, New Zealand) were asked to list down potential issues of hotel supply chains in pandemic to develop the protocol. This preliminary interview guide was tested with a hotel business owner. Using the results from this single interview, the researchers refined the protocol. During the data collection process, the researchers regularly met to discuss their experiences during the early interviews and fine-tuned their interview techniques to obtain the necessary data. Semi structured interviews were conducted to get the detailed picture of real time events in this region. Purposive sampling was used to contact the hotel managers/owners in the region. Researchers have travelled to the region and went door to door to these hotels to talk to the managers. Only those informants were picked who met the three-point guidelines; knowledgeable about the pandemic and its effects, willingness to share information, vast experience of hotel business. We visited 23 hotels in total. Out of these 23 hotels, 15 hotel businesses agreed to participate in the study. However, thirteen of them qualified based on our three-point guidelines.

Most of the respondents allowed us to digital record the interviews, three of them refused and we took the field notes for those respondents. All the digitally recorded interviews were transcribed using the web translation application (Transcribe Wreally). Respondents' names and location were not included in the transcriptions: instead, each respondent was assigned a specific code (for example, C1R1 - case 1 in region 1).

Data Analysis

Data analysis begins along with data collection in the qualitative studies. We made regular interactions with the respondents during the transcription process that aided us generating and enhancing the themes and also improving the findings of this research. We seek the feedback of respondents by sharing the interview transcriptions with them that helped us to validate the research (Kvale & Brinkmann, 2009). We coded the data after the verification of transcripts from the respondents. Initial codes were merged and some were discarded thus leading to generate concepts and themes. We used NVivo 11 software to ease this process. Finally we run the queries to display the data.

The data coding was a complex procedure. Sometimes, more than one code or concept was emerged even for a small paragraph. The coding, categories and themes generation in the NVivo 11 was completed using Silver and Lewin's (2014) four step method. We have used many other general methods to code the data recommended by other authors (Yin, 2014, Miles et al., 2013, Saldaña, 2015, Hesse-Biber & Leavy, 2010).

Research Quality

Lincoln and Guba (2000) emphasize that research quality of qualitative research can be enhanced by four different factors; credibility, dependability, transferability and conformability. In order to improve the quality of this research, we took the following steps:

- Credibility/Internal validity was developed by talking to multiple respondents through interviews.
- Dependability/Reliability was achieved by using interview protocol to conduct detailed interviews.
- Transferability/External validity was attained by using the purposeful sampling and using the criteria to shortlist the potential respondents for detailed interviews.
- Conformability/Objectivity was developed by asking and recording the details of all the respondents and also by seeking the approval of transcripts by the respondents.

Analysis

The analysis focused on supply chain coordination and supply chain issues. In particular, it examined the strategies that various stakeholders (those linked with hotels around Akaroa) adopted, using five dimensions extracted from the literature review: objectives, network structure, management issues, decision variables, and supply chain resilience.

Objectives of Hotel Supply Chains

Analysis of the transcripts revealed that the key objectives of the hotel SC at the start of the pandemic were tourism satisfaction and monetary value. These objectives have been redefined by many of the industry partners. Firstly, tourism satisfaction is based on tourists' perceived value or their overall experience with the tourism products and services (Williams & Soutar, 2009). The data analysis suggests that pre-covid, the focus was mainly on international tourists (see C1R1, C2R1, C3R1, C5R1, C6R1, C7R1 and C13R1). As C13R1 stated:

> Our customers come from variety of different regions, both domestically and internationally, but our main customers are mainly from overseas. (C13R1)

Our analysis found that these tourists have distinct needs compared to local tourists. Over the years, this has led hotel SCs to target and provide products and services designed primarily for international tourists. However, the border closure resulted in local hotel SCs changing their primary objective to target and increase the value proposition for local tourists. This change in objectives has resulted in various modifications in tourism products and services offered by hotel SCs (further details provided in the following section). Additionally, it is important to note that only a few hotels (C4R1 and C12R1) diversified their product and service offerings towards both international and domestic tourists. Thus, their pre-covid business objective meant that they had products and services designed towards both market segments. For example, one business owner stated:

> We are focused mainly on the international market but our local domestic customer proportion was also reasonably. For example, our pre covid customer

division was 60% international and 40% domestic. (C4R1)

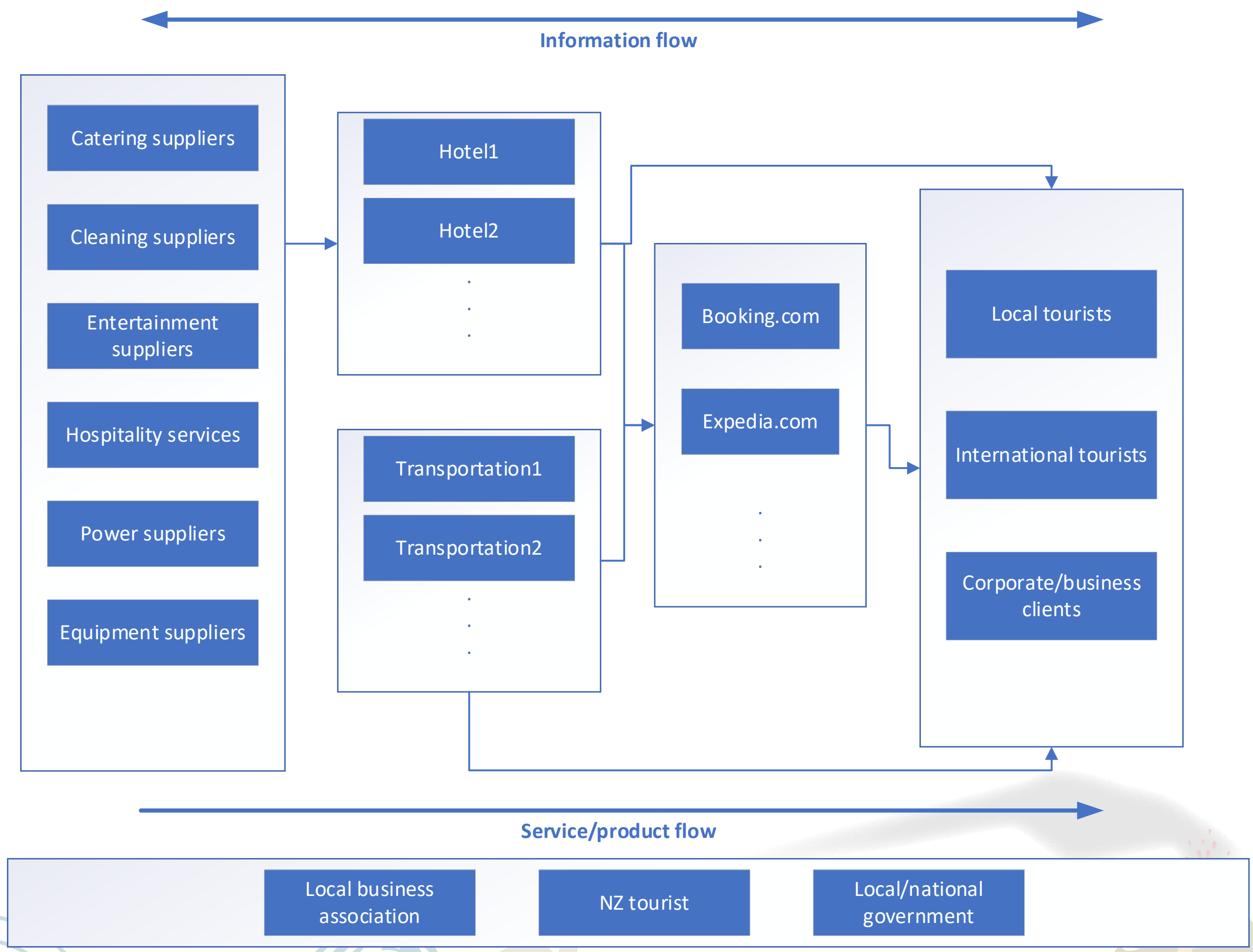
They noted that they collaborated and had pre-existing relationships with their SC partners, including local business associations, competitors, complimentary service providers, and customer loyalty programmes which enabled them to offer diversified products and services. Collaboration with supply chain partners is the critical dynamic capability of any organisation that leads to other capability based outcomes such as supply chain resilience (Dyer & Singh, 1998).

Secondly, during the Covid-19 pandemic, hotel SCs redefined their monetary proposition, mainly by reducing expenditure and operational costs. The pandemic increased the businesses' financial stress due to the cancellation of bookings and having to refund pre-paid customers. These factors were compounded by relatively low demand from local tourists. Significant decreases in their revenue streams meant that some of the businesses were under considerable stress; however, some were able to negate this due to significant reductions in their operating expenditures. For most, the primary monetary objective during the pandemic was to *break-even,* or absorb losses and thereby survive the crisis. This financial scaling down and quick adjustments in strategy has helped these oganisations to survive the negative effects of locked-downs and border closures thus increasing the resilience (Bryce et al., 2020; Tabaklar, 2017).

Network Structure

It is vital to understand the basic network structure of hotel SCs and to analyse supply chain interdependencies, issues, and response strategies. We initially adopted the tourism supply chain structure, developed by X. Zhang et al. (2009) as a model framework. However, in response to the results of our analysis, we produced a modified version. These modifications were necessary as our focus was predominantly on hotel SCs rather than the tourism industry as a whole. Figure 1 shows the overall network structure of hotel SCs in the Akaroa region of NZ.

Figure 1
Network Structure of Hotel SCs



For this research, hotels were the focal organisations. We analysed their relationships with downstream and upstream SC partners.

Upstream SC –We found that hotel SCs only have a few layers, with mostly transactional relationships with the upstream SC partners. This finding may relate to the fact that this research focused on small and medium-sized hotels where the concern was to maintain reasonable expenditure on various supplies. Upstream partners predominantly consist of cleaning, catering, entertainment, hospitality, equipment, and power suppliers. Most of the hotels reported using local or nearby suppliers, especially for their cleaning and catering needs. Some of the hotels mentioned that they switch to local suppliers during the locked down period that helped them to keep running the basic business operations. This flexibility and quick response to focus on local suppliers helped them to stay resilient during these difficult times (Gunasekaran et al., 2008; Yi et al., 2011).

Focal organisations (hotel) structure – The data analysis suggested that the focal organisations can be divided into two different types, based on their business structure:

- Family-owned – Hotels owned and managed by a single family (C5R1 and C7R1).
- Investor/Multiple Investors – Hotels owed by a single or multiple investors. In most cases, however, a general manager runs the day-to-day operations (C1-R1, C4R1, and C10R1). Most of these investors had a number of investments in different tourism products such as restaurants and other attractions.

Downstream SCs – Analysis of the interview data indicated that the businesses had two common ways of approaching the target customers: 1) through online platforms, and 2) directly, through their hotel websites. Apart from local and international tourists, some hotels noted that corporate/business clients were key customers during the pandemic (C1R1 and C2R1). The hotels which had wide customer base were able to quickly respond to disruptions caused by the border closures. This has also helped them to cope well compared to other business and resulted in increased resilience (Oloruntoba & Gray, 2009; Qrunfleh & Tarafdar, 2013).

Other stakeholders – The participating organisations highlighted the positive role of other stakeholders, such as local business associations, New Zealand tourists, and the local or national government during the pandemic. For example, most of the businesses survived due to government support packages provided throughout the various lockdown periods (C2R1, C5R1, C6R1, C7R1, C8R1 and C13R1).

> When the lockdown happened, we applied for funding from the government for our staff. That was very good, and it really helped us a lot during that period. (C2R1)

Similarly, Tourism NZ and local business associations activated their regional promotions to attract local tourism after the first lockdown. This marketing promoted different regions of New Zealand, Akaroa included, as local tourist destinations and helped the hotels to attract domestic tourists.

> Hospitality New Zealand was amazing I have to say. They were really giving a lot of advice with things changing and they were sending newsletters and webinars and what practices should we do and update and that was really helpful. (C2R1)

Management/SC issues

Not surprisingly, the pandemic, and the government's response to it, has led to significant management issues, specifically decisions around demand management, supplier management, inventory management, and day-to-day operations.

Demand management is a critical part of any SC decision which include forecasting around the expected annual number of tourists, pricing strategies, and sales activities. Our data analysis suggests that during the early days of the pandemic (Jan - Feb 2020), the participating organisations did very little to prepare. They did not consider the potential impact to their business until the country went into lockdown in late March 2020. High uncertainty about the nature and potential impact of this crisis was largely unknown, meaning that many of the businesses were somewhat complacent (C7R1, C8R1 and C13R1). As one interviewee said,

> Not really, and at that time (Jan-Feb 2020) I was joking with my husband saying that New Zealand will be fine, and I don't think it's going to affect New Zealand, probably not going to go that big right. […] Yes, we didn't prepare anything and then, just all of a sudden, it's like oh! it came to New Zealand and they needed to shut the whole country and boom everything stopped. (C7R1)

During the lockdown period, many of the hotels closed down their operations (C3R1, C4R1, C6R1, C10R1, C11R1 and C13R1). Others remained open but at a limited capacity, with social distancing protocols in place. These hotels only accommodated essential workers and tourists who were unable to return to their home countries. Apart from this, almost all of the participants reported tourist booking cancellations for the remainder of the year, right up until 2021. This occurred alongside general demand variations during the winter season (Akaroa is typically considered a winter destination), which meant that the local tourism was also very low until the 2020 spring season.

The uncertainty in demand meant that hotels were faced with numerous challenges relating to supplier and inventory management decisions. Due to the size and nature of the hotel industry, many businesses cancelled, or put their orders for various hospitality services on hold, catering and cleaning included (C3R1, C4R1, C7R1 and C8R1). Some of the businesses also faced challenges related to their suppliers who were unable to fulfil orders because of delivery and logistical challenges.

> Well, cleaning products we buy, and we do our cleaning here except the bedsheets, so we stopped ordering from our suppliers. For cleaning products, we buy monthly from our supplier, so we kept the order once, but didn't re-order anything after that. (C8R1)

Once the initial lockdown restriction were relaxed, the businesses faced additional challenges associated with a lack of international tourists due to continued border restrictions (still largely in place at the time of writing). Businesses were left in a situation where they needed to understand the needs of local tourists, which differ from those of international tourists. For example, in contrast to international tourists, local tourists may visit multiple times a year and, thus, require products and services which allow them to return to the same hotel and attractions (C1R1, C2R1, C3R1, C5R1, C7R1 and C13R1). Similarly, demand is typically higher in the weekends (C2R1), which is not the case for international tourists.

> The good thing about Akaroa is we are near to Ashburton and Christchurch, so people come over to Akaroa during weekends, so we are always busy, full on weekends. (C8R1)

> The difference that you have from them [local tourists] is, instead of booking a place months in advance, the Kiwis were booking last minute. You were looking at a blank sheet for the next week and come Monday and you are full. (C1R1)

Overall, the industry has seen a certain degree of market pressure as there are limited local tourists, a fact which has compelled hotels to change their pricing strategies to attract as many customers as they can:

> It [changing price] is a slight disadvantage, of course, I have to keep my prices under [other competitors]. (C8R1)

Decision Variables Related to SC Decisions

Following the initial lockdown and travel restrictions, hotels implemented multiple strategies to survive and recover from the significant drop in international tourists.

One of the fundamental changes in operations strategy was to adopt the required social distancing rules and put extensive cleaning protocol in place. This meant many businesses changed how they interacted with customers, especially during levels 2, 3 and 4. For example, some businesses were accommodating international tourists stuck in NZ during the level 4 restrictions.

> We had 6 couples that were locked in New Zealand that stayed with us over the period of six weeks, then they slowly got home [when the international flights were available]. There was one couple from Germany and the other couples were from the UK. (C2R1)

> After the first news [regarding Covid-19] we did some level of preparation, like extra cleaning plus disinfectants for visitors and changed house rules. (C10R1)

The hotels adapted their operations to cater for local tourists' distinct needs. For example, as local tourists tend to be regular customers, some businesses upgraded their services by including complementary products and services. This meant that they collaborated with other tourist attractions and restaurants to provide combo deals with network stakeholders (C2R1, C4R1, C6R1 and C13R1), a practice referred to horizontal collaboration. Some of the businesses responded to the challenges associated with a lack of tourists by lowering their prices (C2R1, C5R1, C12R1 and C13R1).

> I think the main change is like the whole town changed their prices really low. We do that price strategy as our first step and the second step is to work with the local businesses to attract more people. (C13R1)

Some hotels focused on corporate and business clients as their key customer segments during the crisis. Like local tourists, these clients have distinct needs and requirements. To retain both of these customer segments, many of the businesses encouraged their customers to make future bookings via their official website rather than using an online platform (such as booking.com). This practice enabled them to avoid additional fees charged by these online platforms (C7R1 and C8R1).

> We ran some specials on social media and encouraged people to book directly with us and so people just decide to come to Akaroa and booked with us directly, which was lucky for us. (C7R1)

Regarding pricing strategy, analysis of the data showed that while some of the businesses retained their prices (C6R1 and C10R1), one increased their price (C3R1). However, they noted that this decision was based on significant upgradation of their products and services. Additionally, this hotel had a loyal local customer base before this crisis, and they felt confident in their product offerings. In this case, the business' pre-existing collaborative relationships with other tourist providers enabled them to quickly upgrade their services contributing to price retention.

Regarding upstream SC partners, many of the interviewed hotels changed their sourcing strategy by decreasing the lot size and/or changing to a local supplier to avoid issues associated with transportation and delivery (C5R1 and C13R1). One business reported receiving a discount from one of their suppliers during lockdown (C8R1).

> SkyTV, that's a really big cost here, and having an empty hotel there was no point in keeping SKYTV, but they did offer us a free month and then we got 50% off. (C8R1)

There was a significant push from the tourist industry to promote various tourist destinations across New Zealand. Some of the hotels got involved with local business associations to promote Akaroa as a tourist destination (C2R1, C4R1, C7R1, C8R1 and C13R1). Additionally, hotels got together and collaborated with other tourist attractions to promote their region:

> Well, the whole community try to find out something to attract more people. (C13R1)

Performance/Resilience

To create resilient supply chains, it is important to have the understanding of supply chain operations, objectives, needs, risks, as well as human, capital and network resources (Ali et al., 2017; Scholten & Schilder, 2015).

Overall, analysis of the data shows that although the interviewed hotel owners experienced a significant decrease in tourists from overseas (which resulted in lost sales and revenue), those in Akaroa managed to quickly adapt to the new requirements. This enabled them not only to survive, but, in some cases, thrive through the Covid-19 pandemic. For all of the hotels, the main performance criterion was to maintain a sufficient number of bookings to stay atleast at the break-even point in terms of their finances. Most of the hotels were aware of the needs and risks associated with covid 19 related disruptions and had clear objectives. This knowledge helped them to stay resilient in these difficult times.

Many of the hotels understood their capacity utilisation throughout the initial locked down months, that helped them later on to schedule better and use their resources in efficient way. This helped them to keep the prices in control and also helped them to keep their operations running resulting in better resilience compared to others (Katiyar et al., 2015). Supplier delivery efficiency has also been attributed to fast and quick response to supply chain disruptions, this ability also stems from the knowledge an organisation has about its network and what options are available if something adverse happens. Most of these hotels had good knowledge about their supplier base, during locked downs when it was difficult to get most of supplies beyond their own locations, this helped them to quickly switch to local suppliers for running their day-to-day operations. This supplier delivery efficiency that resulted in effective delivery lead times helped these supply chains to quickly recover from disruptions (Bhagwat & Sharma, 2007; Cho et al., 2012).

This hotel's higher booking rate enabled them to navigate the crisis without incurring a major loss. As noted in the previous section, this hotel owner attributed their success to pre-existing relationships with other tourist attractions and their strong, loyal, local, customer base.

Some businesses tried to balance their revenue stream by reducing their expenditure. Some achieved this by reducing their operational costs; for example, reducing staff hours, reducing inventory costs and temporarily holding off buying hospitality services. By collaborating with the local community and business associations to attract local tourists, the interviewed hotels were able to respond to the crisis. As emphasised by Ali et al. (2017), collaboration and information sharing are the basic elements of achieving supply chain resilience. Similarly, Christopher and Peck (2004) had identified that high level of coordination among supply chain partners can significantly reduce the risks thus help increase the resilience. It was evident through this research that majority of supply chain partners in these hotel supply chains were coordinating with each other, at some places even were doing the joint planning to survive the disruptions.

Conclusion

This research has examined the major challenges and strategies adopted by hotels in Akaroa to respond and recover from the Covid-19 pandemic. Analysis of the data has provided critical insight into the various ways that the hotel industry has navigated the crisis. As the pandemic is ongoing, the insights from this research provides advice for managing the short to medium term impact of this crisis.

The organisations which participated in this research are small to medium size hotels, which makes them more susceptible to disruptions because of a lack of sufficient resources and capabilities (Burnard & Bhamra, 2011). One of the primary ways to achieve resilience is to be prepared for a potential crisis (Ahmad, 2018; Sheffi, 2005, 2015). However, many hotels simply do not have time to do this as they are busy dealing with operational tasks (Ates & Bititci, 2011; Jiang et al., 2019). Our findings showed that many of the businesses were complacent in the early stages of the pandemic and responded only once border restrictions were implemented; in other words, they did not put contingency plans in place during the early stages of the pandemic. This finding echoes Hystad and Keller (2006) claim that tourism operators put minimal effort in planning and preparing for such a disruption.

The pandemic and the government's response to it has significantly impacted on the tourism industry, especially those businesses reliant on international tourists. To combat these challenges, hotels quickly adapted their day-to-day operations and modified or updated their products and services (H. Q. Zhang et al., 2009). Many drew on pre-existing or established collaborative relationships with their network partners (Becken & Hughey, 2013). Our findings demonstrate the development of collaborative relationships across horizontal SC partners, including competitors, other tourist providers, and local business associations. This analysis has shown that many survived by changing their marketing strategies to showcase tourism destinations for locals wanting to travel in their own country.

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Research Update – A framework to study supply chain strategies against global pandemic

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Abstract

During the global pandemic, supply chains often look for an evidence-based framework to evaluate their responses to disruptions compared to other more successful responses. This study proposes such a framework based on the Haddon matrix that is traditionally used to prevent roadside injuries in road accidents. This tool will help to study supply chains and their vertical and societal linkages during the preparation, response and recovery phases of natural disasters such as global pandemics. Implications for the further development of our current research are outlined.

Keywords: *Supply chain resilience, Haddon Matrix, disaster management*

A Framework to Study Supply Chain Strategies Against Global Pandemic

The COVID-19 pandemic has caused significant challenges for global supply chains. Numerous national lockdowns and border closures continue to slow down the flow of raw materials and finished goods, disrupting every actor in the supply chain. However, the pandemic has not necessarily created any new challenges for these supply chains, at many places, it has just escalated the already present vulnerabilities in the system. There are supply chains that collapsed, yet there are few organizations and supply chains that emerged better prepared. These few organizations had better visibility into the structure of their supply chains and survived the severe disruptions through a proactive approach. This shows that some supply chains proactively responded to the disruptions and implemented certain interventions/strategies that helped them survive rather than thrive amid this global pandemic. Considering this, there is a need for a framework that can bring together all these interventions for each phase of disaster which different supply chains can use to enhance their overall supply chain resilience during the global pandemic. This study proposes such tool based on Haddon matrix framework and and presents the steps to use it to successfully respond to the disruptions originating from the global pandemic.

Modified Haddon Matrix

The Haddon Matrix is not a new framework, William Haddon introduced this matrix in 1968 to scientifically study an event to identify its temporal phases and contributing factors (Haddon Jr, 1968). It has been widely used in road-safety research to determine root causes and the potential impact of interventions. Recently, it has also been cited and utilized in disaster management, especially for epidemic outbreaks (Cole et al., 2020; Hecht et al., 2019). The World Health Organization (WHO) has also identified the Haddon Matrix as a dynamic system-based framework for assessing pandemic disasters, where each cell of the matrix provides an opportunity for intervention to reduce the impact of the disruptions (Peden et al., 2004; Timpka et al., 2009). The Haddon Matrix is a two-dimensional matrix where rows represent temporal phases of any event that are described as; pre-event/preparation phase, event/response phase and post-event/recovery phase. The columns represent incident related factors, in particular; human/organization, agent, physical environment and social-cultural environment factors (Peck et al., 2008).

Dividing a problem and the strategies into two dimensions can be helpful to understand, prepare for, and respond to a wide range of disruptions in a practical and user-friendly way (Murray et al., 2014). The Haddon matrix has been used in several epidemiological studies as an effective tool to prevent adverse effects of accidents and diseases (Cole et al., 2020; Peck et al., 2008; Wall, 2012). Anparasan and Lejeune (2017) have utilized this matrix to study a cholera outbreak and provided evidence-based intervention tools for future outbreaks.

The authors demonstrated the effectiveness of this matrix as a planning tool to better react to such outbreaks. These examples show the usefulness of the Haddon matrix and its varied applicability. The main benefit of this matrix is the ability to divide an event/disaster into smaller sections and systematically find intervention strategies. Whereas most previous studies applying the Haddon matrix focus on influenza and cholera outbreaks, this study focuses on Covid-19, a disease that is new and wreaking havoc on supply chains all over the world.

Haddon Matrix – Rows (Disaster Management Life Cycle)

Disaster management is an applied science that seeks the systematic observation and analysis of disasters to improve measures related to preparedness, emergency response and recovery (Carter, 2008). Adopting this approach, the Haddon matrix utilizes the disaster management life cycle's three phases: preparedness, response and recovery (Banipal, 2006; Day et al., 2012; Balgah & Kimengsi, 2022).

The preparedness/mitigation aspects of the disaster cycle are part of the pre-event phase of the Haddon matrix. In case of a pandemic, this phase focuses on preventing supply chains from adversely impacting the related disruptions. This phase can comprise of activities such as; early warning or monitoring systems, maintaining acceptable health and sanitation standards, cultivating awareness, pre-positioning stocks, coordinating with suppliers, and increasing visibility across supply chains (Ali et al., 2017; Allotey et al., 2010; Christopher & Rutherford, 2004; Tomasini & Wassenhove, 2009). Preparation is crucial as many organizations within a supply chain, where an inability to scan the environment and poor preparation for simple supply chains risks and can intensify the consequences (Scholten et al., 2014), especially in the context of a pandemic.

The response phase starts when the disaster event occurs or is ongoing and the supply chain starts facing supply chain disruptions (Cozzolino et al., 2012). Actions and outcomes of this phase largely depend on the preparation phase. Naturally, well-prepared supply chains would be in a better position to respond. In the case of pandemic disruptions, how quickly one organization can communicate to other organizations,

Table 1
Rows in Haddon Matrix

Phases	Pre-event	Response	Post-event
Haddon Matrix	The pre-event phase in the Haddon matrix involves the mitigation and preparedness aspects of a disaster cycle.	The response phase takes place when the agent interacts with the host.	The post-event phase is when the damage has been done
In the case of the epidemic (Anparasan & Lejeune 2017)	In case of a disease outbreak, this phase focuses on preventing the agent or virus from reaching the susceptible host or human body. This phase includes activities such as monitoring for possible indications of a disease outbreak, maintaining satisfactory health and sanitation standards, improving awareness and conducting accrued surveillance among populations at risk.	When a virus enters the body of a human. There is ample opportunity for intervention in order to prevent severe infection or death of the host. Early identification of a host should ideally translate into early treatment mechanisms so that the health of the host does not deteriorate further.	The affected community needs to transition from response to recovery. The post-event phase involves decisions taken to minimize further harm to human life, such as evacuation and improvement of infrastructure, and to return the situation back to normal as soon as possible.
Hecht et al 2019	In case of SC resilience, pre-event phase includes formal emergency planning and staff training	Response activities include staff attendance, operational redundancies (infrastructure, inventory, and location), supplier diversity.	Post-event activities include learning and adaptiveness, and insurance.
Our suggested research approach	In case of Covid 19, we can consider pre-event as the time before the spread of this virus.	Response phase started once countries started lock down and Covid 19 was declared as global pandemic	Post evet is the phase once governments has controlled the situation and markets started opening up, although this is a long term phase that will spread across many years to come.
Timeline	Before Dec/Jan 2020	Varies based on individual countries but generally from January or February 2020	No timeframe needed here. Activities and interventions with long-term impact can be categorised and linked with this phase.

how quickly supply chains can assess the damage and how quickly they can restore their operations are crucial steps in the phase.

The Haddon matrix post-event phase is similar to the recovery phase of the disaster life cycle, where the damage has been done, and the affected organizations in the supply chain need to transition from response to recovery. At this stage, it is critical to exploit the impact of the recovery strategies to help the supply chains adapt and move on from the response phase. In the case of Covid-19, we can adapt the following timeframe and rationale (summarized in Table 1).

- Pre-event – Inventions/strategies introduced before the spread of the virus (before Dec/Jan 2019). We can consider this disruption/event when individual countries started to lockdown their borders and introduced social distancing measures.
- Response – this phase varies based on individual countries. For example, China was the origin of this pandemic; therefore, the response phase started in December 2019, whereas, in most countries, the spread of virus became apparent in January or February 2020 when governments started to shut down their borders and WHO declared Covid-19 as Pandemic.
- Post-event (recovery) – Similar to response, this phase varies as some countries were swift in placing the social distancing measures, hence were quick to restore some level of commerce and social activities. Instead of defining a particular timeframe, activities and interventions with long-term impact can be categorised and linked with this phase.

Haddon Matrix – Columns (Event Factors / Categories)

The columns of the matrix represent four main factors or components that have been determined as relevant to any disaster, these being; the host, the agent, the physical environment and the socio-cultural environment. In most of the previous Haddon matrix studies, the *host* represents human beings and the *agent* represents the virus/vehicles (Peck et al., 2008). Additionally, some authors have studied organizations as the host and risks as the agents (Hecht et al., 2019; Runyan, 1998). In this study, the Authors propose to use the supply chain and all the factors related to its inter-organizational interactions as the *host*. Similarly, supply chain disruptions and risks related to Covid19 can be considered as the *agent* in the second column of the proposed matrix. Next, the Authors propose to categorize logistical issues such as inventory, storage, and transportation as part of the *physical environment* while interventions related to the interaction with other government agencies, research

Table 2
Columns in Haddon Matrix

Definition	Host	Agent	Physical	Socio-cultural environment
Haddon matrix (Anparasan & Lejeune 2017) (Runyan 1998)	The host is the person that is susceptible to injury (children in home, students at school)	The agent is the primary cause of the occurrence of an event, cigarette, matches, firearm and bullets)	The physical environment comprises physical infrastructure and mechanisms that must be in place to effectively address a disaster (home, school)	The socio-cultural environment encompasses social and cultural practices as well as laws and regulations that affect each phase of the disaster
In the case of epidemic (Anparasan & Lejeune 2017)		The agent is the disease-causing virus	In case of an epidemic, the physical environment includes requirements for healthcare facilities, availability of healthcare professional and availability of drugs	In case of an epidemic, the Socio-cultural includes requirements such as funding needs, effective transition mechanisms, and related policies.
Hecht et al 2019	In case of SC resilience, this includes organisations and its related stakeholders.	In case of SC resilience, this includes efforts to manage a risk	In case of SC resilience, the physical environment includes requirements/strategies to plan and respond to a disruption.	In case of SC resilience, Socio-cultural environment is related to developing and maintaining relationships within and across different organisations.
Our research approach	In case of a SC, host include SC network partners (including upstream and downstream SC partners)	In case of a SC, an agent includes the SC risks that can disrupt the flow of goods, and the efforts to manage the SC risks e.g. risks originated from the Covid-19 situation.	In case of a SC, the physical environment includes logistical activities/strategies to plan and respond to a SC risk.	In case of a SC, socio-cultural environment is related to developing and maintaining relationships with the wider community such as government, emergency institutes, local bodies, competitors…

institutes, emergency organizations and competitors as part of the *social environment* (see Table 2).

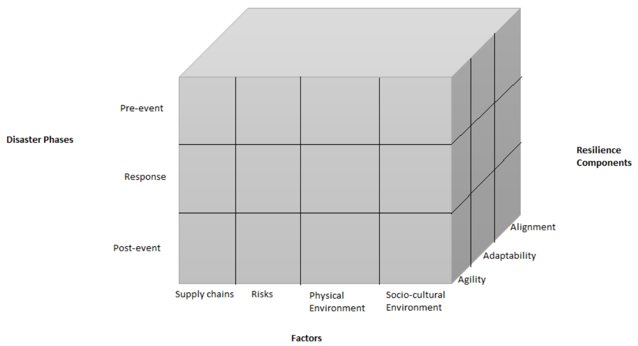
Rationale for a Third Dimension of the Haddon Matrix

The Haddon matrix has been applied in a two-dimension format in nearly all previous studies. However, Runyan (1998) introduced cost, effectiveness, feasibility and preferences as third dimension factors to further analyze the interventions identified in the Haddon matrix, but the focus was only on injury prevention and decision-making around it.

Categorizing the interventions in the disaster management life cycle is one thing, but whether these interventions brining any supply chain resilience is also essential consideration especially during global pandemic. Therefore, in this study, we suggest introducing the supply chain resilience components as the third-dimension elements for this modified Haddon matrix. Resilience can be defined as the ability of a system to bounce back from disturbance (Burnard & Bhamra, 2011). Moreover, Klibi and Martel (2013) define resilience as the ability of a supply chain network to resist and effectively respond to disruptions and to recover quickly from failures. Other scholars have defined it as the capability of supply chains to anticipate/prepare, respond and recover from disruptions in an efficient and effective way (Fiksel, 2003; Ponomarov, 2012). Many resilience concepts are borrowed from other disciplines and it is a wide-ranging research concept. While a full review of this subject is beyond the scope of this research, we define supply chain resilience with reference to Umar et al. (2017) as: The ability to prepare, respond and quickly recover from disasters by employing agility, adaptability and alignment strategies.

Indeed, many other components of resilience are identified in the literature, but these can all be summarized into thehigher-order constructs of agility, adaptability and alignment (Cabral & Grilo, 2012; Dubey & Gunasekaran, 2016; Lee, 2004; Walker et al., 2004). Here, *agility* is a quick response with all available resources, *adaptability* refers to the systems' ability to adapt to the new situation during and after the disruptions, and *alignment* is the alignment of business processes (integration) and commercial interests with other supply chain partners. Thus, the proposed modified Haddon matrix demonstrating the additional third dimension is presented in Figure 1. We suggest that this modified Haddon matrix will help identify the decision-making challenges and opportunities specific to each phase of the pandemic outbreak.

Figure 1
Proposed three-dimensional Haddon matrix



Steps In Using The Matrix

There can be multiple ways to use this matrix, however, we suggest the following steps in order to use this three-dimensional Haddon matrix; different supply chains can modify according to their needs.

1) Rigorous research needs to be done in order to determine the problem in need of intervention, this can be too general such as "SC disruptions originating as a result of the pandemic" or quite specific as "demand fluctuations or delivery delays".
2) Define columns of the matrix as the targets of change, this definition needs to be clear and concise. We have provided one way of defining these in this paper, but there could be other ways as well e.g. relationship between different supply chain actors can also be part of the socio-cultural environment.
3) Define rows of matrix, disaster phases timeline needs to be very well defined here.
4) Determine weights to be applied to each value listed in third dimension: agility, adaptability and alignment. It depends on the organization which value they prefer the most, but all of these three need to be present in one way or the other in order to have resilient supply chain.
5) Interventions can be brainstormed or can be based on the field research, if these are brainstormed then further collect data to assess each intervention.
6) Assess each intervention against the three components of supply chain resilience, factor rating method can be used here to assess.
7) Make decisions about the best options
8) Document the process for future to reanalyse.

Conclusion

The purpose of this study was to propose and assess an analytical framework to help reduce the adverse impacts of future supply chain disruptions. The three-dimensional Haddon matrix includes the disaster phases; preparedness, response, and recovery; contributing factors such as actors, risks assessed in both the physical environment and the socio-cultural environment; adding the third dimension built around the resilience components of agility, adaptability, and alignment. One of the significant advantages of the suggested tool is that it balances the critical trade-off decisions between practicalities and comprehensiveness while allowing flexibility via customization and stakeholder engagement in the evaluation phase. The next steps are elaborating the customized versions of the suggested Haddon matrix for policymaking at the governmental level and for continuity management at institutional and company levels.

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Clearance time prediction of traffic accidents: A case study in Shandong, China

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Abstract

Accurate predictions of the clearance time of highway accidents can help make more effective decisions and reduce the economic losses caused by the accidents. This paper compares two representations of traffic accidents with mixed vehicle types and establishes two different classification models. The traffic accident data in Shandong Province, China from 2016 to 2019 are used as a case study. The interpretability of the parametric model indicates that the types of vehicles involved in the accident, the type of accident, and the weather can significantly affect the clearance time of the accident. The results of this study can not only provide evidence of whether the types of vehicles involved in the accident will affect the accident clearance time, but also provide advice for the authorities to quickly clear accident scenes and prevent further accidents.

Keywords: *Highway, Accident clearance time, Vehicle types, Passenger vehicles*

Introduction

As of the end of 2019, the total mileage of highways in China reached 149,600 km (Statistical Bulletin, 2020). With the highway network growing and the number of motor vehicles increasing rapidly, traffic accidents are occurring more frequently. While expressways promote economic development, they are more prone to major traffic accidents than urban roads due to their large traffic volumes and fast speeds, causing a large number of casualties and huge property losses every year (Lin et al, 2016; Park & Haghani, 2016). In the literature, a lot of research has been carried out to improve the efficiency of expressway traffic safety.

The accident duration prediction can be used to predict the clearance time of a certain accident. At the same time, real-time event duration prediction can help event managers determine the best emergency rescue and traffic control strategies (Ji et al., 2008). In addition, based on the prediction of accident impacts traffic managers can provide the drivers with guidance information so that the drivers dynamically correct their routes to reach the destination in the shortest time (Baykal-Gürsoy et al., 2009; Schrank et al, 2015). Thus effectively mitigating the traffic congestion and improving the level of accident management.

Traffic accident management is of great importance to transportation organizations. Delays caused by traffic accidents directly increase the possibility of secondary accidents, leading to more serious traffic congestions (Chung et al., 2015; Mannering et al., 2014; Meng et al., 2020). For every minute the primary accident remains on the highway, the average risk of the second collision will increase (Cassandra et al., 2012). Accurately prediction of the clearance time of the accidents can facilitate the decision making of the transportation management department and reduce the adverse effects caused by the traffic accidents.

In the past few decades, various statistical models have been applied to model and predict the clearance time of highway accidents. Regression models are typical methods used for estimating and predicting the incident duration for highway incidents (Garib et al., 1997; Valenti et al., 2010). Hazard-based duration models were also widely used to model and predict the accidents duration.

Separate hazard-based duration models were developed by Nam and Mannering to analyze detection/reporting time, response time, and clearance time of highway accidents duration (Nam & Mannering, 2000). AFT models and topic modeling was also applied to predict accident duration, but due to the limitations of the topic model, they did not study the impact of every single variable (Ruimin et al., 2015).

Artificial intelligence-based methods were also adopted to capture the relationship between accidents duration and its influential factors. The K-Nearest Neighbor and artificial neural network model are typical methods to model the clearance time of highway accidents (Wei & Lee, 2007; Wen et al., 2012). Lin et al. (2016) proposed an improved model based on M5P. They replaced linear regression of each leaf by HBDM algorithm and compared the traditional M5P model, HBDM algorithm, and the proposed M5P-HBDM. The results showed that M5P-HBDM could identify more important and meaningful variables. Recently, a complex network algorithm, which combines the modularity-optimizing community detection algorithm and the association rules learning algorithm, was proposed to identify the factors that affect highway accidents clearance time (Lin et al., 2014).

Previous studies (Li et al., 2017; Ding et al., 2015) have identified various factors that influence the incident clearance time, including incident characteristics(e.g., number of vehicles involved in an incident, truck/taxi/bus involvement); weather conditions(e.g., rain, fog, and/or snow); temporal factors (e.g., time of day, day of the week, and/or season); traffic characteristics (e.g., traffic volume) and some other factors. In particular, Crashes that occur in rainy or foggy weather are more likely to have long accident clearance times. And accidents with hazardous material dumping may take longer to clear (Nam & Mannering, 2000). When a large vehicle is involved in a crash, such as large trucks or buses, the accident clearance time may be longer (Chung, 2010). Traffic flow and upstream and downstream speeds around the accident location can also affect accident clearance times (Lee et al., 2010).

As expected, incidents involving chemical spills, hazardous materials and large vehicles have longer clearance time. In addition, incidents during congested periods typically take longer to clear (Hou, 2013). While the way these factors affect incident clearance times is consistent across multiple studies, some studies have found the opposite to be true. For example, while incident clearance during peak hours typically lasts longer, Hojati et al. (2013) observed shorter clearance times for incidents that occurred during the afternoon peak hour.

In the previous studies of clearance time prediction, researchers have considered the number of vehicles involved in the accident, whether there were large vehicles (Xia, 2016), and the number of heavy vehicles involved in the accident (Xu et al., 2013). Few studies have considered different types of vehicles involved in the accident to better represent their impact to the clearance time of the accidents. Specifically, for the same number of vehicles, if the types of the vehicles are different, the clearance time of the accident may be different.

This paper considers two different representations of vehicle types and measures their impact on predicting the clearance time of traffic accidents. A case study using the data obtained from the highways of Shandong province, China is presented. We introduced the data and its preprocessing firstly. When processing data, we delete the data with the accident clearance time exceeding 400 minutes. Because the reasons for the excessively long accident clearance time are single and there is the possibility of erroneous records. Then two models, the generalized linear model and the mixed-effects model, are compared for the task of predicting the clearance time of traffic accidents. The impact of different types of vehicles involved in the accident on the clearance time is also analyzed, based on which policy suggestions are provided to improve traffic accident management.

Data Collection and Analysis

Accident Database and Variable Definition

The accident data used in this article comes from four expressways including G2, G25, G35, and G1511 in Shandong Province between 2016 and 2019. These four expressways are important arterial roads in Shandong Province. In the four years from 2016 to 2019, there were a total of 4,255 accidents. The dataset contains information about the location, the weather, the time, and the vehicles involved in the accident. Based on this information, we carry out two preprocessing operations. First, we group the time of the accident into four time periods to generate four new variables, namely time of day1, time of day2, time of day3 and time of day4. Second, all the categorical variables are converted into dummy variables as shown in Table 1.

There are 29 variables in the extracted data set. In the latter two models, we use dummy variables to define the types of vehicles involved in the accident, so there are 34 variables before the screening variables. The dependent variable is binary, with a value indicating, “long” or “short”, in which “long” refers to the clearance time of the accidents is longer than 120 minutes. The 2009 edition of the Manual on Uniform Traffic Control Devices defines accidents with clearance duration longer than 120 min as large-scale traffic accidents (Zhang et al., 2012). Large-scale traffic accidents can cause more serious congestion and economic losses.

There are 28 independent variables, of which 6 are continuous variables and 22 are dummy variables. To alleviate the influence of diverse value ranges, we divide the variables medium truck flow, large truck flow and embedding congestion, respectively by 1,000, 10,000, or 100,000 such that their value ranges are aligned to a range from 0 to 10. The dataset used by the mixed-effects model is slightly different. The categorical variable location is added (location contains information on 15 different areas on the four highways), and the weather variable is transformed from four dummy variables to one categorical variable. The variable are shown in Table 1.

The passenger car unit (PCU) is calculated at a later stage. According to the traffic volume survey vehicle classification and vehicle conversion coefficient, different weights are assigned to different vehicle types, as shown in Table 2. Then we calculate the weighted sum of vehicles involved in each accident, as shown in Table 3, which represents the number of vehicles involved in the corresponding accident.

Data Preprocessing

There are 332 records that contain missing information, and they are excluded from this study. As a result, there are 3923 remaining data. It is known from the accident description that most of the accidents with long duration are difficult to be clear in a short time, such as the spontaneous combustion of the truck, collision or rollover of the loaded truck,

Table 1.
Variable definition

Variable name	Type	Description
minivan flow	Continuous	minivan flow/10000
medium truck flow	Continuous	medium truck flow/1000
extra large truck flow	Continuous	flow of extra large trucks/10000
container truck flow	Continuous	container flow/1000
embedding congestion	Continuous	The ratio of the total traffic volume of the road network to the total capacity allowed by the road network
time of day1	Dummy	The accident happened during 6:00~10:00:1; other time :0
time of day2	Dummy	The accident happened during 10:00~16:00:1; other time :0
time of day3	Dummy	The accident happened during 16:00~22:00 :1; other time :0
time of day4	Dummy	The accident happened during 22:00~6:00:1; other time :0
night	Dummy	19:00-07:00 :1; 07:00 -19:00 :0
cloudy	Dummy	Cloudy:1; other weather :0
sunny	Dummy	Sunny :1; other weather :0
rainy	Dummy	Rainy /snowy:1; other weather :0
car	Dummy	The car is responsible for the accident :1; Other vehicles are responsible for the accident :0
passenger car	Dummy	The passenger car is responsible for the accident :1; Other vehicles are responsible for the accident :0
truck	Dummy	The truck is responsible for the accident :1 Other vehicles are responsible for the accident :0
rear end	Dummy	The type of accident is rear end collision :1; The accident type is other type :0
Crash barrier	Dummy	The type of accident is guardrail collision :1; The accident type is other type :0
spontaneous combustion	Dummy	The type of accident is spontaneous combustion :1; The accident type is other type :0
other types of accidents	Dummy	Types of accidents except rear end collision, guardrail collision and spontaneous combustion :1
pcu	Continuous	Passenger car unit.
spilled goods	Dummy	Goods were spilled in the accident :1
car-involved accident	Dummy	Whether there is a car involved in the accident.
bus-involved accident	Dummy	Whether there is a bus involved in the accident.
coach-involved accident	Dummy	Whether there is a coach involved in the accident.
small truck-involved accident	Dummy	Whether there is a small truck involved in the accident.
van-involved accident	Dummy	Whether there is a van involved in the accident.
large truck-involved accident	Dummy	Whether there is a large truck(Semi Trailer) involved in the accident.
short clearance time	Binary	dependent variable Accident duration 1 refers to the accident duration is shorter than 120 minutes, and 0 refers to the opposite.

and the reason for the error recording is not excluded. The clearance time of some highway accidents is even more than 720min (12h), so we suspect the possibility of wrong records or other objective reasons. The data set does not explain in detail the reasons for the excessively long clearance time of highway accident, and the data is not representative. Because of the particularity of these accidents with extremely long clearance time, the classification model will have poor performance on such cases. Therefore, the accident data with a clearance time of longer than 400 min is removed, and finally we obtained 3832 observations.

Table 2.
Weights of different vehicle types

Vehicle type	Car	Bus	Coach	Small truck	Van	Large truck
weight	1	1.5	1.5	1	1	3

Table 3.
Calculation of PCU

Vehicle types	Vehicle types	Vehicle types	pcu
Small truck	Small truck	Small truck	3
Car	Small truck		2
Car	Large truck		4

Table 4.
The maximum, quantile and mean of the accident clearance time of the processed data

Minimum	1st-quantile	Median	Mean	3rd-quantile	Maximum
1.0	28.0	51.0	70.21	88.0	400.0

Figure 1.
Accident clearance time distribution of processed data

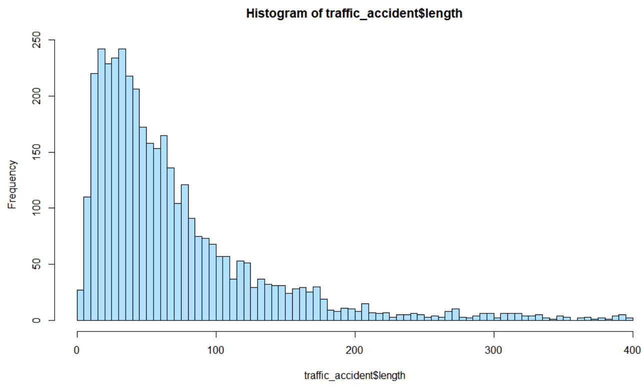

Figure 1 shows the distribution of accident clearance time after removing the accident data with clearance time longer than 400 min. It can be seen from Table 4 that the average value of the retained data is 70.21, and the median value is 51. Most of the data are within the range from 0 to 200 min. With a ratio of 4:1, we obtained a training set with 3,000 observations and a test set with 832 observations.

Table 5.
Descriptive statistics of variables left after screening

Variable name	Type	Mean (percentage for dummies)	variance	min	max
minivan flow	Continuous	0.2968	0.0416	0.0002	1.6216
medium truck flow	Continuous	1.2900	1.1778	0.0000	9.8170
extra large truck flow	Continuous	0.5823	0.1821	0.0001	3.5261
container truck flow	Continuous	1.1543	2.3984	0.0000	9.5250
embedding congestion	Continuous	1.0440	0.1817	0.0010	3.5020
time of day1	Dummy	0.1683	-	0	1
time of day2	Dummy	0.3852	-	0	1
time of day3	Dummy	0.2578	-	0	1
time of day4	Dummy	0.1887	-	0	1
night	Dummy	0.3617	-	0	1
sunny	Dummy	0.6665	-	0	1
car	Dummy	0.5055	-	0	1
rear.end	Dummy	0.7059	-	0	1
Crash barrier	Dummy	0.1561	-	0	1
spontaneous combustion	Dummy	0.0287	-	0	1
pcu	Continuous	2.2192	1.5520	1.0000	13.0000
spilled goods	Dummy	0.0284	-	0	1
short clearance time	Binary	-	-	0	1

Variable Selection

It is found that the two variables, i.e., vehicle equivalent and large truck flow, have a strong correlation with other variables. Hence, these two variables are removed from the data set. Because there are too many variables, the Akaike information criterion (AIC) is used for variable screening (Akaike, 1974). AIC is a standard metric to measure the goodness of fit of statistical models. It is based on the concept of entropy, which can measure the complexity of the estimated model and the goodness of the model fitting the data.

The formula of AIC is

$$AIC = 2 * k - 2\ln(L) \qquad (1)$$

where k represents the number of parameters in the fitted model. L represents the likelihood of the model.

First, a generalized linear model is established which includes all the variables except the two highly correlated variables. Then use the 'step()' function in the R software for variables selection. The step function is based on the AIC, and by selecting a model which has the smallest AIC, the set of variables that contains the most useful information is kept. The variables obtained after the variable selection are shown in Table 5. There are 17 variables left (not including dependent variables), of which 6 are continuous variables and the other 11 are dummy variables. The mean, variance, and extreme values of the continuous variables are also shown in Table 5.

When we use dummy variables to represent the vehicle types involved in the accident instead of the PCU, the variables filtered using the AIC are shown in Table 6. In this case, there are 17 variables left (not including dependent variables), four of which are continuous variables, and the other 13 are dummy variables. The mean, variance, and extreme values of the continuous variables are also shown in Table 6. Although six dummy variables were introduced to represent different types of vehicles involved in accidents, only the two variables car-involved accident and small truck-involved remained after the screening.

Table 6.
Results of logistic regression

Variable name	Type	Mean (percentage for dummies)	variance	min	max
minivan flow	Continuous	0.2968	0.0416	0.0002	1.6216
medium truck flow	Continuous	1.2900	1.1778	0.0000	9.8170
container truck flow	Continuous	1.1543	2.3984	0.0000	9.5250
embedding congestion	Continuous	1.0440	0.1817	0.0010	3.5020
time of day1	Dummy	0.1683	-	0	1
time of day2	Dummy	0.3852	-	0	1
time of day3	Dummy	0.2578	-	0	1
time of day4	Dummy	0.1887	-	0	1
night	Dummy	0.3617	-	0	1
sunny	Dummy	0.6665	-	0	1
car	Dummy	0.5055	-	0	1
rear end	Dummy	0.7059	-	0	1
Crash barrier	Dummy	0.1561	-	0	1
spontaneous combustion	Dummy	0.0287	-	0	1
car-involved accident	Dummy	0.6649	-	0	1
small truck-involved accident	Dummy	0.4468	-	0	1
spilled goods	Dummy	0.0284	-	0	1
short clearance time	Binary	-	-	0	1

Methodology

Generalized Linear Model

Logistic regression is a generalized linear model, which is commonly applied to binary or multi-class classification problems. Moreover, logistic regression can show the influence of each independent variable on the dependent variable compared to other classification algorithms.

In the generalized linear model, the dependent variable Y follows the exponential family distribution. The relationship with the covariate $X_1,\ldots,X_P$ is through the formula $\eta = \beta_0 + \beta_1 X_1 + \ldots + \beta_p X_p$. $g(x)$ is the link function.

$$g(\mu) = \eta \quad (2)$$

$$\mu = E(Y) \quad (3)$$

For Bernoulli distribution, if the probability of Y = 1 is p_1 , then

$$E(Y) = P(Y = 1 \mid X_1,\ldots,X_n) = p_1 \quad (4)$$

Through Equation 3.2,

$$\mu = p_1 \quad (5)$$

In logistic regression, the logistic function is $h(\ ) = \frac{1}{1+e^{-}}$, and thus $\eta = \ln(\frac{h(\eta)}{1-h(\eta)})$.

It can be found that when η is in the range of negative infinity to positive infinity, $h(\eta)$ range from 0 to 1 and increases monotonically: when η >0, $h(\eta) > 0.5$ when η < 0, $h(\eta) < 0.5$.

From Equations 3.1 and 3.4, we have:

$$p_1 = \mu = g^{-1}(\eta) = h(\eta) = \frac{1}{1+e^{-\eta}}. \quad (6)$$

That is

$$g(p_1) = \ln(\frac{p_1}{1-p_1}) \quad (7)$$

Then we get the logistic regression model as follows:

$$\ln(\frac{p_1}{1-p_1}) = \ln(\frac{1}{e^{-\eta}})$$
$$\eta = \beta_0 + \beta_1 X_1 + \ldots + \beta_p X_p, \quad (8)$$

$\frac{p_1}{1-p_1}$ is called the odds, when the value is greater than 1, $p_1 > 0.5$, we think that event {Y = 1} is more likely to happen.

Mixed-effects Model

The principle of the generalized linear model has been introduced in (3.1). By adding a random effect term u_i to the model, the conditional distribution expectation of the dependent variable Y_{ij}, is defined as followed:

$$\mu_{ij} = E(Y_j \mid u_i, X_j) \quad (9)$$

The conditional mean value is combined with the conditional linear prediction value η_{ij} through the link function :

$$g(\mu_{ij}) = \eta_j = X_j^{'}\beta + Z_j^{'}u_i \quad (10)$$

Equation (3.9) is the general form of the generalized linear mixed model, and Y_{ij} : indicates the j^{th} observed response variable of the i^{th} category, $i = 1,...,m,\ j = 1,...,n_i$. It is independent under the condition of random effects u_i and follows the exponential distribution family, which can be binomial distribution, Poisson distribution, Gamma distribution, etc. X_{ij} indicates the explanatory variables; β indicates the fixed effect parameter vector; u_i indicates the random effect and it follows the multi-normal distribution with zero mean and a variance-covariance matrix of γ. u_i represents the heterogeneity between the classes caused by the hidden factors and the observed correlation within the same class and are independent of each other between different classes. Z_{ij} indicates the explanatory variable related to random effects. The design matrix has two parts, i.e., fixed effects X and random effects Z.

The generalized linear mixed model is also called the conditional model. When $Z = 1$, $\eta_{ij} = X_j^{'}\beta + u_i$, is the simplest mixed-effects model, namely the random-intercept model. u_i represents the influence of the i^{th} category on the observed value within the class (variation that cannot be explained by the covariate can be observed). σ_u^2 reflects the heterogeneity between different classes.

Due to the non-linear relationship between the dependent variable and the independent variables and the existence of random effects u_i in the model, it is difficult to estimate the parameters of the model. Assume that the likelihood function of the ith category is:

$$L_i(\beta, u_i) = f_y(y_i \mid u_i, X_i, \beta) = \prod_{j=1}^{n_i} f_y(y_j \mid u_i, X_j, \beta) \quad (11)$$

Suppose the density function $f_u(u_i, G)$ of random effects u_i is. with marginal likelihood function:

$$L_i(\beta,\gamma) = \int_{u_i} L_i(\beta, u_i) f_u(u_i,\gamma) du_i$$
$$= \int_{u_i} \left\{ \prod_{j=1}^{n_i} f_y(y_{ij} | u_i, X_{ij}, \beta) \right\} f_u(u_i,\gamma) du_i, \quad (12)$$

γ is the variance covariance matrix of u_i, and is the parameter estimate of G. The following likelihood function is constructed:

$$L(\beta,\gamma) = \prod_i L_i(\beta,\gamma) \quad (13)$$

It can be seen from the above equations that the calculation of the likelihood function is much more complicated than the linear mixed-effects model, and the problem of high-dimensional integration of random effects u_i needs to be solved. Many approximate inference methods for maximizing the likelihood function have been proposed, e.g., the main integral approximation methods are Laplace approximation (Breslow & Clayton, 1993), Adaptive Gaussian integration, first-order Taylor sequence expansion approximation (Li et al., 2007).

Results Analysis and Disscussions

Model Results with Vehicle Types Encoded as Dummies

First, we use dummy variables to encode the types of vehicles involved in the accident instead of PCU to build the model. Then we use AIC for feature selection. The results of the generalized linear model with vehicle types encoded as dummies are shown in the Table 7. (Only the variables with significance levels above 0.1 are shown in the results.) The AIC of the model is 1969.8, and thus most of the variables are significant. The variables representing the embedding congestion, accident type, responsible car type, and whether there were cars or small trucks involved in the accident are all significant with a level of 99% .

Then we establish a mixed effect model with vehicle types encoded as dummies by using these variables and location. The variable representing whether it is a sunny day is replaced by the variable weather (here weather1 represents the sunny day, weather2 represents cloudy, weather3 represents the rainy day, weather4 represents fog and haze, weather5 represents snowy day). Moreover, we choose time of day, night, and location as random intercept terms to establish three random intercept models.

Use the “anova()” function of the R software to test the AIC and significance of the three models. The results show that the AIC of the model with location as the random intercept term is the smallest, and it is more significant than the other two models. The results show that the medium trucks flow, minivan flow, container truck flow, and extra large truck flow are not significant in the model, and it is also found that the time of day is not very significant. Therefore we remove these five variables.

Next, we take location as the random intercept term and embedding congestion, car1involved accident, and spilled goods as the random slope terms to establish three generalized linear mixed-effects models. Use

Table 7.
Results of logistic regression

	Estimate	Std. Error	z value	Pr(>|z|)	Significance level
(Intercept)	0.7691	0.2859	2.690	0.0071	**
minivan flow	-0.8980	0.4078	-2.202	0.0276	*
medium truck flow	0.1538	0.0778	1.978	0.0479	*
embedding congestion	0.6512	0.1844	3.531	0.0004	***
night1	-0.4612	0.1614	-2.858	0.0043	**
sunny1	0.3871	0.1243	3.115	0.0018	**
car1	1.5619	0.2530	6.174	<0.0001	***
rear end1	0.7848	0.1617	4.854	<0.0001	***
crash barrier	0.7259	0.2087	3.478	<0.0001	***
spontaneous combustion	-0.5984	0.2771	-2.160	0.0308	*
spilled goods	-1.5372	0.2549	-6.030	<0.0001	***
car-involved accident	1.0538	0.1765	5.970	<0.0001	***
small truck-involved accident	0.5644	0.2118	2.665	0.0077	**

Null deviance: 2584.3 Residual deviance: 1935.8 AIC: 1969.8
*parameter significant at the 0.1 level;
**parameter significant at the 0.05 level;
***parameter significant at the 0.01level.

Table 8.
The random effects in the generalized mixed-effects model

Group name	Variance	Std. Error	Corr
Location (Intercept)	0.4820	0.6942	
embedding congestion	0.4257	0.6524	-0.9100

Table 9.
The fixed effects in the generalized mixed-effects model

	Estimate	Std. Error	z value	Pr(>|z|)	Significance level
(Intercept)	0.3242	0.2767	1.172	0.2413	
night1	-0.6648	0.1232	-5.396	<0.0001	***
weather2	-0.4750	0.1430	-3.323	0.0009	***
weather5	-0.9329	0.3235	-2.884	0.0039	**
car1	1.5937	0.2535	6.288	<0.0001	***
rear end1	0.7616	0.1635	4.658	< 0.0001	***
crash barrier	0.7175	0.2125	3.376	0.0007	***
spontaneous combustion	-0.6111	0.2811	-2.174	0.0297	*
car-involved accident	1.1404	0.1745	6.535	<0.0001	***
small truck-involved accident	0.5751	0.2140	2.687	0.0072	**
spilled goods	-1.5597	0.2569	-6.070	<0.0001	***

AIC: 1976.8 Log-likelihood: -972.4 Number of observations: 3000
*parameter significant at the 0.1 level;
**parameter significant at the 0.05 level;
***parameter significant at the 0.01level.

the “anova ()” function(analysis of variance or deviance tables for one or more fitted model objects.) to test the AIC and significance of the three models. The results show that the AIC of the model with embedding congestion as the random slope is the smallest and the most significant. The results are shown in Tables 8 and 9. We found that the variables including whether the accident occurred at night, the weather of the accident, the type of accident, the type of vehicle responsible for the accident, and whether there were cars or small trucks involved accident in the accident, were all significant at the 99% level.

Same as the generalized linear model with vehicle types encoded as dummies, the coefficients of car-involved accident and small truck-involved accident of this model are also positive. The AIC of this model is 1976.8, which is larger than the generalized linear model with vehicle types encoded as dummies, meaning that the mixed effect model with vehicle types encoded as dummies has induced less information loss by introducing the random parameters.

Model Results with PCU Equivalents

The logistic regression model with PCU equivalents was established with the variables selected by AIC. Check the coefficient and significance of each variable, the regression results are shown in Table 10. The AIC of the model is 1982.3, and most of the variables are significant. Embedding congestion, accident type, responsible car type, and PCU are all significant with a level of 99%. The generalized mixed-effects model with PCU equivalents was established by using the selected 14 variables and location. We use time of day, night, and location as random intercept terms to establish three random intercept models.

Similarly, we use the “anova()” function of the R software to test the AIC and significance of the three models. The results show that the AIC of the model with location as the random intercept term is the smallest, and it is more significant than the other two models. The results show that the medium trucks flow, minivan flow, container truck flow, and extra large truck flow are not significant in the model, and it is also found that the time of day is not very significant. Therefore these five variables are removed.

Table 10.
Results of logistic regression

	Estimate	Std. Error	z value	Pr(>|z|)	Significance level
(Intercept)	0.0236	0.2389	0.099	0.9213	
minivan flow	-0.8665	0.4148	-2.089	0.0367	*
medium truck flow	0.1939	0.0847	2.289	0.0221	*
extra large truck flow	-0.5738	0.2723	-2.107	0.0351	*
container truck flow	-0.0900	0.0394	-2.285	0.0223	*
embedding congestion	1.0927	0.2787	3.921	<0.0001	***
time of day3	0.4052	0.1888	2.146	0.0319	*
night1	-0.5074	0.1603	-3.165	0.0016	**
sunny1	0.3845	0.1233	3.119	0.0018	**
car1	1.7684	0.1654	10.691	<0.0001	***
rear.end1	1.4421	0.1770	8.149	< 0.0001	***
crash barrier	0.7678	0.2087	3.680	<0.0001	***
spontaneous combustion	-0.6714	0.2781	-2.414	0.0158	*
pcu	-0.2633	0.0525	-5.012	<0.0001	***
spilled goods	-1.6344	0.2533	-6.451	<0.0001	***

Null deviance: 2584.3 Residual deviance: 1948.3 AIC: 1982.3
*parameter significant at the 0.1 level;
**parameter significant at the 0.05 level;
***parameter significant at the 0.01level.

Table 11.
The random effects in the generalized mixed-effects model

Group name	Variance	Std. Error	Corr
Location (Intercept)	0.4932	0.7023	
embedding congestion	0.4456	0.6675	-0.9300

Table 12.
The fixed effects in the generalized mixed-effects model

	Estimate	Std. Error	z value	Pr(>|z|)	Significance level
(Intercept)	1.2830	0.2024	6.339	<0.0001	***
night1	-0.8007	0.1201	-6.666	<0.0001	***
weather2	-0.4939	0.1415	-3.491	0.0005	***
weather5	-0.9089	0.3177	-2.860	0.0042	**
car1	1.9383	0.1594	12.160	<0.0001	***
rear end1	1.4573	0.1779	8.194	< 0.0001	***
crash barrier	0.7504	0.2124	3.533	<0.0001	***
spontaneous combustion	-0.6597	0.2812	-2.346	0.0190	*
pcu	-0.2524	0.0519	-4.861	<0.0001	***
spilled goods	-1.7033	0.2554	-6.669	<0.0001	***

AIC: 2000.9 Log-likelihood: -985.5 Number of observations: 3000
*parameter significant at the 0.1 level;
**parameter significant at the 0.05 level;
***parameter significant at the 0.01level.

Next, we take location as the random intercept term and take embedding congestion, PCU, and spilled goods as the random slope terms to establish three generalized linear mixed-effects models. We then use the “anova ()” function to test the AIC and significance of the three models. The results show that the AIC of the model with embedding congestion as the random slope is the smallest and the most significant. The results are shown in Table 11 and Table 12. We found the variables representing whether the accident occurred at night, the weather of the accident, the accident type, the type of vehicle responsible for the accident, and the PCU were all significant with a level of 99%.

It can be seen from the coefficients that the variable coefficients of the fixed effects part of the generalized mixed-effects model with PCU equivalents are similar to the variable coefficients of the generalized linear model with PCU equivalents. Except for the significant degree of changes in some variables, there is almost no difference. The AIC of this model is 2001, which is larger than the generalized linear model with PCU equivalents. So the generalized linear model with PCU equivalents performs better in predicting the clearance time of highway accidents.

Comparison and Discussions

Compared with other weather, the accident duration is more likely to be “short” on sunny days. The results were the same as those found in previous studies (Nam & Mannering, 2000). The results show that the highway accidents clearance time attends to be “longer” at night. Studies have also found that accidents that occur at night are more likely to be severe (Ding et al., 2015)

An accident with a car as the responsible party is more likely to last shorter than 120 minutes compared with an accident with a truck or a bus as the responsible party. The accidents with rear-ending collisions and crash barrier collisions are more likely to have a shorter duration than other types of car accidents. When the accident type is spontaneous combustion, the clearance time of the accident is more likely to be longer than 120min. When PCU is larger, i.e., there are more vehicles involved in the accident or the vehicle involved in the accident is a large truck, the accident clearance time is more likely to be “long” which is consistent with certain previous studies (Li et al., 2017). If goods are spilled during an accident, it is more likely that the accident lasts longer than 120 minutes.

In addition, the results show that the heavier the embedding congestion is, it is more likely that the clearance time of the accident is shorter than 120 minutes, which is inconsistent with our intuition. An explanation is that the heavier the embedding congestion is when an accident occurs, the person in charge will clear the traffic more efficiently to avoid more serious congestion. It can be seen from the model results that the variables representing car-involved accidents and small truck-involved accidents are significant. A positive coefficient means that when a car or a small truck is involved in a car accident, it is more likely that the accident clearance time is less than 120 minutes. On the other hand, if there is a large truck or bus in the accident, it may take longer to clear the accident.

Conclusions

This study analyzed the traffic accident data of 4 expressways including G2, G25, G35, G1511 in Shandong Province to predict whether the clearance time of a traffic accident is greater than 120 minutes. Comparing the results of two generalized linear models and two mixed-effects models, we found the factors that affect the duration to clear traffic accidents. These factors are night, weather, embedding congestion, car, rear end, crash barrier, PCU, spilled goods, car involved accident, and small truck involved accident.

The results of the four-parameter estimation models show that embedded congestion, weather, accident type, and accident vehicle type are the factors that affect the accident clearance time most significantly. If the weather is sunny, it is more likely that the accident clearance time is less than 120min. The accident with a car as the responsible party is more likely to last shorter than 120 minutes. The larger the number of vehicles involved in the accident is or the greater the PCU is, it is more likely that the accident clearance time will be greater than 120 minutes. When the type of vehicle involved in the accident is a small vehicle, such as a small car or a small truck, it is more likely that the clearance time of the accident is 'short'. From the results, when the accident involves multiple vehicles or the type of accident is spontaneous combustion, the person in charge shall deal with the accident scenes as soon as possible. Prevent such accidents from causing serious congestion or more serious accidents.

Due to the limited data we have, the lane closure type and the number of injured are not included. This information may affect the duration of highway accidents. In a future study, we can collect more data to apply to our model. For future work, we are planning to obtain more traffic accident data and investigate the application of artificial intelligence-based methods for accident clearance time prediction. Future studies can compare the fitting and prediction Performance of these models, and we can also introduce more model evaluation criteria, such as Mean Absolute Error (MAE) and Mean Absolute Percentage Error (MAPE). Besides, different variable screening methods will be explored, as when the variables used in the models are different, the factors related to the clearance time of the accidents will also be different.

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Practice Update – Improving security and trust for IoT devices during rescue operations

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Abstract

This paper briefly introduces pilot evaluations that have taken place under the umbrella of the First Responder Advanced Technologies for Safe and Efficient Emergency Response (FASTER) initiative, a project co-funded by the European Community and Japan. The FASTER Research Consortium included research organizations, emergency response practitioners, and industry from 11 countries and 23 organizations. This paper concerns a pilot evaluation carried out in Japan in July 2021 to evaluate the technologies developed by European FASTER partners and their interoperability with a distributed network of trust framework created by the Japanese partners. The expected outcome of the evaluation pilot was that the distributed network of trust would enable secure and trustable communications among first responders employing technological tools during rescue operations. This paper presents details of the pilot and the architecture of the technical solutions. Because all the FASTER pilots involve close collaboration with emergency first responders during the design of the pilots and during the pilots themselves, the evaluation of the data obtained from pilots incorporates not only a technological assessment of the distributed network of trust created by the authors of this paper but also initial insights from the practitioners as to the usability of the tools provided by European FASTER partners, as part of the assessment.

Keywords: *Distributed Ledger Technologies, IoT Devices, First Responders*

This paper presents the results of an evaluation pilot held in Japan, which took place on July 26th, 2021, at the Hyogo Prefectural Emergency Management & Training Center and Firefighting School in Miki City, Hyogo Prefecture. A second Japanese pilot was scheduled at the same location in February 2022 with broad participation from most FASTER European partners. However, because of COVID-19 restrictions, the pilot was canceled, and instead, the Japanese team participated in another pilot held by the partners in Madrid, Spain, in April 2022. During these pilots, the Japanese team aimed to evaluate the security and reliability of tools developed during the course of the FASTER initiative.

FASTER contributes to developing a new approach to disaster response, using technology to increase situational awareness and consequently improve first responders' (FR) safety during emergencies. As this paper describes, the Japanese pilot was part of a group of pilots, most of which took place in various European countries. The primary purpose of the Japanese pilot evaluations was to assess a distributed-ledger technology built from the ground up to support real-time quantum-safe[1] communication security of the tools developed by other FASTER team members.

The FASTER project was funded by Horizon 2020 in Europe and The Japan Science and Technology Agency in Japan. The project ran from May 2019 to April 2022 in Europe and from May 2019 to March 2023 in Japan. Despite the global COVID-19 pandemic, which required pilot cancelations and scaling down, the project partners made significant progress in Europe and Japan. However, because of the travel restrictions imposed by governments in response to the pandemic, the project had to evolve. In particular, the Japanese team found it necessary to adapt the original evaluation strategy to evaluate its research efforts by canceling a second Japanese pilot and instead performing additional tests

[1] Post-quantum cryptography (sometimes referred to as quantum-proof, quantum-safe or quantum-resistant) refers to cryptographic algorithms (usually public-key algorithms) that are thought to be secure against a cryptanalytic attack by a quantum computer.

locally and during a pilot held in Madrid, Spain in April 2022.

Faster Project goals

The following list summarizes the primary goals of the FASTER project (Dimou et al., 2021).

- Data collection to provide a secure IoT platform for distributed, real-time gathering and processing of heterogeneous physiological and critical environmental data from smart textiles, wearables, sensors, and social media;
- Operational capabilities to provide flexible, multi-functional autonomous vehicles, including swarms, for extended inspection capabilities and physical risk mitigation;
- Risk assessment to provide tools for individual health assessment and disaster scene analysis for early warning and risk mitigation;
- Improved ergonomics to provide augmented reality tools for enhanced information streaming, as well as body- and gesture-based interfaces for vehicle navigation and communication;
- Resilient communication at the field level to provide haptic communication capabilities, emergency communication devices, interoperation with K9s, and at the infrastructure level through 5G technologies and Unmanned Aerial/ Ground Vehicles (UxVs);
- Tactical situational awareness to provide innovative visualization services for a portable Common Operational Picture for indoor and outdoor scenario representation;
- Efficient cooperation and interoperability amongst first responders, LEAs (Law Enforcement Agencies), community members and other resource providers, under the umbrella of a secure network of trust, provided by a custom-built distributed-ledger technology that meets the stringent FASTER real time, privacy and security restrictions.

Overall Architecture

The architecture considers a constant interaction between bio-monitoring and situational awareness factors and the FASTER control center. FASTER aims to improve disaster response and monitoring capabilities by providing first responders with a suite of tools to augment their situational awareness and, as a result, enhance their safety and operational capacity. The focus of disaster response is on mitigating the impact of disaster and ensuring the security of first responders during the emergency (Dimou et al., 2021).

FASTER's integration architecture connects various tools and devices through a distributed network of trust called AIngle, built from the ground up to support real-time, quantum-safe security. Each tool and device gathers and shares information with a Common Operational Picture (CoP) panel and a command and control center to coordinate rescue operations. The idea is to take advantage of AIngle's unique and efficient mechanisms to interconnect all technologies developed by FASTER partners and used by the first responders at the edge layer to facilitate secure, encrypted, private, and efficient information traffic. The section below provides more details on the first pilot, which took place at two training fields strewn with collapsed building debris. One field was sponsored by the Japan International Cooperation Agency (JICA); the other by Hyogo Prefecture. In addition, some aspects of pilot training also took place in a large indoor disaster training facility. An overview of the system architecture is provided in Figure 1.

Summary of Previous Pilots

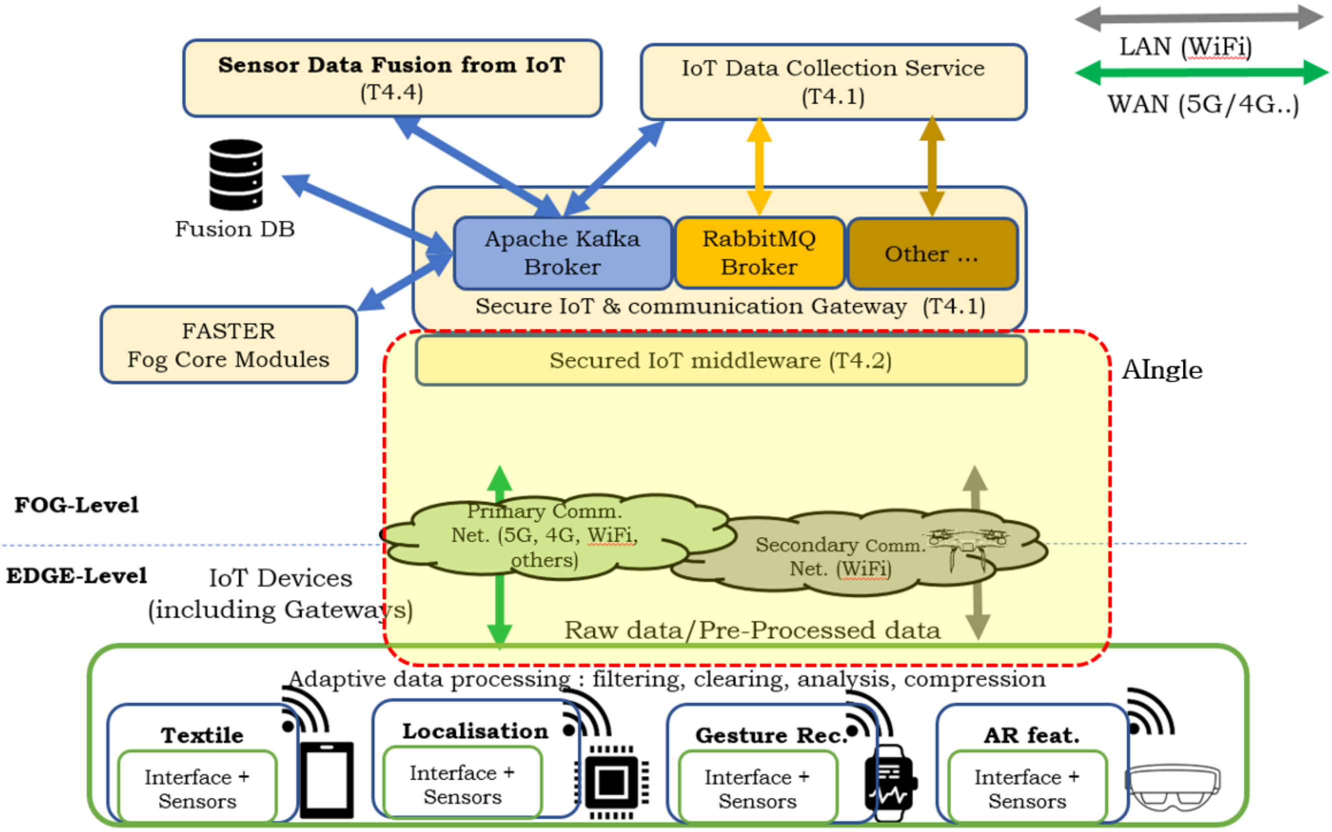
The FASTER project plan called for pilots. It used scenarios to test the impact of the various tools developed by the partners on first responders in rescue situations. Some of the pilots carried out in European partner countries before the Japanese pilot are described below.

Spain Pilot (Madrid)

The first FASTER pilot was held in Madrid in November 2020 (FASTER, 2020, November). The objective was to simulate major earthquake effects and test the efficacy of some of the FASTER tools. However, due to the pandemic, the safety protocols were adapted following the health procedures provided by the community of Madrid (this additional challenge was valuable because it proved the importance of integrated systems in a pandemic environment). The scenario consisted of a 7.3 Richter scale earthquake at 7 am (Madrid local time) and collapsed areas and buildings in hazardous conditions. The pilot involved the fire department of the community of Valencia and the municipal police of Madrid.

In the Madrid pilot, the FASTER technology proved valuable in supporting operational tasks. Through the aerial images transmitted by drones to the control center and 2D or 3D mapping, it was possible to assess the disaster areas and identify the most compromised buildings in real time through the CoP interface. Without the intervention of FASTER tools, the task (assessing a disaster area) would have taken much longer.

Figure 1
FASTER Architecture with AIngle Integration



Communication between people and the control center was smooth despite the limitations of the communication networks. Rescue dogs (K9) were monitored in real time by the CoP.

Italy Pilot (Moncalieri)

The second pilot was held in Moncalieri, a city south of Turin, Italy (FASTER, 2021, May). After several postponements due to the pandemic, it was carried out in January 2021. This pilot recreated a flood (a typical disaster in this area of Italy) that occurred in 2016 after heavy rains flooded several towns near the Apennines, especially Cuneo, Asti, Alessandria, Turin, and Moncalieri. The scenario consisted of a flooding situation after several storms with heavy rainfalls (between 500 and 600 mm). The tools used in this pilot included the Mission Management Tool, or MMT (that the first responders used to send and receive multimedia with geolocated content), a smartwatch that sent information to the control center in real time about the position, status, and activities on the ground.

Furthermore, the situation on the ground was reported through drones to the CoP via 2D and 3D maps. The Control Center communicated with the first responders by sending messages, assigning missions, and sending reports. In contrast, the first responders sent photos and videos to the CoP only via the MMT chatbot (as the smartwatch did not have a camera). In this pilot, all first responders were asked to agree to data sharing with the CoP using voice control and gesture control.

Finland Pilot (Kajaani)

The third pilot simulated a terrorist attack in an indoor environment of a school building in Kajaani, Finland (FASTER, 2021, May). The tools used in this pilot included motion sensors, weather station, and Control Center reports, airflow status (ventilation) and smoke sensors, and dog suits worn by participating K9 units. The pilot considered training reaction procedures in response to a terrorist attack using FASTER technology to improve response and information flow. The first part involved an indoor explosion. The Emergency Response Center then received a terrorist attack alarm and the Kainuu Rescue Department dispatched units to the explosion scene. Smart textiles in rescuers' uniforms allowed continuous monitoring of biometric data, such as heart rate, respiratory rate, body temperature, and blood pressure. The data were displayed on the first responders' devices. When predetermined thresholds were reached, an alert (LED light) was activated, displaying data on a central information hub (CoP). The mobile Augmented Reality (AR) was used as operational support to show the nearest extinguishing and evacuation routes, along with the position and orientation of first responders (using HoloLens). The 3D visualization tool revealed abnormal heat locations, smoke, CO2 values, and route planning reports. In the meantime, the police force set up a perimeter while canine units (K9) performed search and rescue of trapped victims. The pilot recreated an intervention in a classroom with hostages. Canine units with sensors and communication tools were used to maintain continuous information sharing with rescue personnel. It was a successful pilot that included an unpredictable situation (i.e. hostage-taking).

Japan Pilot

Building upon the significant progress achieved during the pilot experiments introduced above, this paper aims to describe the results of the Japanese pilot. The Japanese pilot was held on July 26th, 2021. During the pilot, the Japanese team tested various aspects of AIngle, a distributed ledger technology (DLT) designed and developed in Japan as the communication framework that integrates all the FASTER technological components (See Figure 1). The hypothesis was that AIngle would provide quantum-safe security of interconnections at the edge layer without interfering with the practical use of FASTER tools. To accomplish this, AIngle adopted a well-known approach to post-quantum cryptography by employing hash-based cryptography of all data in and out, in accordance with the Merkle Signature Scheme (Merkle, 1990), thereby guaranteeing that it is impossible to break the cryptography even with a yet-to-be-available quantum computer, as proven by Luis Garcia (Garcia Coronado, 2005). In addition, AIngle needs to meet stringent requirements for data privacy regulations, trustworthiness, and resilience through decentralization, speed, and efficiency. Thus, the pilot experiments described in this paper needed to demonstrate the viability of AIngle and thereby prove the hypothesis while meeting these stringent requirements. The primary focus of the Japanese pilot was the response to an earthquake that caused buildings to collapse. The scenario took place indoors and outdoors. The purpose of the Japanese pilot was to evaluate the viability of the AIngle framework to interconnect various devices and measure data throughput, latency, and reliability. This function is necessary because there are limited—if any at all—DLT frameworks capable of providing real-time interconnection to mission-critical technological solutions employed by first responders in life-or-death situations.

The Japanese pilot incorporated the technologies provided by Horizon 2020, FASTER and other local partners, which are described in Table 1 in the following subsection. Figure 2 illustrates the functional overview

Figure 2
Japanese Pilot Functional Overview

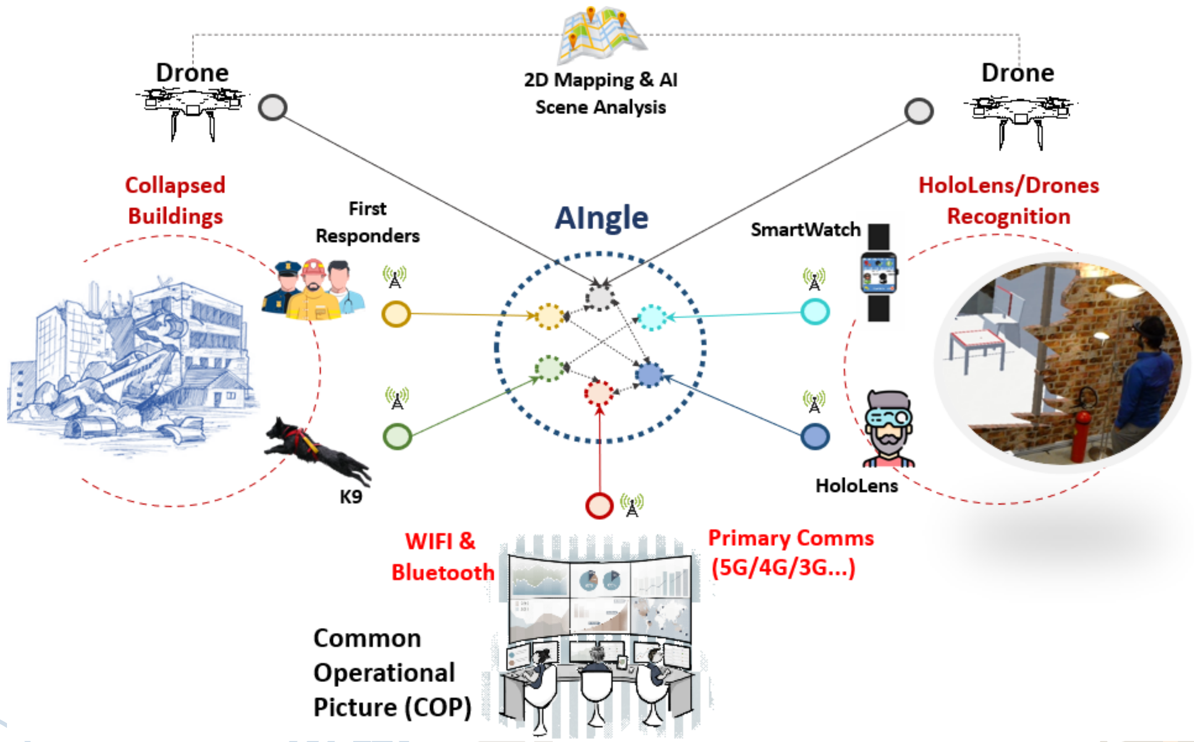


Table 1
Tools tested in first Japanese pilot

Tools / Developer	Hardware / Software	Description
MORSE (MOvement Recognition for firSt rEsponders) Developed by UNIWA (FASTER, 2021b)	Smartwatch Fossil Gen5	MORSE will provide non-visual/non-audible communication capabilities, translate movements or critical readings from paired wearable devices to coded messages, and communicate to cooperating agents on the field through vibrations on wearable devices. The messages will be transmitted using IoT communication protocols (e.g., Bluetooth Low Energy; BLE)
AR Operational Support Developed by CS (CS Group, 2021)	Microsoft Hololens 2	The main aims of the AR system are to visualize the first responder and the team members' position on a map (for an indoor or an outdoor environment) and visualize alerts (related to FR health and immediate hazard) and commands within an intuitive and non-disruptive interface. In addition, the AR system will display on-demand information regarding direct threats, mission information, and its current position on a map.
CoP (Common Operational Picture) Developed by ENG (FASTER, 2021a)	Tablet/Laptop	The FASTER Portable Control Centre allows FR teams to make an efficient and effective decision, use a dynamic interface to show critical situations, and select and organize the proper response. It is a new way to merge and visualize essential information in a CoP, having an overall and continuously up-to-date situation awareness.
2D Mapping AI Scene analysis Extended Vision UxV gesture control Developed by CERTH (Konstantoudakis et al., 2020)	Drones Mavic enterprise2 Microsoft HoloLens2 Smartphone with Android 8 (or higher) Laptop/Tablet	• Extended vision: This tool enables users to view a real-time video from a drone's camera on an augmented reality head-mounted display. • Gesture Control: This tool enables users to control drones using simple, one-handed gestures. • 2D Mapping: This tool will allow first responders to generate an accurate 2D map of the affected area in an automated manner using one or more drones. It is accessed through the CoP, where users can mark the site to be mapped, select the drone(s) that will execute the mission, and designate other mission parameters.
Dog Suite Developed by Tohoku University (Ide et al., 2021)	Dog Suit	Search and rescue dogs perform well in finding victims within 72h in disaster sites. The dogs can tell us the location of victims by continuous barks. However, it is not sufficient for triage, which requires the location and the victims' number, states, and conditions. Tohoku University research proposes a method of recording and visualizing the dog's activities by using robot technologies.
AIngle (Distributed Network of Trust) Developed by KGU	AIngle (Semantic DLT)	A distributed network of trust allows technologies developed by other FASTER team members to communicate securely and independently, without the need for deep integration, while maintaining desired levels of privacy. Thus, a DLT (distributed ledger technology) based on a directed acyclic graph (DAG) has been developed from scratch.

of AIngle with FASTER tools employed during the Japanese pilot.

Japanese Pilot Participants

As mentioned in the introduction, the FASTER project consortium consists of 23 organizations from 10 countries in Europe, and Japan. This multidisciplinary consortium consists of first responders, industrial corporations, and academic institutions. In addition to the FASTER consortium members, local partners in Japan included

the Kobe City Fire Department, the Japan Rescue Association, a civil canine trainers' organization, RUSEA (Regional Revitalization & Disaster Prevention Useful Drone Promoters Association), a civil drone operators' group, and the Hyogo Prefectural Emergency Management and Training Center. Also, Tohoku University is providing K9 suits, the first non-FASTER-developed technology to interoperate with the FASTER toolset to demonstrate FASTER's broad applicability.

Venue for the Japanese Pilot

The Japanese pilot took place at the Hyogo Prefectural Emergency Management and Training Center, which is co-located with the Hyogo-based Firefighter's Academy. The center serves as a wide-area disaster prevention base that covers the entire prefecture, provides operational and logistical support during natural disasters, and functions as a hosting facility for disaster emergency personnel. In addition, the center is a hub for training staff, fire brigade members, disaster prevention and response organizations, and leaders. It also carries out disaster prevention training for citizens of the prefecture. The center is part of a much larger Disaster Management Park (see the operations map in Figure 3). The park includes an open athletic stadium, a domed sport, and events stadium, an earthquake simulation facility, a large green park area, and a disaster museum, among other facilities. The total area of the Disaster Management Park is 256 hectares. This prefecture became a nationwide leader in disaster mitigation education following the

Great Hanshin-Awaji Earthquake of 1995 and has many educational and training facilities where first responders and community organizations can organize training for disaster management, prevention, and response. This made the facility an as-close-as-it-gets environment to conduct the experiments for the Japanese pilot.

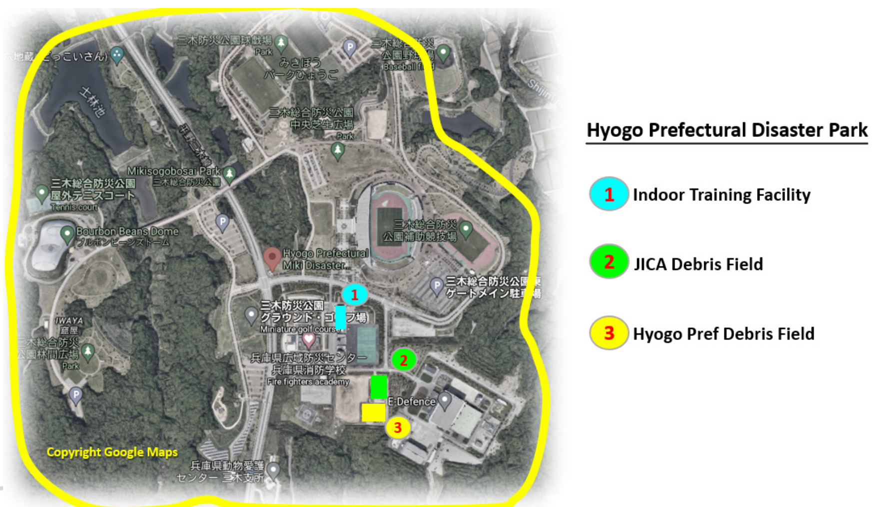
The Japanese pilot took place at two training fields strewn with collapsed building debris on the fields. One field was sponsored by JICA; the other by the Prefecture. In addition, some aspects of pilot training also took place in a large indoor disaster training facility.

The Role of AIngle in the Pilots

This section briefly summarizes the novel AIngle DLT framework. AIngle was constructed from the ground up to support a lightweight, fast and reliable transactional network that enables interconnected IoT devices to support mission-critical distributed smart applications. The etymology of AIngle is a combination of the acronym for “Artificial Intelligence” (AI) and the last four letters of “tangle” (ngle) to form the plural form of the old Scottish word “AIngle” meaning angels or “messengers.” This latter meaning captures the exact purpose of the AIngle framework, which is to act as a messaging platform among participant messaging nodes, i.e., a network of IoT devices. The design and construction of AIngle are intended to meet four important requirements:

- Lightweight. Support for IoT nodes with low computational power and low memory capacity.
- Fast. Support for distributed applications that can process real-time transactions and support encrypted gossip of streamed data.
- Reliable. Support for ad hoc IoT networks, which may or may not have a connection to the Internet.
- Powerful but light consensus. Support for a feeless, energy-efficient consensus algorithm.

Figure 3
Pilot venue at a certain Disaster Management Park



AIngle is inspired by IOTA.org which is also based on the DAG[2] graph-based structure. Although AIngle improves many of the techniques introduced by IOTA.org, its most notable contribution is that AIngle incorporates a distributed knowledge graph database capable of supporting the development of knowledge-oriented or intelligent applications. This distributed knowledge graph database supports highly interconnected data by providing a concept-level schema (or ontology) that fully implements the Entity-Relationship (ER) model. To accomplish this, AIngle enables the distribution of knowledge graph shards through their inclusion in AIngle nodes, wherever they might be needed to support the creation of intelligent applications.

The underlying AIngle knowledge graph database adapts an early version of TypeDB, developed by Vaticle.com (formerly known as Grakn.ai), a type system that implements knowledge representation and reasoning principles. Through TypeDB, AIngle enables the construction of distributed smart applications by providing an expressive distributed graph modeling language to perform deductive reasoning over large numbers of knowledge graph shards distributed among AIngle nodes. With this distributed knowledge graph structure, AIngle effectively became the first DLT that supports distributed knowledge for artificial intelligence and distributed cognitive computing systems, called “Smart Distributed Applications.” While upcoming papers will contrast Smart Distributed Applications with much-hyped Smart Contracts by highlighting their common traits and significant differences, this paper aims to focus on its role in the FASTER project and to evaluate its viability for mission-critical applications such as disaster first response.

Security and Trust Concerns

The need to introduce a robust system such as AIngle to manage edge-layer communication for interoperating rescue technologies might not be obvious at first glance. However, the following examples of cyber-attacks

2 DAG stands for Directed Acyclic. A DAG is a graph that is directed and without cycles connecting the other edges.

and infrastructure failures make a strong case for introducing the AIngle framework as a distributed network of trust for real emergency rescue operations.

- Recently, cyber-attacks seem to be more prominent in headline news. The Colonial Pipeline Ransomware Cyber Attack that stopped the flow of gas throughout the Eastern United States and the Qbot trojan attack suffered by Japanese Company Fujifilm (Fujifilm, 2021) are some examples. In Fujifilm's case, although its network was partially shut down and disconnected from external correspondence to protect the business, their operations were down for almost four days, including global operations such as healthcare, imaging, workplace services, and materials. These types of cyber-attacks are very damaging. They can be even more dangerous if they occur during a disaster and affect ongoing rescue operations. For instance, if hackers were to take over a rescue drone, or a rover, or even take over the computerized equipment or control the command center, the effect on rescue operations would be catastrophic. In the best scenario, it could result in the loss of private data; in the worst scenario, it could result in the loss of human life. AIngle's primary role is therefore to prevent cyber-attacks through a distributed network (DLT) that encrypts all information shared. This distributed network of trust uses encryption algorithms to prevent malicious intrusions. In addition, a distributed ledger ensures decentralization of the database, thus generating a network of trust among participant elements of the FASTER ecosystem.
- Smooth and resilient communication among first responders and other stakeholders is vital during catastrophic events. Any interruption in transmission during an emergency can hinder rescue operations. For instance, during the devastating floods in the Uttarakhand National Park in India in 2013 (Kishorbhai & Vasantbhai, 2017), a large-scale black-out caused an interruption in communication, resulting in thousands of casualties due to the inability of rescue teams to maintain smooth communication. This event highlighted the need for the development of a system that could withstand sudden connectivity outages. AIngle provides resilient communication mechanisms among devices and tools even in the event of internet outages because it can create ad hoc local networks. Once internet connectivity is restored, AIngle is also capable of updating the main AIngle network (a.k.a. SemDAG).

How Can AIngle Address these Security and Reliability Concerns?

AIngle has been evaluated so far through benchmarking experiments and compared to two other well-known distributed ledger technologies, namely, Ethereum and Iota.org. The results of these benchmark experiments can be seen in Table 2.

As Table 2 shows, AIngle's performance in terms of experimental Transactions Per Second (TPS) is significantly better than that of Ethereum and Iota.org, whereas IOTA has better theoretical TPS scalability because it handles a much larger number of nodes than AIngle. As AIngle's nodes increase in number, it is anticipated to perform at the same level or better than IOTA. However, AIngle's performance in natural disaster scenarios needs further evaluation. For this reason, the Japanese pilots aim to perform a series of experiments, which will evaluate:

1) Speed. These experiments aim to answer whether response times meet the requirements necessary to respond in rescue operations.
2) Reliability. These experiments focus on assessing how reliable the AIngle framework can be during rescue operations. The investigation involves stress tests and Internet connectivity tests by disconnecting from the Internet to test whether the local connections can support the communication requirements through AIngle ad hoc connections.

Exit interviews and questionnaires will be employed to gather important information from first responders to assess the usability of the AIngle framework and other FASTER technologies used during the pilot. This paper presents all the results from these experiments.

As mentioned in the introduction, the key hypothesis is that AIngle will provide quantum-safe security of interconnections at the edge layer, without interfering

Table 2
Tools tested in first Japanese pilot

DLT	Operation	TPS[a]	Theoretical TPS Scalability[b]	Execution Time (In Seconds)[c]
Ethereum	Blocks	13.1	16	
Iota	Tangle	108.0	18,000	
AIngle	Semantic DAG[d]	1,240.0	10,800	

[a]Transactions Per Second.
[b]Ethereum Scalability taken from WP (https://ethereum.org/en/whitepaper/#scalability).
[c]Time elapsed between sending and receiving data
[d]A Semantic Directed Acyclic Graph (Similar to the Tangle, but with a distributed graph database).

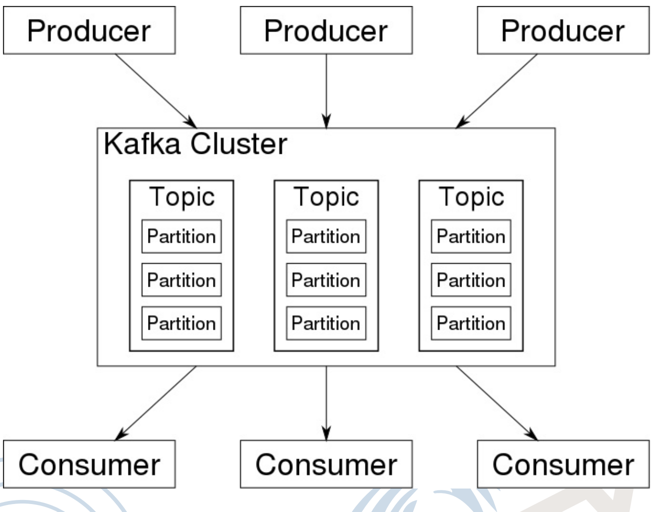
with practical use. Thus, after successful completion of the first pilot evaluation targets, the second pilot will focus on evaluating whether AIngle is also able to meet a series of stringent requirements for security, data privacy regulations, trustworthiness, and resilience through decentralized smart applications. As the results of the experiments described below prove, AIngle is capable of meeting the above series of requirements. The evaluations below show that by the end of the Japanese pilot, the AIngle met speed and reliability tests.

Important Pilot Considerations

Before introducing the evaluation results of the first Japanese pilot for FASTER, it is important to point out a few key points to highlight the significance of the results.

First, as Figure 1 illustrates, AIngle sits at the edge layer of the FASTER architecture. What this means is that all technological components employed by first responders within the FASTER umbrella could be connected to other layers through AIngle. In reality and for practical reasons, the FASTER architecture currently uses Apache Kafka (Kreps et al., 2011) as a messaging platform to provide a one-stop interconnection at the edge layer. Although this is a fairly common approach for interconnecting various systems with minimal integration costs and effort, it is also a fairly insecure approach as it depends on a centralized architecture. As depicted in Figure 4, the Kafka architecture consists of a cluster of segmented services called Topics. A topic can be loosely defined as a channel to which so-called producers can write and so-called consumers can read data. Partitions can be loosely interpreted as sub-services that provide granular functionality. In the context of FASTER, a technological component that, for example, sends sensor data can be considered a producer. Consumers can be any technological component that reads or consumes those services. To illustrate, a producer could be a drone that is pushing its GPS location while generating a 2D map of the affected area. The consumer could be the CoP that is reading the GPS position to display it in real time at the CoP. The same data could be also consumed by the service that stitches together the images being produced by the drone. This service then produces the final 2D map and publishes it to Kafka, and the CoP, in turn, consumes the 2D map to superimpose it on the CoP interface.

Figure 4
Apache Kafka overview



In the first pilot, for practical reasons, it was necessary to create a Kafka broker that acts as a go-between between AIngle and Kafka to measure the speed and reliability of AIngle. In the second pilot, the broker will only play a secondary role, as FASTER components will communicate directly with AIngle. This will enable us to test other aspects of the AIngle framework such as data anonymization and end-to-end encryption, which is currently not provided by Kafka.

Another important consideration, which is necessary to understand the scope of the AIngle evaluation during the first pilot, is that AIngle basically has two kinds of nodes: Light nodes and perma-nodes. A light node, as the name implies, is a node that stores very small amounts of hashed data in the form of Merkle trees for the Semantic DAG. This information is what is relevant to the light node. A perma-node is a node that stores larger amounts of data relevant to a network or subnetwork of nodes that use it as a storage bin. In the pilot evaluation, it was necessary to use a single perma-node because of the temporary limitations introduced by the Kafka broker approach. Thus all of the AIngle network and its Semantic DAG are stored there.

Because the Kafka broker is directly connected to a so-called AIngle perma-node—a full node capable of producing, consuming, and, more importantly, storing the data—we can observe a very interesting phenomenon. Figure 5 illustrates the topological shape of the Semantic DAG resembling a worm. This, of course, is due to the fact that there is only one perma-node. In order to achieve the full potential of AIngle, all IoT devices and other FASTER components need to incorporate an AIngle light node to be able to interact with more than one perma-node depending on the resources available to other components in their immediate vicinity. In this case, we expect the topology of AIngle to transition to the topology depicted in Figure 6.

Figure 5
The shape of Semantic DAG created during the first Japanese Pilot

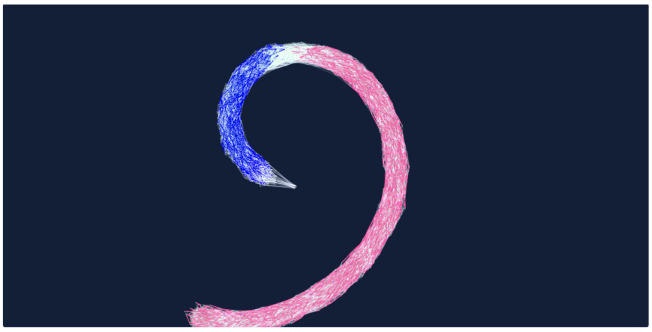


Figure 6
The expected shape of Semantic DAG during the second Japanese Pilot

With these considerations in mind, let's now describe the positive results obtained from the pilot evaluation in the following section.

Evaluation Results

On the day of the pilot evaluation, AIngle was able to provide data writing and reading service to a total of 105 topics; 49 of which were topics generated by the FASTER technical components connected through Kafka to AIngle, while the remaining 56 were internal support topics produced by the AIngle to Kafka broker. There were also 317 Kafka partitions generated and the same number of Kafka partition replicas, indicating that there was a one-to-one relation with the partition. This can be interpreted as an indicator of the stability of write-read roundtrip transactions. If the numbers were different, this would represent compensation for data loss, none of which occurred during the day of the evaluation.

It is important to note that the pilot tried to simulate a very realistic disaster scenario. The site of the pilot sits in an area with inconsistent internet connectivity. The internet was available only through 4G connections and it was unreliable. The average temperature on the day of the pilot evaluation was around 34°C with about 70% relative humidity, which translates to a heat index of about 47°C. Some of the devices, such as PCs, smartphones, drones, HoloLens 2 AR glasses, etc., did not operate optimally and sometimes would stop working altogether, even after applying dry, quick cooling sprays to reduce the heat generated by these devices. Despite these harsh conditions, AIngle performed better than expected.

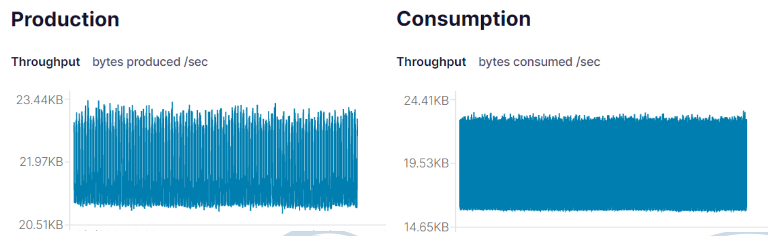
Reliability

Even under the very harsh conditions on the day of the evaluation, the results for data throughput were significantly positive as demonstrated in Figure 7. Production of data written to AIngle through Kafka occurred at an average of 21.31 Bytes/second, while the total data throughput was between 21 and 23.44 Kilobytes/second (see Figure 7a). Consumption of data occurred at an average of 22.94 Bytes/second for a total data throughput between 15 and 24 Kilobytes/second (see Figure 7b). These are averages per connection for the 105 topics generated and interacting with the AIngle framework, which means that the framework was very reliable and that despite the Internet connection was unreliable, the data was partitioned such that no data loss occurred.

Speed and Availability

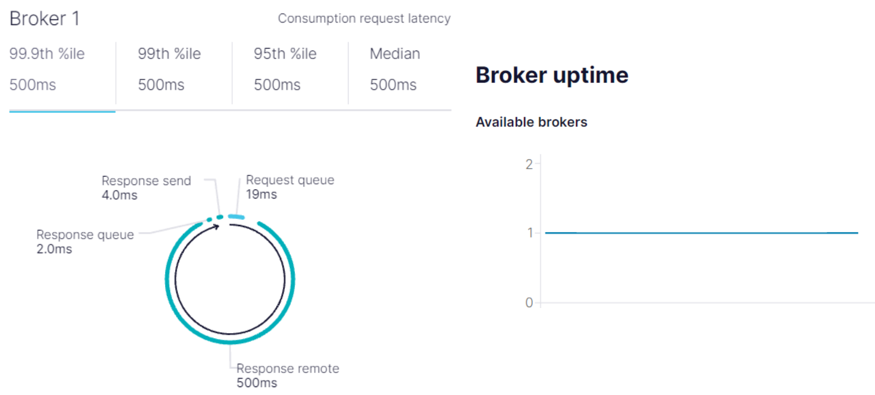
Figure 8, although a Kafka table, demonstrates that the AIngle framework also performed admirably with regard to read/write speeds. Figure 8a unequivocally shows that all the read/write transactions occurred within 25 milliseconds, which is the reason why 99.9% were within the 500-millisecond category in the figure. This exceeds expectations and validates AIngle as a first-of-a-kind DLT for IoT interconnections. On the other hand, Figure 8b demonstrates the Kafka broker, which writes to and reads

Figure 7
AIngle data throughput during the first Japan Pilot



a) Average throughput of 21.31 Bytes/second
b) Average throughput 22.94 Bytes/second

Figure 8
AIngle data latency and reliability during the first Japan Pilot



a) Average latency is about 25 milliseconds for processing requests and responses by AIngle

b) Even under very realistic conditions with very unreliable internet, a single broker was up 99.9% of the time

and two supervisors, who observed the pilot, responded to the questionnaire after the pilot. All questionnaires were answered in Japanese. An English translation was used for the analysis presented in this section.

It is worth mentioning that the questionnaire was focused on subjective evaluation of the FASTER tools provided by the European partners and did not include any question about AIngle, as AIngle is transparent to the first responders. Responses focused on subjective end-user experiences in using the FASTER tools provided by European partners, which included both hardware and software tools. For end-users, these two are treated as one. Therefore, the responses did not include AIngle functionality because of its transparency to the user experience.

from all the devices into AIngle, was available 100% of the time. Furthermore, Figure 9 depicts the total data throughput that occurred through the Kafka broker on the day of the pilot. In total, the amount of data was approximately 9.5 Gigabytes.

In conclusion, the data depicted in Figures 7 through 9 demonstrate the viability of the AIngle framework for real-time as well as mission-critical applications such as those required of FASTER tools by disaster first responders.

First Responder Questionnaire Evaluation

The organizing team distributed the Japanese-translated version of the uniformed questionnaire developed by FASTER to evaluate usability by first responders. In the case of the first Japanese pilot, first responders included five firefighters, two K9 units and 2 handlers, one drone operator, and one venue manager. Only five firefighters

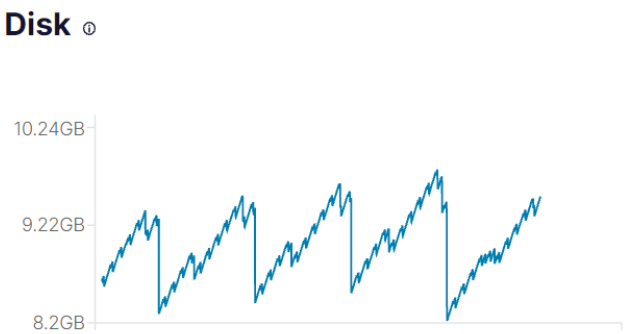
Figure 10 shows the number of respondents according to each tool. All the respondents evaluated MORSE and AR tools for operational support. Four firefighters evaluated UxV gesture control, three firefighters evaluated the 2D mapping, and one firefighter evaluated the CoP.

Questionnaire Evaluation

Analysis of the questionnaire indicates the following important points per tool:

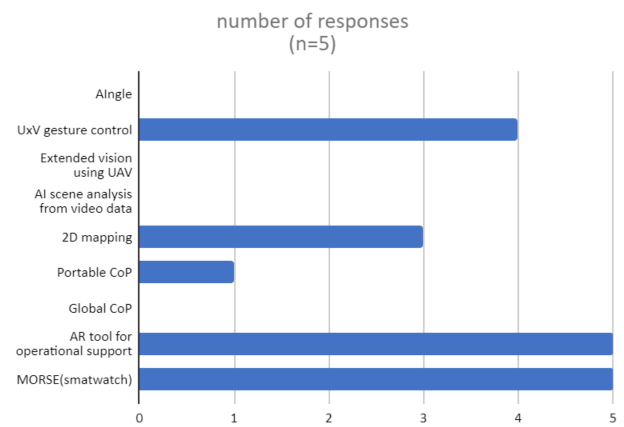
MORSE: The firefighters highly praised MORSE's accuracy and transmission, compared with the radio. On the other hand, they mentioned the dysfunction of signals, as MORSE mistakenly recognized even small body movements as gestures. Also, some firefighters mentioned the difficulty of complex operations.

Figure 9
AIngle data latency and reliability during the first Japan Pilot



Total Data Consumption data throughput was 9.5GB with no data loss, during the day of the first Japanese pilot evaluation even with a very unreliable internet connection due to the remoteness of the pilot site.

Figure 10
Number of responses to the first responders' questionnaire by tool



AR Operational Support: The firefighters highly praised the accuracy and the usability of the visualized information. On the other hand, all the firefighters who participated in the pilot mentioned the vulnerability of the AR glasses to heat. Also, they mentioned the difficulty of complex operations as they expressed trepidation when using AR glasses in the debris field for fear of damaging the equipment while searching for survivors.

Common Operational Picture (CoP): The firefighter who participated in the CoP operation expressed satisfaction with the centralized situational awareness provided by the tool. On the other hand, one firefighter who did not operate the CoP was skeptical of a centralized CoP. It should be noted that other firefighters who did not operate the CoP had conflicting opinions regarding the use of the CoP at the rescue site.

2D Mapping: One firefighter expressed satisfaction with 2D mapping of the disaster site, and mentioned that he had seen some other institutions using similar systems effectively to gain a better understanding of the disaster area.

UxV gesture control: One firefighter, who used this tool, suggested that hand gesture drone control was extremely satisfactory. This firefighter went as far as to say that of all the tools evaluated on the day of the pilot, it was perhaps the only one tool that could be used as is, with minor improvements in real rescue operations. On the other hand, one firefighter, who did not use the tool, expressed skepticism about using gestures to control a drone at the disaster area.

Overall: Here are three main points summarizing the overall comments from firefighters about the FASTER tools evaluated during the pilot.

Firstly, more effort should be invested in simplified usability of the tools. Although the organizing team had two training sessions for firefighters beforehand and provided the training materials as handouts and posters on site, the firefighters did not feel fully prepared to use the tools during the day of the pilot.

Secondly, it was suggested that the hardware should be more stable and durable to operate under harsh, rugged conditions of real disaster area conditions, such as heat, dust, smoke, rain and other natural phenomena. In particular, during the day of the pilot the temperatures reached 34°C with 70% relative humidity. Under these conditions, which equate to a 47°C heat index, hardware often malfunctioned. Although some measures to reduce the impact of heat, such as applying dry quick-cooling sprays directly onto the devices, helped, the constant heat made it impractical to use the devices for extended periods of time.

Thirdly, the electronic communication environment should be improved. Because real disaster situations are less likely to have good network connectivity, the researcher should provide a feasible solution for the provision of electronic network connectivity quickly on-site. Although this did not affect the usability of AIngle as demonstrated in this paper, it did have a negative impact on the use of some of the tools, which would lose connection to the network sporadically.

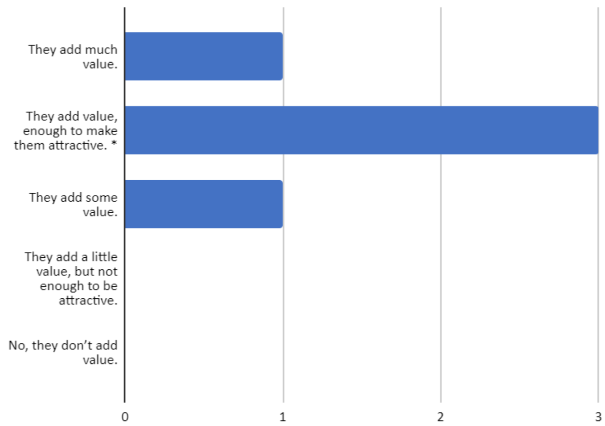
Finally, it is important to note that all respondents praised the potential of FASTER tools for future use in real disaster response. Considering the question *do you think FASTER tools bring added value to your work?,* one respondent out of five responded *They add much value*. Three out of five responded *They add value enough to make them attractive*, although one of three added a note *I hope it will add value in the future*. Finally, one responded *They add some value* (See Figure 11).

Having that said, some respondents expressed important criticisms. For instance, one respondent suggested:

> *Because all the tools are not usable as is, my response to this questionnaire would be negative at present, but if the main issues can be cleared, these tools would be attractive in the future... Regarding the idea to manage the information from each tool on a single PC (via the CoP), I think that we do not need to have it in usual Japanese disaster situations.*

Aside from the above response, some other respondents also used the word *future* in their responses, which connotes that the FASTER tools are still in work-in-

Figure 11
Responses to question Do you think FASTER tools bring added value to your work?



progress and have room for improvement before their actual use.

Conclusion

Overall, we can conclude that the Japanese pilot successfully demonstrated the viability of the AIngle framework in terms of speed and reliability, which are very important requirements for any real-time, mission-critical interconnection framework to support first responders in life-or-death situations. One future goal for AIngle is its ability to create a distributed smart application capable of providing real-time anonymization of private data being produced and consumed through AIngle (for example, masking the faces of people included in images or video produced and consumed through the AIngle framework). Another remaining future goal is the robustness of the encryption provided by the Merkle hash trees used in AIngle. To accomplish these two goals, a follow-up evaluation experiments will interconnect more devices than the Japanese pilot described in this paper. But rather than using a broker for Kafka, all devices will incorporate a lightweight AIngle plug-in that will enable those devices to become active nodes of the AIngle Semantic DAG. Moreover, instead of just producing or consuming data directly from AIngle, the devices will also support the smart applications that will provide the anonymization services needed to ensure privacy according to the strict privacy requirements of GDPR[3].

During the follow-up evaluation experiments, AIngle will not rely on a Kafka broker to communicate with the FASTER toolbox. Thus, it will be possible to evaluate the security of the AIngle framework through standard penetration testing techniques. The authors are confident that as the framework is theoretically quantum-safe, the evaluation will demonstrate that it meets the high standards for security required in mission-critical applications. As for other FASTER tools—provided by European partners—evaluated during the pilot, it is important to pay attention to the impressions provided by first responders, as described in the *First responder questionnaire evaluation* section. Certainly, the valuable feedback provided by Japanese first responders will help improve the usability and user experience of these tools.

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Research Update – Using SARA app and video feedback for dispatchers to improve the out-of-hospital cardiac arrest handling

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URL: http://trauma.massey.ac.nz/issues/2022-IS/AJDTS_26_IS_Morand.pdf

Abstract

Survival of out-of-hospital cardiac arrest (OHCA) is significantly improved by using an external defibrillator and performing cardiopulmonary resuscitation within the first minutes of the arrest (Perkins, Handley, et al., 2015). Dedicated mobile applications enable any bystander of an emergency to report it or to be called to perform first aid on victims (Ciravegna et al., 2016; Garcia et al., 2015). This paper presents the SARA app, which allows call centres to guide the person calling to enact first aid gestures through video. However, even if rescue community recognize the primary role played by citizens in emergencies by the rescue community, barriers still exist to an optimal collaboration. Citizens expressed a fear of hurting the victim and the health professional are reluctant to rely on non-expert. We also have to measure the usability of the app and evaluate the pertinence of video guidance.

Keywords: *Cardiac arrest, apps, community engagement, collaboration, Living-Lab*

On July 3, 2020, a new legislation was published in France aiming to create the status of citizen rescuer, to fight cardiac arrest and to raise awareness of life-saving gestures. The status of citizen rescuer is defined as follows: "Anyone who provides voluntary assistance to a person in an apparent situation of serious and imminent danger is a citizen rescuer and benefits from the quality of occasional collaborator of the public service" (Legifrance, 2020, p.14). The law stipulates, "The citizen rescuer performs, until the arrival of the emergency services, the first aid gestures by, if necessary, the implementation of chest compressions, associated or not with the use of an automated external defibrillator". It is also specified "When a prejudice results from their intervention, the citizen rescuer is exonerated from any civil responsibility, except in case of heavy or intentional fault on their part". The following headings emphasize the necessity to reinforce emergency training and to clarify the appropriate organizations to provide this training. The enactment of this law reflects the ongoing concern about a major public health issue: out-of-hospital cardiac arrest survival. This concern is shared by rescue professionals who are trying to provide technological and organizational responses, like the numerous regional initiatives that can be witnessed at professional events. It is also the concern of other more distant partners, companies, IT developers, and applications designers, who are putting their skills into this cause and designing new applications, intended to respond to emergencies with more efficiency. Among others, we can mention the "tech and rescue" events launched by an association of firefighters since 2019 which gives the opportunity to Departmental Fire and Rescue Services (SDIS) and promoters of technological solutions to present at a national level some local technological solutions, field-tested, aiming at improving the conditions of emergency handling.

Thus, there is national and public health interest in improving the management of cardiac arrest, combined with the emergence of technology solutions from collaboration between developers and first responders. In this context, we present a dedicated mobile app, SARA, developed and implemented by a first responder. Our research aims to analyze the conditions and limitations related to the use of SARA and ultimately its effect on cardiac arrest management improvement. First, the current state of the art on the necessity of rapid management of cardiac arrest will be presented, followed by a review of the obstacles associated with the management of cardiac arrest by non-expert citizens, and finally the technological solutions available to address the cardiac arrest issue. The second section of the paper presents the SARA application, its main specifications and its innovative features. Finally, there will be a discussion regarding the restrictions we have identified on the application's use (usability, mistrust of professionals towards citizens, citizens' fear of wrongdoing) and how to address them.

State Of The Art

The need for rapid intervention on cardiac arrest

Out-of-hospital cardiac arrest is still currently an important cause of death. The survival rate of patients in Europe and the United States varies between 7 and 10% according to studies (Gräsner et al., 2020; Rumsfeld et al., 2016; Berdowski et al., 2010). Two factors increase the survival rate: cardiopulmonary resuscitation (CPR) and the use of an external defibrillator (AED) (Perkins, Handley, et al., 2015). The time of action is particularly decisive as the probability of survival decreases within minutes spent without CPR (Herlitz, Svensson, et al., 2005; Herlitz, Engdahl, et al., 2005; Capucci et al., 2002). However, only 32% of cardiac arrest victims receive CPR from bystanders and 2% receive defibrillation (Weisfeldt et al., 2011). In this context, the question of increasing the chances of survival by actively involving bystanders in providing cardiac massage is central.

Engaging untrained citizens

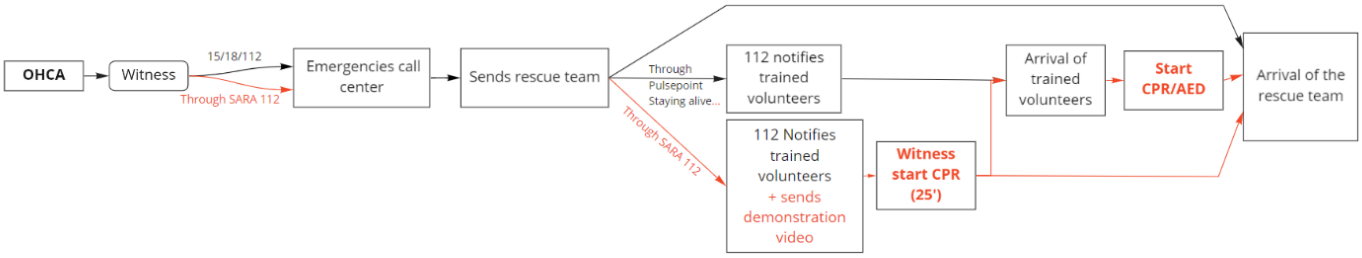
While the participation of bystanders is recognized as an essential factor in the survival chain, they are considered as the first actor in the rescue chain when dealing with a cardiac arrest, there are nevertheless impediments on the professionals and citizens side (Reuter et al., 2013). According to studies, untrained volunteers appear to some first responders to be more of a burden than a help (Scanlon et al., 2014). The issue is a lack of prior experience (Bird et al., 2020) and knowledge (McLennan et al., 2016). Indeed, in France, the rate of people trained in first aid is quite low, less than 20% according to the Ministry of Health's March 26, 2018 release . In contrast, in Switzerland, all licensed drivers have undergone mandatory training in first aid. As a matter of fact, the fear of performing CPR incorrectly is a major barrier for the citizen (Bouland et al., 2017; Kanstad et al., 2011; Dami et al., 2010), even when the population is widely trained like in Switzerland, where Basic Life Support course are mandatory to obtain a driving license (Regard et al., 2020). Some authors mention a lack of communication between both communities, which leads to misunderstandings and frustrations on both sides when the urgency of the situation requires quick and efficient communication (Reuter et al., 2016). Yet, collaboration between stakeholders in the response to crises or emergency situations is crucial (Kropczynski et al., 2018).

Mobile applications as a resource for first responders

Among the solutions provided by professionals themselves and the network of innovative actors in the world of civil protection in Europe, mobile applications have become part of the current panel of tools. One solution is to increase the number of trained volunteers available to respond to the situation. In this perspective, the use of mobile applications to call trained citizens seems to be efficient. Several international guidelines have already included this approach in their recommendations (Kronick et al., 2015; Perkins, Travers, et al., 2015; Rumsfeld et al., 2016). A review of various mobile apps conducted on Google Play, identifies 250 emergency-related apps (Gómez et al., 2013). 50.8% of the applications[1] concern a request for help related to a health problem (iSOS for example) followed by applications providing instructions to solve a certain emergency (42.4%) then 23.2% relate to a police help demand (Emergency Panic Button, SOSbeacon, Mayday Emergency Lite). Furthermore, the final user of the application is for 59% the victim, the professional rescue team (14%), volunteer rescuers (14%), witnesses (7%) and finally general public (6%). Most applications require access to 3 elements, location (81.2%), connection (bluetooth, internet access) and the use of communication tools (SMS, calls). The authors note that few applications focus on the potential of bystanders as witnesses or volunteers. They conclude their paper by expressing the necessity of an innovative application for 911/112 that could connect citizens and emergency control centres. Indeed, various mobile applications have been developed to notify first aid trained volunteers in the surroundings of an emergency. For cardiac arrests handling, we can mention Pulsepoint (Brooks et al., 2016), Save-a-life and Staying alive (Derkenne et al., 2020). The latter has enabled to increase the survival rate of victims from 16% to 35% thanks to a faster intervention (the first helpers notified are within a maximum radius of 500m from the victim). Therefore, it seems relevant to attempt to initiate CPR by the people closest to the victim. In fact, some developers have chosen to create applications where not only people trained in first aid are considered as potential rescuers, but any citizen

1 A given application can belong to one or more identified groups.

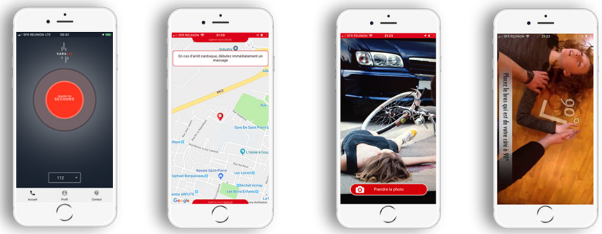
Figure 1.
Segments of actions in emergencies related apps



present at the time of the emergency such as SARA, the application described in this retsearch (Ciravegna et al., 2016; Garcia et al., 2015; Mazumdar et al., 2015; Díaz et al., 2013).

As can be seen in Figure 1, SARA allows an intervention in a currently unexploited segment. The bystander can call the emergency services via the emergency numbers or via SARA. The emergency services can dispatch a rescue team, activate an application with trained citizens who will arrive before the emergency services and send a demonstration video via SARA in order to initiate the cardiac massage with the bystander.

Figure 2.
SARA app



The Sara Application

Product description

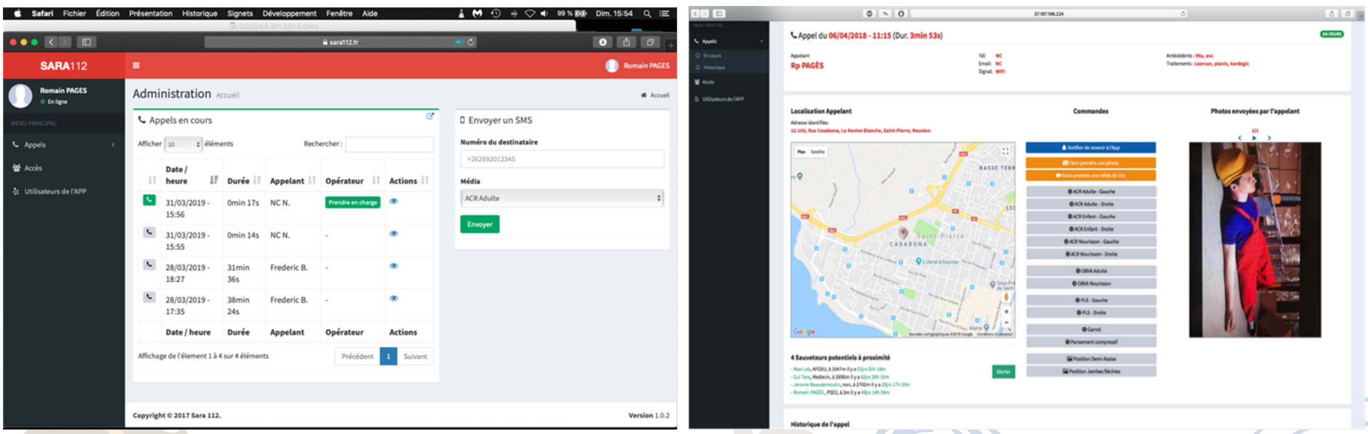
SARA is an application developed since 2017. The prototype version is currently available on iPhone and Android, on a prototype version and is not implemented in any dispatch call centre. It allows any citizen witnessing an emergency to connect with a regulation centre by calling 112 or any emergencies number. While remaining on the caller's line, the dispatcher can then:

- Identify the caller and know his medical history and treatments.
- Geo-locate the person.
- Ask the caller to take photos or videos of the emergency.
- Call for reinforcements from first aid certified personnel in the area.
- Trigger the video of the emergency actions to perform (e.g. cardiac massage).

Two elements are required for SARA to be functional. The application must be downloaded on the citizen's mobile (Figure 2), and the back office must be installed in the call centre to receive and control the application (Figure 3).

SARA is also a platform that offers 3 distinct solutions:

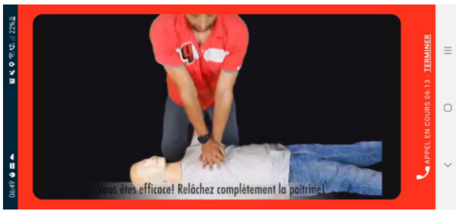
Figure 3.
SARA Back-office



- **SARA General public**; this solution includes all the features described above. It can be used by any person trained or not in first aid and by any emergency services (EMS, fire brigade). The objective is to propose a solution for everyone with a strong impact on the survival rate of victims and regarding the cardiac arrest response.
- **SARA Event**; This solution is based on the technological foundation of the general public version. It is intended for event organizers (trail, Olympic Games, festival, etc.). It allows a call to a dedicated number chosen by the organization. This app considers all the emergency teams in the field, by providing them with a dedicated mobile application that integrates the tools necessary for the optimal management of a victim (an assessment form, for example). The integration of connected objects (blood pressure meter, oximeter...) allows an implementation of the data. The transfer of the assessment to the referring medical service is also faster.
- **SARA Enterprise**: for SMEs, it allows in addition to the general public version, to alert (SMS, notification, email), a first-aid worker of the company as soon as the call to the emergency services is initiated. The App allows the simultaneous transmission of a potential work accident to the company's dedicated back-office. The system also enables the integration of a company or site map and the addition of data (access points, defibrillators, specific risks, etc.).

We will develop furthermore two innovations implemented in SARA; the demonstration videos in the application which aims at an efficiency and a speed of intervention and the interaction between bystander and dispatcher in case of cardiac arrest.

Table 1.
Demonstration videos

	Audio messages	Duration	Illustration
Cardiac arrest (Adult)	*Instructions* If there is a defibrillator nearby, ask someone to get it. Place the victim's arm at a 90° angle. Position yourself astride the victim as shown in the video. Place your hands on top of each other between the two breasts. Keep your arms straight and press as hard as you can. Follow the rhythm. Press with the heel of your hand. *Incentives* You are effective, relax the chest completely. You are doing very well, help is on the way, keep going. Good job, keep up the pace. Don't stop massaging.	24" seconds before starting CPR. 2'30 loop on cardiac massage	
Total Airway Obstruction (Infant)	*Instructions* Check the child's mouth and remove any foreign objects. If possible, sit and hold the infant as shown in the picture. Place the infant flat on your arm, resting on your leg. With the heel of your hand, tap vigorously up to 5 times. Turn the infant over and check that the mouth is empty. Place 2 fingers in the middle of the chest between the two breasts, on the line of the 2 nipples. Compress the breast and repeat 5 times maximum. Repeat the manipulation.	41" loop	
Lateral Safety Position	*Instructions* If necessary, remove the victim's glasses. Place the arm that is on your side at 90°. Grab his other arm and press it against his cheek. Raise the opposite knee, press it down to turn the victim. Gently remove your hand from the victim's face. Place his knee at 90°. Open the victim's mouth with one finger. Watch the victim.	48"	
Pressure bandage	*Instructions* Take a cloth, t-shirt, scarf or other fabric. Fold the cloth to fit the size of the wound. Place it directly over the wound to cover it. Compress the wound firmly. The other hand wraps the cloth around the limb. Tie a tight knot, preferably over the wound. Tie a second stopper knot to prevent the dressing from coming undone. Monitor the victim's condition, and if anything changes, call for help.	44"	

Demonstration Videos

When a citizen calls via the SARA application, the dispatcher can assess the situation and decide to send him a demonstration video to be viewed on his smartphone to assist him in the emergency gestures. The video is then displayed on the user's screen while the audio instructions are played over the call. The Table 1 shows the different videos with duration and instruction.

Overall, there are eight videos. Three on cardiac resuscitation (adult, child, infant) lasting 2 minutes 30 seconds in a loop after a start of resuscitation at 24 seconds for the adult, 2 minutes in a loop for the child after a start of resuscitation at 24 seconds and insufflations every 20 seconds and 1 minute in a loop for the infant after a start of resuscitation at 18 seconds and insufflations every 15 seconds. There are two 40 seconds loop videos on total airway obstruction (adult and infant) with demonstration of two techniques; back bow and Heimleich maneuver for the adult and back bow and chest compressions for the infant. There is also a 48 seconds video on the lateral safety position, a video on applying a garrot (1 minute 40 seconds) and a video on pressure bandaging (44 seconds). We can note that only the resuscitation videos include supportive messages such as "Help is on the way. That's very good, keep going, don't stop". The dispatcher can also display two pictures, the semi-seated position and the bent leg position.

Users' journey for cardiac arrest

As we can see in Figure 4, the interaction originates from the discovery by a bystander of a cardiac arrest victim. He must take his smartphone, open the SARA application, and then press "call for help", the application will open the call application with the number 112, 18, 15 ready to call. On the back-office side, the dispatcher operator receives a call request and takes it. This gives him access to the location, the information's, and the type of connection (Wi-Fi or data) of the caller – allowing to adapt the quality of the videos. The caller will then describe the situation and the operator may request to take a picture to understand the situation. The command will then be displayed directly on the caller's screen "take a picture". The dispatcher can then send a video demonstration of the cardiac massage that will be displayed on the screen of the Smartphone while the instructions are given through the audio. The bystander start CPR after watching 25 seconds of the demonstration video and continues until the arrival of the rescue team.

Concerns To Address Regarding The Use Of Sara

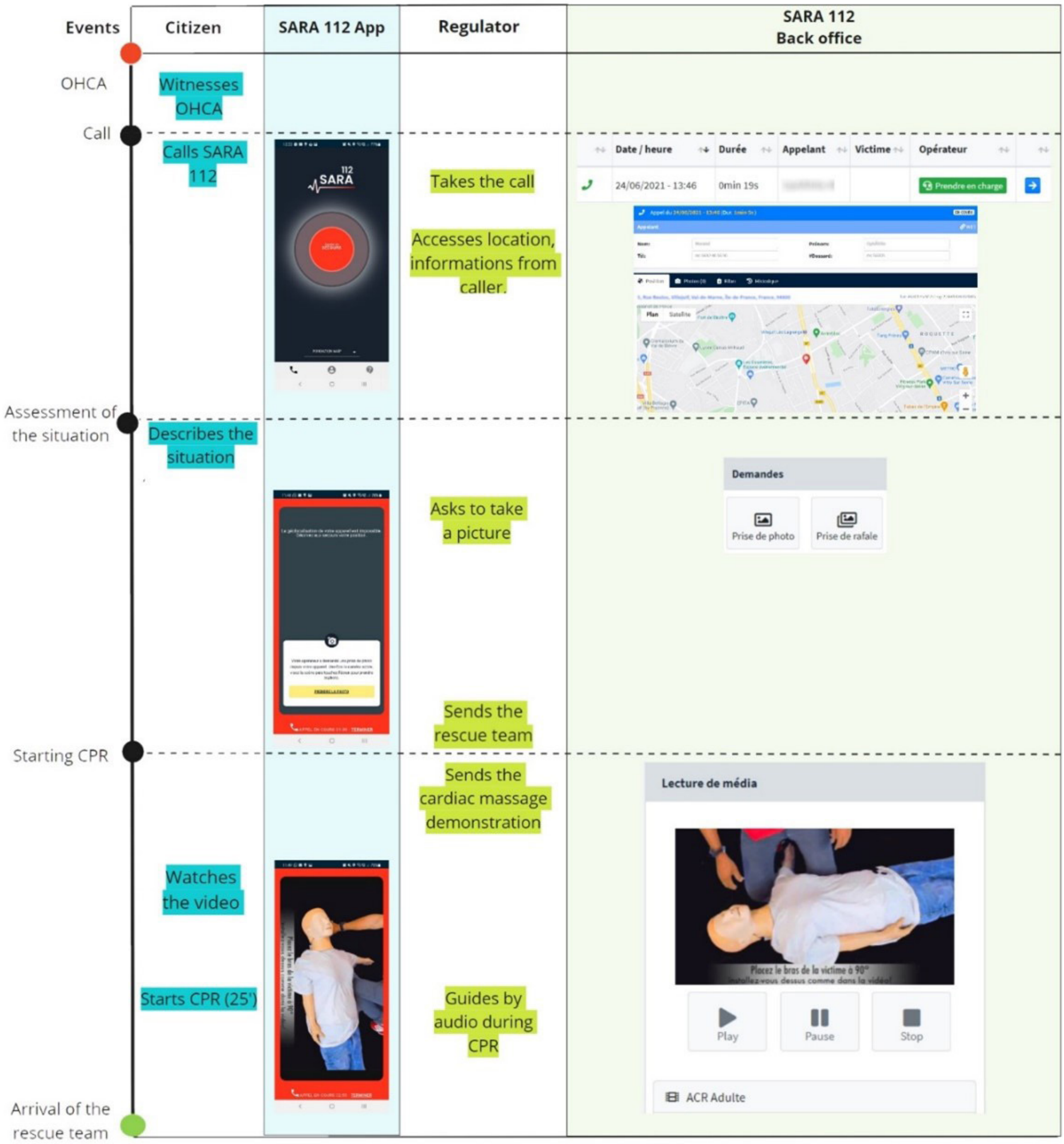
Collaboration between citizens and first responders

As discussed in our state of the art, one of the first concerns about SARA is the non-expert status of the citizens. We are facing the same problems as those mentioned in the literature: lack of trust of professionals towards non-expert citizens due to their lack of knowledge of rescue procedures and gestures, and fear of acting for citizens. The literature argues that mediated interaction through an application for example, has the consequence of deteriorating the quality of communication which can lead to a decline in trust between different parties (Riegelsberger, 2005). Nevertheless, the contribution of an application that allows several forms of communication; audio, photo, video can enrich the interaction and provide "evidence to build trust" can be beneficial. Effective communication and collaboration come from pre-established trust between the parties (Foulquier & Caron, 2010). During the handling of an emergency, the usual parameters for building trust are altered; time pressure does not allow trust to be built over a long period of time (Tehrani, 2020), it requires communities and individuals to collaborate when they usually don't work together (Boin, 2009). These observations can be the biggest obstacles to an efficient collaboration; therefore, we think that establishing a setting where the discussion and the sharing of a common experience based on the application can be a lever for further collaboration.

Video guidance in emergency situations

A major innovation of SARA is the possibility to trigger videos to help the bystander to perform the appropriate first aid procedures. A study has been conducted to assess the video guidance effectiveness compared to audio guidance in providing CPR by non-expert (Lesaffre, 2014). The study consisted of a simulation using an inanimate person (mannequin) for which the participants had to perform CPR. There were two groups; a group making a simple call for emergency assistance (control group) and a group watching the tutorial video prepared for the occasion after calling for emergency assistance. The findings indicate that participants of the video group carry out on average more compression than did the audio group. The time to start CPR is longer for video guidance but once started, there are less interruptions in compressions. The mannequin sensor showed a difference in favor of the video group with 96.5% of compressions well positioned 95.9% compared to the

Figure 4.
Example of users' journey with SARA in case of cardiac arrest



audio group ($p < 0.05$). This data suggests that cardiac arrest bystanders can be guided by video on a cell phone without compromising the quality of cardiac massage and may even improve it. Some parameters can be enhanced such as frequency, number and duration of interruptions, hand position, total number of compressions and proportion of effective compressions. However, there was no significant difference between the video group and the audio group on the primary endpoint: the number of effective compressions in six minutes. This finding should be moderated since other studies have shown that viewing tutorial videos do increase the quality of assistance provided by non-experts (Stipulante et al., 2016; Bobrow et al., 2011; Yang et al., 2008, 2009; Johnsen & Bolle, 2008).

The application is also being tested in the Geneva hospital (HUG). The test continues the investigation of the efficiency of video assistance compared to audio guidance in case of an emergency. The results will be the subject of a medical thesis. The first feedbacks are positive regarding the quality of the gestures performed, the physician associated with the project specifies " I was able to see at the level of compression rate and depth that the people guided by video were clearly better. They took a little longer to start CPR, but the quality was incomparable". Although studies have shown the effectiveness of using videos for guidance, the results published (Lesaffre, 2014) do not show significant results in terms of compression numbers. In addition, other demonstration videos (total airway obstruction, compression bandage, lateral safety position) are available and their effectiveness has not been evaluated. In case of chocking, the first minutes are crucial as is it is for out of hospital cardiac arrest. Case reports showed success in relieving Foreign Body Airway Obstruction (FBAO) with back blows, abdominal thrusts and chest thrusts (International Liaison Committee on Resuscitation, 2005). The recommendation adds that more than one technique is often needed to success. The demonstration video shows 2 techniques: back blows and abdominal trusts under 1 minute that can be performed simultaneously with the viewing of the video. It would therefore be interesting to evaluate whether these videos help bystanders perform maneuvers faster or more efficiently. The application also allows the dispatcher to access the camera of the citizen present at the scene. So far, no study has been done to evaluate the possibilities of this implementation from the point of view of the dispatcher. If the aim is to create collaboration between the citizen and the dispatcher, it would be interesting to highlight the benefits that the operators can obtain themselves. We think for example of the evaluation of a stroke. Stroke has been classified as the second most important cause of death in the world, with an estimated annual death rate of 5.5 million and 50% of the survivors have chronic residual disabilities (Lopez et al., 2006). One of the causes of delay in stroke management is the lack of recognition of early warning signs in the general population (Donkor, 2018). Indeed, studies show that less than 50% of people know the risk factors and recognize the warning signs of stroke (Cossi et al., 2012; Hickey et al., 2009; Yoon et al., 2001). Consequently, it might be beneficial for an expert not present on the scene to be able to assess the situation remotely and take action at the earliest stage possible.

Usability of the application

One other point to consider is the usability of the interface. Usability is defined as follows: 'The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use' (International Organization for Standardization, 2018). If the application is not perceived as "usable" by users then chances are it will be abandoned as are 1/4 of the applications on the market (Tan et al., 2018). Usability is linked to 6 factors (Hoehle & Venkatesh, 2015); app design, app utility, user interface graphics, UI input (the degree to which users perceive that app allows easy input for users), UI output (the degree to which users perceive the app displays information effectively) and UI structure (degree to which users perceive the app is structured well). These factors are associated with "continuance intention," the willingness to persist in using the application after the first experience (Tarute et al., 2017; Hoehle & Venkatesh, 2015) or intention of use (Venkatesh et al., 2003; Venkatesh & Bala, 2013). A study on disaster apps shows that the utility of the application is the first determinant of usage followed by UI output, which must be particularly easy to understand in critical and stressful situations (Tan et al., 2018). The United Nations Office for Diaster Risk Reduction insist on the fact that it is imperative to improve the usability of such services providing information in a clear and concise way (Mentler et al., 2017). Moreover, the study shows that UI input and UI graphic have a negative effect on the intention of use. Therefore, the authors recommend the simplest and most sober interface possible. To achieve acceptance of SARA by the public and by emergency responders, we have to evaluate its usability with the aim of implementing appropriate modifications if needed.

Data collection and privacy

The collection and responsibility of the data collected by the app may also become an issue. Indeed, the user is providing the application personal data about himself: his medical history and his location (McCarthy, 2013). SARA is a private application and therefore must comply with the personal data processing regulations according to the law General Data Protection Regulation (2018). The law does however provide for an exemption from confidentiality within the context of vital emergencies treatments. It is therefore necessary to determine at which category the application belongs to, considering the range of interventions that it addresses.

Further Development Of The Project

To address the issue of the usability itself, a questionnaire will be used. It was built from items developed in the UTAUT 2 (Unified Theory Of Acceptance and Use of Technology, (Venkatesh et al., 2012) along with items from the User Experience model (Hassenzahl, 2007) and validated (Martin, 2018). It allows evaluating a technology before and after use on 6 dimensions influencing the intention to use.

The others concerns mentioned in the previous section led us to seek a methodology that would allow us to test and evaluate the functionalities of SARA while bringing together all stakeholders. Conducting tests in real-life situations seems rather difficult, first because by doing so we could disturb practitioners and compromise their actual work (Leitner et al., 2007). It can also raise concerns about the user and researcher safety. On the opposite, a laboratory experimentation seems to be overly distant from reality since all variables are under control and there isn't any possibility of uncertainty (Mentler et al., 2017). Some variables cannot be replicated in the laboratory (stress, for example). Therefore, several authors suggest using simulations or future use scenarios to reproduce emergency situations (Gerhold et al., 2020; Mentler et al., 2017) which enable experimentation in a semi-realistic context (Gerhold et al., 2020; Borglund & Öberg, 2014; Yao et al., 2010). Scenarios can preserve the richness and complexity of a given situation and allow it to be experienced in an embodied way (Gerhold et al., 2020; Martin et al., 2017). Conducting simulated real-life experiences enables users to manipulate and gain a sense of activity (Daniellou, 2004) and thus develop pertinent responses and knowledge for these situations. We also aim to develop collaboration between stakeholders in an environment that is conducive to collaboration. Simulation with usage scenario has been tested in Living-Labs in emergency field (Derkenne et al., 2020; Gerhold et al., 2020; Munkvold, 2016) and have shown benefits (knowledge transfer through the creation of a common discourse for example). This methodology has been defined as "physical regions or virtual realities in which stakeholders form public-private-people partnerships of firms, public agencies, universities, institutes, and users all collaborating for creation, prototyping, validating, and testing of new technologies, services, products, and systems in real-life contexts" (Leminen et al., 2012, p. 7). Stakeholders are invited to test the actual product. In this way, questions about the technologies, their benefits and potential negative effects arise and can be discussed at once while enabling all attendees to learn from each other (Gerhold et al., 2020).

Conclusion

The SARA application meets many needs; inclusion of citizens as an entry point in the emergency chain (Gómez et al., 2013), getting volunteers to perform cardiac massage (Weisfeldt et al., 2011) and potentially more effective guidance through demonstration videos (Lesaffre, 2014; Yao et al., 2010). Its use nevertheless raises many questions regarding the involvement of non-expert citizens, the improvement of collaboration between professionals and bystanders and the actual usability of the application. All these questions require answers if this application intends to be disseminated, as it appears quite promising to improve the chances of survival of cardiac arrest victims.

Acknowledgements

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Conflicts of Interest

The authors reported no potential conflict of interest.

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Adaptable socio-cyber physical systems for supporting disaster response

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Abstract

Effective disaster response highly depends on disaster types, scale, and attributes of disaster affected regions. Although deeply interconnected, social, cyber and physical aspects are usually not considered together when shaping an appropriate disaster response strategy. We introduce a conceptual framework in which disasters are socio-cyber-physical systems that codify attributes impacting effective responses. The framework enables rigorous analysis and evaluation of response plans by disaster managers. We inform our conceptual model through a range of disaster-response case studies and our personal disaster first-responder experiences.

Keywords: *disaster management, disaster response, socio-cyber physical system, situational awareness*

Disasters, either natural or man-made, are destructive events with disruption to infrastructure, and society. *Disaster management* is a catch-all phrase that includes all phases of a disaster: mitigation, preparedness, response and recovery (Lettieri et al., 2009). Indeed, the goal of mitigation and preparedness phases is to ensure a systematic response in the event of a disaster. In this paper, we outline a methodological approach to specifying a *socio-cyber-physical (SCP)* system which is designed to aid decision-making for specific operational activities within the disaster-affected region.

The recent significant increase in the frequency and severity of disasters (Madanian et al., 2020; Ogie & Pradhan, 2019) has been leading to an increase in research studies, investments in technology utilisation and improving disaster management systems, especially for the disaster response phase. To have a better response to the requirements and demands of disaster casualties, the use of technology is inevitable. Technology utilisation helps in improving overall disaster management, facilitating response when a disaster occurs, enhancing support after a disaster, and keeping records for better future preparedness. In order to accomplish this, different Information and Communication Technologies (ICT) can be utilised and integrated to enhance the overall response missions' effectiveness. This integration needs a systematic framework that is discussed by (Madanian et al., 2020) with the main aim of facilitating finding out where and in what way technologies can be practised and integrated within disaster management. Among all phases of disaster management, this research concentrated on disaster response, exclusively.

Disaster mitigation, preparedness and recovery possess a critical role in managing disasters. However, they have the convenience of longer time scales allowing for detailed plans. Contrasting these phases to the unpredictable nature of disasters, has necessitated an increased focus on disaster response. While disaster preparation and recovery are planned over longer timeframes, disaster response must be accurate and in real-time in order to save lives.

In disaster response every second counts which highlights the importance of leveraging the advancements in ICT. In this regard, ICT can play an important role in supporting disaster managers, and disaster response activities. Using different technologies assists disaster responders and managers by providing more real-time information about the disaster affected region, preparing more organised responses, and effectively and efficiently controlling and leading disaster response operations. This helps in minimizing the probability of further disturbance occurring, wasting of resources, delivering inappropriate services and amortization.

The current challenges in disaster response and resource distribution are covered in the following section. To address these challenges and to further support disaster managers and authorities, in this research, we propose a methodology based on socio-cyber physical systems which is integrated with system adaptability, and situational awareness concepts for supporting disaster response missions. These concepts are explained and discussed before their usage in disaster management are explained through a case-study in the subsequent section. The modelling of Disaster Management Life Cycle using this methodology is discussed in the final section of this paper.

Disaster Response and the Current Challenges

Large-scale disasters have increased in frequency and intensity over the past few decades and have wrought substantial damage to the livelihoods of populations across the globe (Ogie & Pradhan, 2019). This includes financial, psychological and social burdens on households (Leung). Based on the available literature, there is a long list of disaster response difficulties and challenges and by referring to disaster damage statistics, it can be concluded that this is not an area specific problem and affects both developed and underdeveloped nations alike (Biddison et al., 2018).

Response missions have always been negatively affected by factors such as disasters' unpredictability of location, time, number of injured people, and the severity and types of injuries (Latifi et al., 2007). This leads to further challenges often including accessing those most affected by the disaster, response prioritization, equitable distribution of resources and communication between stakeholders, in regional, national and international levels. These factors specifically affect search and rescue missions as well as providing health support for victims. From the recent catastrophes, it is evident that disaster management and medicine response activities have been far from perfect operations. Poor coordination and communication, information fragmentation, lack of preparedness, and frequent failures in sharing vital information among response agencies result in poor disaster management and responses, both within and between response agencies, which cause unnecessary loss of life (Madanian et al., 2020; Norris et al., 2015).

When disasters occur, there is a heightened need for immediate emergency response in order to save lives and minimize damages (Bürkle et al., 2012). To accomplish this emphasis should be placed on the allocation and distribution of resources to the affected areas. In this regard, disaster managers primarily consider plans coordinating personnel and first-responders to distribute scarce resources within the disaster-affected region. Resource allocation plans form the basis for disaster management, disaster medicine and more recently, disaster healthcare (Madanian et al., 2020).

For effective resource allocation, disaster management and planning should be placed in a holistic setting, and new initiatives are found in order to ensure that a disaster is viewed as a shared responsibility (Trim, 2004). Once the decision has been made as to what resources to allocate to affected areas, the next challenge lies in the distribution of those resources and in doing so posing many other strategical challenges. However, in volatile environments affected by disasters, this leads to extra challenges (Biddison et al., 2018; Chacko et al., 2014). These challenges are often centred around the information availability and their quality, and decision-making process between those managing the situation on the ground and how command chains are formed.

It is also known that gaining access to resources in post-disaster settings can be extremely challenging (Biddison et al., 2018), especially in locating required resources and matching them with the level of demands. In resource allocations, many factors should be considered such as methods of resource allocation, the participants' organisation in rescue missions and their role, and the required types and amount of resources based on individual and community needs. However, the availability of infrastructure and accessibility to disaster-affected areas is required to deploy resources.

This resource allocation is a part of operation managers' responsibilities not just to manage the allocation of resources, but real-time managing the gap between available resources and resources necessary at the disaster-stricken locations (Gabdulkhakova et al., 2012). Additionally, the availability of resources is dynamic and constantly changing which creates logistical challenges for all the involved parties. Incoming information can also be unclear, obsolete and outdated, subjective and even contradictory further burdening the decision making of those in charge (Gabdulkhakova et al., 2012). Therefore, it is concluded that in any disaster response mission, having or collecting the right information, sharing them with the right responsible organization in a timely manner can significantly enhance disaster response, and resource distribution (Kuo et al., 2007). According to (Chacko et al., 2014) some of these could be mitigated utilizing different technologies. For example, social media and social media mining (Pohl et al., 2020) and their usage in emergency dispatch (Grace et al., 2019), different types of decision support systems for resource allocation (e.g. COVID-19 vaccine (Baharmand et al., 2021)), auto-identification technologies for resource management (Madanian & Parry, 2021), big data analytic (Ragini et al., 2018), or delay-tolerant network for gathering and disseminating resource needs (Basu et al., 2020).

Research Gap and Research Objectives

Despite all the recent technologies' enhancements, there are many risks and uncertainties when preparing for and responding to disasters. Many factors have to be taken into consideration and those factors are fluid and constantly chaining (Amendola, 2004). Both the occurrence and consequences of each disaster are quite difficult to anticipate. Following the occurrence of a disaster the uncertainty of each response holds inherent risks due to the precarity of the disturbed environment, the potential for continued impact of weather events and uncertainty of the affected population and volunteers on the ground (Liberatore et al., 2013). These risks exist for both the individuals (or victims) affected by the disaster as well as the first- responders, volunteers and field workers responding to it. Uncertainty affects the victims being responded to as it is often unclear if or when a responder will arrive. This can lead to fear and anxiety in addition to any physical ailments they are suffering as a result of the disaster. Also, for the responders the location of the victims is often unclear, as are hidden obstacles inhibiting their access and what resources are required when they arrive.

These issues have necessitated enhancements in disaster response and managing its supply chain. Although the number of studies in the area of technology and ICT utilisation for disaster response have been growing significantly, resiliency in the disaster supply chain should be improved. According to the National Academy of the Sciences (2020) resilience should be embedded in disaster supply chains and is crucial in maintaining the consistent delivery of goods and services to the affected populations.

The challenges associated with resource allocation could be mitigated utilizing strategic systems (Chacko et al., 2014) that can best determine interventions that provide the best possible outcome. This is the case for both single hazard events, but even more so for multi-hazard events which often stretch resources well beyond demand (Chacko et al., 2014). Utilization of strategic systems to assist in resource allocation has grown substantially over the past few decades and has seen a significant amount of growth and improvement. The use of spatial partitioning has been utilized in recent years in order to locate the best segmentation of an area for optimal resource allocation (Kolomvatsos et al., 2013). However, most of the available or proposed systems have been inflexible and constrained by capacity (Underwood, 2010).

Different field response works following disasters such as Hurricane Irma in Central Florida uncovered several response limitations concerning the use of cyber systems in disaster response. In our research, we are looking for the potential of technology and theory integration to optimize response activities and integrate the physical world to the digital using a self-adaptive system. The objective is the conceptualisation and re-developing disaster management and disasters as a socio-cyber physical system (SCPS) and software engineering theories such as self-adaptive systems and incorporating situational awareness concepts to further support disaster response missions. With this new angle into disasters and disaster management context, disasters can be viewed as a socio-cyber physical system, and its requirements can be viewed as system requirements that should be satisfied. In this concept, disaster affected regions and disaster preparedness can be represented by systems' configurations and system constraints that should satisfy the defined system requirements.

This new approach to disasters as SCPS helps us in developing self-adaptive systems, especially useful for disaster response. As SCP systems are dynamic (components can be changed), they are layers and can be managed in a way to maintain and meet the system requirements. For example, in pre-disaster phases, sufficient resources, based on the response strategy and plan, are allocated at every location in the region to satisfy resource demands. Finding a suitable allocation essentially corresponds to a constraints solving problem $\alpha \models K$, where resourcing demands are formalised as logical predicates K and an allocation is modelled by the satisfying assignment function α (Johnson et al., 2020). However, due to a disaster's inherently uncertain and unpredictable nature, disaster managers must assume that the scenario evolves: i.e., more resources are required at a location, initial resourcing is inadequate and new locations arise and must be resourced. In response, plans must be continually devised to transport resources to the locations where they are needed.

Adaptable Socio-Cyber Physical Systems

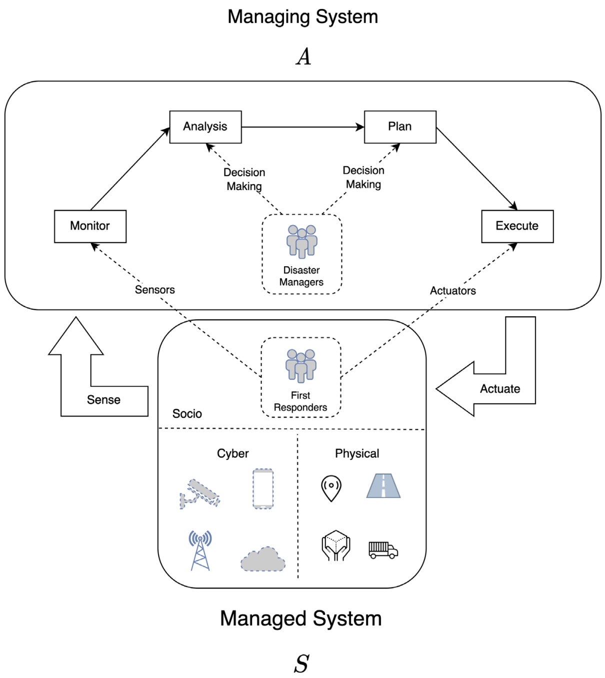
Cities are evolving into *cyber-physical systems*, a complex mixture of software and hardware embedded within the physical environment. Cyber-physical systems that also represent humans as part of the system are called *socio-cyber-physical (SCP)* systems (Paterson et al., 2019). This is an important class of systems for which we may reason with, and understand, human roles within cyber-physical systems and how they interact with technology. This section develops a socio-cyber-physical system to represent resource allocation and distribution within a disaster-affected region. The sorts of resources needed during a disaster scenario are ranging from emergency medicine and sustenance to supplies and disaster first responders. This section introduces key mathematical notation used throughout the paper, summarised in Table 1.

Resource allocation during a disaster is a challenging problem since demands for resourcing frequently change. Disaster could cause ongoing damage to road infrastructure, making resource distribution by the first-responders difficult. The topmost portion of Figure 1 presents the *managing system A*, comprising Monitor, Analyse, Plan and Execute components which sense the situational state of the *managed system S*. The disaster management team maintain situational awareness of *S* to effectively command and control transport workers tasked with resource delivery.

Table 1
Mathematical Notation for the Algebraic Model of the Adaptive SCPS

Symbol	Meaning
S	SCPS of the Disaster-Affected Region
A	MAPE Loop Managing S
P	Resourcing Policies (Requirements)
σ	Current state of the SCPS S
σ'	Updated state from observing physical event
$\sigma_{good} \models P$	State σ_{good} is a state satisfying resourcing policies P
$\{\mathbf{a}, \mathbf{b}, \ldots\}$	Unique names referring to locations within the disaster-affected region
p_b	Quantity of resources specified by $\sigma_{good}(\mathbf{b})$
q_b	Quantity of resources needed at location $\mathbf{b}$ to satisfy P

Figure 1
Adaptive Socio-Cyber-Physical System for Resourcing a Disaster-Affected Region



Managed System Components and Requirements

The goal of the managed system *S* is to support the disaster management team in their decision making process for resourcing within the disaster-affected region. The required amounts of resources and their location within the region are typically expressed in terms of a policy *P* and are outlined during the mitigation and preparedness phases of disaster management.

The bottommost portion of Figure 1 depicts scp system *S* components impacting disaster preparedness within the region, delineated by dashed lines, including:

Physical components which correspond to characteristics of the geographical region, such as road infrastructure, physical attributes of the resources being distributed to locations within the region and reliability of the vehicles used.

Cyber components which comprise disparate ICT contained within smart cities, to be utilised to improve the ability to retrieve, compute and visualise information from the region that is relevant to resource distribution within the region. This category of components may include drone technology, computing devices, cameras and CCTV, cloud-based technologies, and telecommunication infrastructure.

Socio components comprising human first responders and medical teams who play the most important role during a disaster response to distribute resources as they are needed.

Situational State of the Managed System

Key to our approach is defining the *situational state σ* of *S*, an object which defines the current situation of every real world element represented by a component of *S*, such as the quantities of resources allocated within a region, the position of first-responders and their current status. The situational state σ can be represented using high-tech and low-tech ways. For example, using a physical map and radio communication, a disaster manager team can track resourcing in the region, maintaining a rudimentary situational state of *S*. We expect that resourcing policies also change depending on the severity of the disaster and the updated policies are also reflected as part of the managed system's situational state.

When using a modelling approach, σ is a mathematical object, meaning that *formal verification* tools such as constraint solvers can be used to automatically check current resourcing properties of the system. In symbols, we write $\sigma \models P$ to mean that the system state σ satisfies all resourcing policies in *P*, e.g. no resources are needed to be transported within the region represented by *S*. We say that σ is a *good* state of *S* whenever $\sigma \models P$. We outline this approach in the final section of this paper.

Self-Adaptive Capabilities of the Managing System

The components of the managed system *S* are subject to change and this is especially true when the region represented by *S* experiences a disaster, where outstanding resources may be required at one or more locations. To support the disaster management team in keeping the system in a good state, *S* is coordinated via the managing system *A* which comprises a MAPE control- loop (Kephart & Chess, 2003) depicted on the topmost part of Figure 1. The adaptive functionality is delineated into four distinct *Monitor*, *Analysis*, *Plan* and *Execute* phases. These phases act as a feedback loop performed continually by the disaster management team to maintain resourcing across the region.

Human Roles and Responsibilities. Humans play a critical role in both the managed scp system *S* and its managing system *A*. There are two specific roles for humans, *first responders* and *disaster managers*. It is the role of disaster managers to command and coordinate first-responders in *S* during the disaster response. They are responsible for decision making based on analysing the current situational state of *S*, and developing a resource allocation and distribution plan informed from the *Analysis* results. These responsibilities are depicted in Figure 1 by dashed lines from the Disaster Managers component of *A* to the *Analysis* and *Plan* phases of the MAPE loop. For the scp *S*, *first responders* act as sophisticated *sensors*, denoted as a dashed line that acts as input to the *Monitor* phase. This means first responders report back on road conditions, resourcing quantities at locations within the region in order to form information to update the disaster manager's situational state of the system *S*. In turn, first responders also perform resource transportation and distribution according to plans made by disaster managers, which alters the situational state σ of the managed system *S*. These actions are denoted by the dashed line from the *Execute* phase to the first-responders component within the managed system *S*.

Sensing and Monitoring. In the first phase of the MAPE loop, system components are perceived by *sensors* from the SCP system and input to the *Monitor*, to be synthesised into the situation state σ of *S*, as denoted by the vertical arrow on the left-hand side of Figure 1.

In the *Monitor* phase, disaster managers build up a current snapshot of the region, particularly:

- kind and location of resourcing,
- updated resourcing policies, brought about from e.g. increased demand, and
- status and location of first responder staff working within the region.

Sensors are defined as any system component whose perception give usable information for decision-making. Broadly speaking, this can be high-tech solutions which are helpful automating the collection of sensor data, or it could be human-centric, such as situation reports from first responders (on-going via radio or upon return to the command centre), healthcare workers or other people in the region deemed as a reputable source of information to base decision-making upon.

High-tech solutions depend on communication infrastructure within the region. Technological sensors such as cameras and drones can record and transmit pictures to communicate digital images to the management team. Devices can be commanded from a distance and observe parts of the region impossible for humans to safely access. In most cases, and especially during a disaster, it is too difficult and expensive to instrument the region with sensors to extract useful information.

For resource allocation during a disaster, it is vital to keep track of resources, and how they may be distributed within the region. Physical components such as the roadways, locations, resources and vehicles can become affected by a disaster at any time. For example, roadways may be negatively impacted by adverse weather conditions, which make travel slow and difficult. In some cases, a disaster may damage a roadway, making it completely impassible and therefore must be avoided. As a result, locations may become impossible to reach, making resource distribution difficult.

Our approach accounts for uncertainty in sensing the situational state σ of S. For example, it is usually impossible to obtain full information of resource needs and changing requirements through the disaster-affected region. However, if hospitals and clinics operate auditing software for their on-site resourcing, then it can be utilised, capturing very accurate resource usage information.

Analysis and Planning. The *Analysis* phase takes the completed situational state σ of S as input and applies analytic processes to determine whether or not there is a need to deploy first responders to transport resources as required within the disaster-affected region. The situational state keeps track of a finite number of unique locations {a, b} of interest within the region and, broadly speaking, if σ_{good} represents a *good* state of the system before the disaster hit, then $p_b = \sigma_{good}(b)$ is the ideal quantity of resources available at the location b. To simplify the presentation, let p_b be a single number. In real-life disaster scenarios, p_b would be a list of resources: sustenance, first-aid supplies etc.

The management team computes current resource needs at **b** by the difference equation

$$q_b = \sigma_{good}(\mathbf{b}) - \sigma(\mathbf{b}).$$

If $q_b > 0$, then the quantity q_b of resources needs to be transported to **b**. Otherwise, **b** currently satisfies it's resourcing requirements as determined by the situational state σ against the resourcing policies *P*. These resourcing policies may have been updated as a result of changes in demand or addition of new kinds of resources, as perceived during the monitoring phase.

Formal verification techniques automate these calculations during a disaster scenario, where logic and mathematical models to encode resourcing requirements. The final section of this paper outlines the kinds of models and techniques used in our previous work (Johnson et al., 2021; Johnson et al., 2020).

Determining resourcing needs is carried out by the management team with uncertainty about how many resources are needed. The *Analysis* phase yields quantities of resources to be distributed to locations within the disaster-affected region. The next phase is the *Plan* phase which works out the logistics for moving resources where they are needed. Disaster managers must consider the health and safety of the first responders. They take into account their team's personal circumstances, such as competencies, capabilities, capacities and level of fatigue. Once a responder is given a quantity of resources, they mainly select a shortest path route through the region, typically computed by GPS, when available. Alternatively, the route may be selected according to the most reliable and least affected by the disaster. At times, the first responder may not know the exact location where the resources and simply drive in the general direction where resources are likely needed.

Execution and Actuation. In the *Execution* phase, the plan considered by the disaster management team is realised. For a disaster scenario, this means that resources are secured and loaded onto an emergency response vehicle. We denote this *source* location by a, which represents the staging area from which resources are supplied to locations within the disaster-affected region. In general, there may be one or more source locations, where resources are either strategically prepositioned during the disaster preparedness phase or transported to a centralised location to be distributed as part of the disaster response.

The first responder team sets out to their target location, such as **b** to deliver the resources. In this sense, the first responders are system *actuators* which alter the current state σ to a new state $\sigma' = transport(\sigma, q, \mathbf{a}, \mathbf{b})$, where

transport is an algebraic operation on situational states yielding σ', satisfying the equations

$$\sigma'(\mathbf{b}) = \sigma(\mathbf{b}) + q_b$$

$$\sigma'(\mathbf{a}) = \sigma(\mathbf{a}) - q_b.$$

In some cases, it may be possible to utilise high-tech solutions for distributing resources across the region. For example, drones may be useful for quickly reaching areas that are impassible via the ground. Often times however, humans play a critical role in actuating resource distribution since technology may simply be unavailable to the disaster responders. Deliveries of resources and other changes to S update its situation state, which are sensed by future iterations of the MAPE loop.

Integrating SCP Design and Operation into the Disaster Management Life Cycle

Table 2 associates disaster management life cycle phases[1] with corresponding SCP system engineering steps. The mitigation phase coincides with component and requirement specification of the SCP system *S*. In this step, disaster managers work together with engineers to specify key components and translate disaster requirements into policies *P*. At the end of this step, we define the situational state σ of the system *S*.

In the preparedness phase, disaster managers distribute resources (according to policies *P)* to locations in the region to help the community prepare for a disaster. Non-perishable resources are typically stored on-site either in the building or in nearby storage containers. This includes the majority of equipment, electronics and safety/rescue vehicles. During this phase, *S* becomes operational and is initialised in a good situational state σ_{good} satisfying all resourcing policies. In symbols, $\sigma_{good} \models P$.

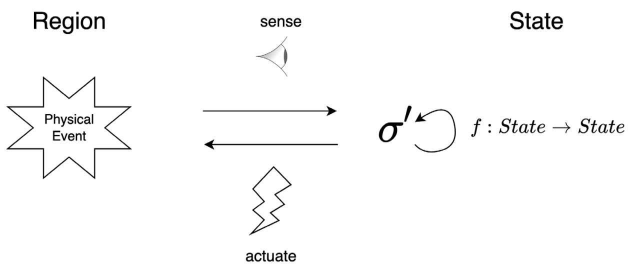
Figure 2 presents the functionality of managing system *A*, logically delineated into MAPE control loop phases, and continually managing changes in *S* to inform planning during the disaster response phase. For example, depletion of resources at location **b** might be perceived by

- first-responders
- healthcare staff, or
- automatically by auditing eHealth software.

Table 2
Disaster Management Phases and SCP System Engineering Steps

Disaster management Phase	SCP System
Mitigation	Component and Requirements Specification
Preparation	Situational State Initialisation
Response	MAPE Control-Loop
Recovery	[illegible]

Figure 2
Translating Physical Events in the Region to Algebraic Operations on the Situational State σ of S



[1] disasterphilanthropy.org/issue-insight/the-disaster-life-cycle

The *Monitor* updates the situational state σ_{good} with an operation *f* corresponding to the physical event. For example, the updated state

$$\sigma'(\mathbf{b}) = \sigma_{good}(\mathbf{b}) - q_b'$$

for the quantity q_b' of used resources at **b**. The *Analyse* part of the MAPE loop analyses σ' to determine if $\sigma' \models P$ If so, actions are formulated by *Plan* to be approved by the disaster management team and actuated by *Execute*, including transporting enough resources to **b** to put *S* into a good situational state again.

The recovery phase can synthesise knowledge from the operational logs from *S* that describe behaviour of the SCP system during a disaster, to inform future disaster response policies.

Case-Study

To demonstrate the applicability and functionality of our proposed methodology and considering disaster as the SCP system, we develop a case-study based on Hurricane Irma. The attempt is to specify the socio, cyber and physical aspects of Irma disaster response operations and how we can conceptualize disaster management into SCP system.

Despite the fact that different categories of disasters (such as earthquakes, flooding, and terrorist events) lead to different consequences, most disasters have many common elements (Uchida et al., 2004). Therefore, as storms and floods are the two most prevailing disasters in the Asia Pacific region (Alisjahbana et al., 2021), in terms of fatalities and the affected people, cyclone/hurricane disaster type was chosen. With this in mind, we developed a case-study based on first hand response to Hurricane Irma considering the wealth of the available knowledge and our first responder's experience deploying to Southern Florida for disaster relief efforts following Hurricane Irma in 2017.

Based on our field experience in responding to Hurricane Irma, there is a long list of ad-hoc types of response challenges that are different in nature, types and root causes. This makes disaster response adherence to the pre-defined strategies and plans challenging, especially due to constant changes in disaster affected regions while disaster managers often have outdated, or inaccurate information about the region.

Hurricane Irma

Hurricane Irma made landfall on the continental US over the Florida Keys as a category 5 hurricane on the morning of September 10, 2017[2][3][4]

The majority of the damage was caused by hurricane strength wind reported to have reached over 180mph and flooding that caused the evacuation of nearly 6 million Floridians (Hong & Frias-Martinez, 2020). The category five storm ripped off roofs, flooded coastal cities, and knocked out power to more than 6.8 million residents. By Sept. 11, Irma weakened to a tropical storm and as it moved North the storm lost power causing substantially less damage over time. By Sept. 13, it had almost completely dissipated and the majority of the major damage was over. Affected residents were left with an immediate and desperate need for resources all across Florida. According to a preliminary estimate Hurricane Irma cost as much as 42.5 to 60 Billion (USD) in wind and flood damage to both commercial and residential property (LaVito, 2017).

When our disaster responder deployed with the Red Cross, the Southern Florida region of Naples was strategically chosen as one the main hubs for response and resource distribution due to the disaster impact on a densely populated area and it's ease of accessibility by main roadways and a major airport. In disaster response, main hubs are usually positioned in a larger city due to their heightened access to valuable resources, resupplies via their access to a multitude of transport options, and accommodation for responders and volunteers. Access to an airport is also critical for any disaster response hub as it allows all responders, volunteers and replacements easy access to the disaster stricken region and expedites medical evacuations for those in need. Cities also have better access to technology-based systems, internet, and access to hospitals and other localized emergency response teams and equipment.

Irma Disaster Response

Our fieldwork expert was deployed in response to Hurricane Irma as a Red Cross disaster responder and Emergency Response Vehicle Driver (ERV). ERV teams main responsibilities during disasters are centred around resource distribution, risk communication and health services throughout the disaster- affected region. Tangible resources on response vehicles include supplies such as food, water, blankets, medical kits, clean up kits and tarpaulins for sheltering and coverage. ERV teams typically deploy in pairs, however when available, teams are accompanied by a nurse or other medical professional to attend to any medical needs during the days responses.

Figure 3
Disaster Relief Vehicle Traversing City Roads

RV teams responding to victims of Irma were briefed each morning by a disaster manager in the main staging area. The location of the briefing is typically the same location as the main staging area for all supplies, logistics personnel, responders, volunteers and response vehicles. The morning briefing broke down a situation report (SITREP) containing the day's chain of command, available distributable resources, and established teams and their vehicle assignments. STRIP is a periodic status report with a quick understanding of the current situation for decision-makers. Weather forecasts and updates on any further road closures or road openings from the past twelve to twenty-four hours were also discussed. These briefings usually ended with a question and answer session to clarify any details or misunderstandings about the days proceedings.

Following vehicle assignments, each team loads their ERVs based on any specific needs they were briefed on concerning the location of their morning assignment. Selecting and loading various resources also depended on the availability of hot meals from predominantly elderly volunteers from a local church and the availability of bulk supplies from the previous day's restock. Some locations were without power and grocery stores had been closed so getting them meals was of most importance, other areas had flooding damage (shown in Fig. 3) that contaminated their water source and just needed clean-up kits and fresh water.

For Hurricane Irma's response, each ERV team was assigned to a disaster- affected location which would range in distance from the main staging area. Sometimes a team would be deployed within a kilometre of the

[2] www.worldvision.org/disaster-relief-news-stories/2017-hurricane-irma-facts#timeline-path
[3] en.wikipedia.org/wiki/Hurricane Irma
[4] www.fema.gov/sites/default/files/2020-11/fema florida-hurricane-irma-recovery case-study. pdf

staging area, or deployed as far away as a two-hour drive or more. An ERV team could expect to respond between two to eight times every day depending on location, conditions and distance. It was rare that specific drop-off points were assigned for resource distribution, rather the majority of responses entailed driving through the most affected areas and assessing and reacting to their needs face to face.

Different challenges such as the unpredictability of the resource drop-off areas, nature of the required resources and the types of casualties' requirements, made resource distribution difficult. It was especially difficult to know what supplies might be needed for each response region, and often it was based on the ERV team's guess with limited communication between those affected, the responders and the disaster managers. Utilizing a basic loudspeaker with a dash-mounted communication system enabled the response team to announce their presence on each street and would stop if someone came out and waved them down. Unfortunately, this was often the only way victims could communicate their needs with the responders as all stakeholders in disaster response were overwhelmed with requests.

Having limited even or no communication was a regular occurrence during daily responses, which reflects back on the importance of relaying information to the disaster manager after returning to the staging area for teams to stay informed of what supplies were most needed on the ground. This information could be directly fed to each ERV team through handheld radios or disseminated at the following days' morning briefing. Flexibility was also key for ERV teams as they were often the first responders on-site and their role frequently expanded to differing forms of comforting and counselling. This flexibility was key as communication was difficult for those affected by the Hurricane due to power lines and cell towers being damaged and rendered inoperable. This caused heightened anxiety, panic and fear as they could not reach out for help or contact loved ones.

Communication wasn't only difficult for the victims of the Hurricane but also for the disaster responders and managers. Much of the information at the morning briefing was found to be inconsistent or unreliable as communication of information was not consistently gathered or received from established and reliable sources and was also heavily reliant on word of mouth from responders' direct experiences in the field where often resources are needed immediately. Communication also inhibited effective resource distribution as communication between different ERV teams and the Disaster Management team was also inconsistent.

Lacking communications, advanced technological support systems and a clear vision of the disaster-affected area and casualties' requirements leads to delivering supplies that were often not in need. Without appropriate communication of supply needs an ERV loaded with hot meals could easily respond to an area in need of fresh water and clean up kits. This mostly created an issue as ERVs would regularly carry hot meals which, for health and safety purposes, had to be distributed within a certain time frame. If enough disaster-affected households were not identified by the ERV team, food supplies would often go to waste.

Situational awareness was also of the utmost importance for the involved agencies as it helps them understand 'what is going on in the disaster field', stated by (O'Brien et al., 2020). Road damage, downed power lines and flooding frequently complicated or inhibited access to certain areas that had not been identified or discussed at the morning briefing. This caused logistical issues for the ERV teams as to whether a flooded road was beyond the impasse (Figure 2). This often lead to on the spot judgement calls by the ERV team who for the most part were not trained to do so or waste of precious response time or resources. While most of the issues could be addressed using better communications technology, either through local informers on the ground communicating information to authorities, or satellite technology relaying the information to stakeholders on the ground.

Socio-Cyber Physical System of Hurricane Irma

Based on what has been explained in the Irma case-study, in this section we conceptualised the scenario into the form of a SCP system and its components. This helps disaster management field experts to breakdown disaster response activities into Socio, Cyber and Physical elements that may reduce the complexities of their management in dealing with response operations, especially for resource distribution.

We envision the region affected by Irma as an SCP system. The goal of this system is to maximize the efficiency and effectiveness of field workers and first-responders endeavours and efforts when responding to disasters. Efficiency is absolutely critical in disaster response as every second lost can put lives at risk. This SCP system is equipped with the adaptive MAPE control-loop and by integrating all the elements, the solution potentially improves situational awareness, required a disaster response mission.

As discussed in the third section of this paper, our SCP system can be translated as disaster- stricken area and with the analysis of 'Physical' components such road access based on flooding, downed power lines, and most efficient routes of travel supports the situational awareness in the system. The 'Socio' elements includes all human activities, behaviour, roles and responsibilities in disaster management. Therefore in the Irma case-study, once disaster response workers and disaster managers are mobilised and assembled at the required staging area, disaster response tasks are primarily centred around resource distribution, addressing the socio aspects. The socio aspect, manage or handle the physical elements including resources for distribution (food, water, clean up kits, and tarpaulins), and manage basic medical assistance, and counselling services, as well as any manual labour required (e.g. furniture moving and assembly, etc.). To support relief efforts, disaster managers often rely on a collection of low and high-tech solutions to keep track of resources in the region. In an ideal situation, resources can be digitally tracked and traced and specialised software applications can accurately determine current resource allocations to each location. This approach has the benefit of automatically checking current allocations against requirements to determine what resource is needed, and where. However, as discussed in earlier, in responding to Irma instead of cyber systems, disaster responders were responsible for such task using a manual counting system which is time-consuming, and less reliable with minimum room to perform the MAPE loop and boot the efficiency.

Different cyber systems can be used to report on specific supply needs of different disaster-affected areas (e.g. a particular area may have sufficient water but require tarpaulins, whereas another area might be in need of water or medical supplies), availability of supplies for distribution to disaster-affected areas, and location of available supplies. In relation to situational awareness this same cyber system would also monitor incoming inclement weather for purposes of evacuating affected citizens, disaster responders and field workers. Currently, information around road access and supply-needs is communicated to mobilised disaster response workers and emergency managers in face-to-face briefings as there is no centralized cyber system for disaster managers at the staging. This constrains disaster and operational managers' ability to efficiently communicate information, updated news, or report to the ERV drivers and first responders. The current reality in the field highlights a communication issue where disaster managers do not necessarily have access to what resources are needed at disaster affected locations, often leaving them in the position of guessing what might be required. This is the same for those in disaster affected regions that cannot communicate specifically what resources are needed for their particular situation, and in their particular region. Due to the aforementioned communication issues the distribution of resources in this SCP System lacked organization. Due to these basic communication issues the distribution of resources lacked organization.

Therefore, the ability for disaster field workers on the ground and disaster managers at the main staging area to access and update the system in real time would be optimal in order to support disaster response efforts. If the system was also able to be accessed and updated by other emergency response groups, such as the police and the fire brigade it would provide additional support. Integration with other emergency response groups would corroborate existing information as well as providing additional information around such things as evacuations in progress, casualties, etc.

Current cyber technologies being utilized in Red Cross ERV's are basic dash mounted communications systems with a roof mounted loudspeaker similar to what is utilized in most police vehicles. When available ERV teams will also be equipped with a hand-help radio to communicate with disaster managers in the staging area. Navigational tools are often extremely limited, and Red Cross responders are often limited to use of their own cell phones, or ones issued by the Red Cross.

Run-time Formal Verification of SCP Systems

Formal verification refers to the class of processes that check whether a formal, mathematical model M of a system satisfies the formal specification P of a property or requirement. Model checking is an automatic formal verification technique that accepts formal behavioural models of systems in the form of state machines or automata, and property models in the form of temporal logic formulas or automata. Formal methods like model checking guarantee that, as long as the system and requirement models are correct or true representations, if M satisfies P (written as $M \models P$), the system will satisfy the given property. Alternatively, and perhaps more importantly, model checking can automatically identify paths in system execution, called counter examples, that do not satisfy the given requirement. Other formal methods, such as SMT solvers, can comprehensively determine if a given problem, posed as a Boolean or first-order logic formula, can be satisfied under a given set of system constraints. The ability of formal verification to comprehensively and unambiguously answer questions relating to the satisfaction of requirements is highly desirable in planning a disaster response.

This section focuses on run-time verification, where the key challenge is to ensure models are updated according to changes in the system, and are simple enough so that analysis can quickly yield actionable plans for the management team during a disaster scenario.

SCP Models and Requirement Specifications

Our previous work (Johnson et al., 2021; Johnson et al., 2020) formalises system components and their requirements as mathematical models such that

- region is modelled by the graph G comprising locations in the region represented by a finite set of nodes, labelled **a**, **b**, . . . and directed edges $\mathbf{a} \rightarrow \mathbf{b}$ representing routes between locations
- resources requirements are specified by logical formulae K translated from the policies in P
- a resource allocation α satisfying K.

Together, these models specify the situational state $\sigma = (G, K, \alpha)$ of the socio- cyber-physical system S.

Resourcing Requirements as Logical Formulae

At the heart of our approach is the translation of resourcing requirements from P into a set of logical formulae formalising constraints, denoted K. For example the formula

$$\phi_{\mathbf{b}} \equiv (bMed \geq 15) \land (bSus \geq 10) \land (bSup \geq 20) \quad (1)$$

$$\land\ (bMed = bSup) \quad (2)$$

in K specifies resource requirements for the location labelled **b** in the disaster- affected region. The formula comprises four propositions connected by the conjunctive operation $\land$. The propositions on Line (1) specify the least amount of each resource type needed at the location. e.g. $bMed \geq 15$ specifies at least 15 units of medical supplies are needed at **b**. The expression on Line (2) adds a further constraint on the resources; particularly that the amount of medicine must equal the amount of medical supplies at **b**.

A resource allocation satisfying all the resource requirements is solution α of $\phi_{\mathbf{b}}$ assigns a number to each variable such that its evaluation is true. For example $\alpha(bMed) = 21$, $\alpha(bSus) = 10$ and $\alpha(bSup) = 21$ is a number assignment to the variables in a way that satisfies $\phi_{\mathbf{b}}$. We write $\alpha \models \phi_{\mathbf{b}}$ if, and only if, α is a solution to $\phi_{\mathbf{b}}$. We use Satisfiability Modulo Theories (SMT) solvers (de Moura & Bjørner, 2008) which are advanced software tools to automatically and efficiently compute an assignment α of values to variables, satisfying a given input formula $\phi_{\mathbf{b}}$. In symbols,

$$\alpha = smt(\phi_{\mathbf{b}})$$

Formulas for disaster resourcing may be designed per-location or also depend on proximity constraints, such as *any location within 10KM of location* **b** *must have more than 50 units of sustenance.* As a result, formulas quickly become very large with complex inter-dependencies that make them difficult to manage. Therefore, it is preferable constraints be generated automatically using high-level English language templates to select standard resource requirements. This approach benefits disaster managers by

- providing instant feedback when requirements are incompatible, making a solution satisfying impossible to obtain, and
- being easily adaptable to change in resourcing policies during or after a disaster since only the high-level English language templates need to be updated to generate a new set of constraints.

Modelling Stochastic Properties of SCP Components

During a disaster, the best route for first-responders to take is the easiest and most reliable route, which is not necessarily the shortest one. In our previous work (Johnson et al., 2021), we modelled reliability of the disaster-affected region's transportation network as a *Markov Decision Process (MDP)*. Stochastic models such as MDP have been used to calculate best routes based on changing travel infrastructure conditions within the region (Paterson et al., 2019; Rashid et al., 2020). Underlying these models is a graph whereby nodes represent locations and edges represent routes between locations. Each edge is labelled with probabilities measuring the likelihood of failure; e.g. unsuccessfully traversing the route. In (Paterson et al., 2019), transition probabilities are continuously updated by sensing adverse events on routes using natural language processing techniques on social media data. Transition probabilities are updated according to rules defined by domain experts, governing how initial probability values should change depending on the kind of event. Other sources of information for calculating transition probabilities may include data automatically collected from one or more sensors. Analysis of Markov Decision Processes to compute route reliability leverages software such as a *probabilistic model checker pmc*, which automatically verifies a probabilistic temporal logic formula T on an MDP P such that

$$\pi = pmc(M, T) \quad (3)$$

computes the path π through the MDP M satisfying T.

Figure 4 presents a fragment of the MDP M written in Prism's (Kwiatkowska et al., 2011) high-level programming language. Each line represents a transition between states of M that model locations within the disaster-affected region. The first line of the fragment represents one possible directional choice labelled [a_to_b], to travel to location **b** from location **a**. This choice succeeds with probability pb and fails with probability 1 - pb. If successful, the MDP is in state b and only one transition labelled [succ] is available from b to the succ state, representing the successful execution of the *transport* (σ, **a***,* **b***,* q) operation. Otherwise, if the transition to b fails, then we transition to, and stay in, the fail state. This models the failure of *transport* (σ, **a***,* **b***,* q). Alternatively, [a to c] represents the directional choice to travel to **c** from **a**, which succeeds with a probability of *pc* and otherwise fails with probability 1-*pc*.

Probabilistic model checking in Equation (3) checks the MDP M against the probabilistic temporal logic formula $T = P{=}?[F(s{=}succ)]$, to determine the *strategy* π of directional choices from the source location to target with the maximum probability of success; e.g. reaching the succ state.

Disaster managers may suggest π first responders to maximise the likelihood of resources to be delivered within the disaster-affected region and the safety of the first-responders. Markov models can be automatically synthesised from the graph structure G of the transportation network. Sensors, including both humans and high-tech cyber systems to monitor traffic and other travel conditions are used to measure the probability of successfully traversing a route.

Modelling Stochastic Properties of Humans in the SCP

Figure 4
Fragment of the Markov Decision Process M

```
[a_to_b] (s = a) -> pb:(s'=b) + (1-pb):(s'=fail);
[a_to_c] (s = a) -> pc:(s'=c) + (1-pc):(s'=fail);
[succ] (s = b) -> 1.0:(s'=succ);
[fail] (s = fail) -> 1.0:(s'=fail);
```

Certain task critical attributes of humans can be modelled in the SCP system S to enhance decision making. The Opportunity-Willingness-Capability (OWC) model was first developed in (Eskins & Sanders, 2011) and used in our work (Johnson et al., 2021) to measure the likelihood that a first-responder can successfully complete a resource transport task according to:

- *opportunity* : access to an appropriate vehicle and adequate resources
- *willingness*: they are not fatigued, and
- *capability:* they have correct training and experience.

The OWC attributes can be modelled using Markov models and anal- ysed in parallel with the MDP M to maximise the probability of successfully transporting resources within the disaster-affected region.

Challenges. Furthermore, like many other muti-disciplinary work, the common challenge would be the gap and lack of common language between technical people vs first responders and disaster managers. this might negatively impact the project implementation on the early stage when technical people intent to extract the requirements and constrains for modelling. While domain experts can assist disaster managers to design and implement models during the disaster preparedness phase, the key challenge in using formal verification techniques to support decision making is maintaining these models. This means that changes in the socio-cyber-physical system S are sensed and translated into algebraic operations on the situational state of the system S. This inherently involves much uncertainty, as disaster responses typically involve limited communications and lack high-tech sensors. However, advanced probabilistic model checkers such as Prism are able to verify probabilistic systems that are only partially observable (Norman et al., 2017).

Concluding Remarks and Future Directions

In this paper, we developed a conceptual framework in which concerns about locations, infrastructure, actors and resource management raised by disaster managers during the mitigation phase are represented as components in a *socio-cyber-physical* system. The process of articulating these issues as components help to simplify requirements in a way that disasters managers could easily put into play and explain to responders. The process also delineates the roles and responsibilities of first responders during a disaster.

The SCP systems designed during disaster mitigation and preparedness phases are managed systems, adapted according to the four phases of the MAPE loop. This is a control feedback loop which monitors the current state of the system components. If analysis deems the system to be in an unfavourable state, then a plan is devised to adapt, returning the system to a good state. System adaptation strategies for the SCP correspond to disaster-response plans for resource distribution within the disaster-affected region to satisfy resource requirements. Using formal verification, Mathematical models of system components can be used to largely automate analysis steps to provide irrefutable evidence of the effectiveness of adaptation plans. We applied our approach by designing an adaptive SCP system for a real-life case study using our first-hand experience as emergency responders during Hurricane Irma.

Our research programme (Johnson et al., 2021) aims to develop a generic and re-usable self-adaptive framework for socio-cyber-physical systems where components and phases of the MAPE loop are extended with standardised interfaces. The interface for components name operations that provide functionality, with axioms that govern its behaviour. The component interfaces may be realised with one or more implementations which can help disaster managers plan for alternatives to key tasks during the disaster-response, such as sensing the environment or actuating delivery of resources. Although this sensing requirements could be interrupted because of the dependency on networking infrastructure, different technologies are available to address the issue. For example, satellite connectivity, or using Internet of Things (IoT) sensors to capture data and retransmit when the connection is re-established, are seen as a promising solution to overcome network interruption and sensing in disaster response.

The conceptual SCP system framework in this paper will form the basis for

developing simulations based on formal verification techniques which optimise the assignment of resource distribution tasks to first responders, based on their location and the current resourcing of the disaster-affected region.

Conflicts of Interest

The authors declare no conflict of interest.

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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

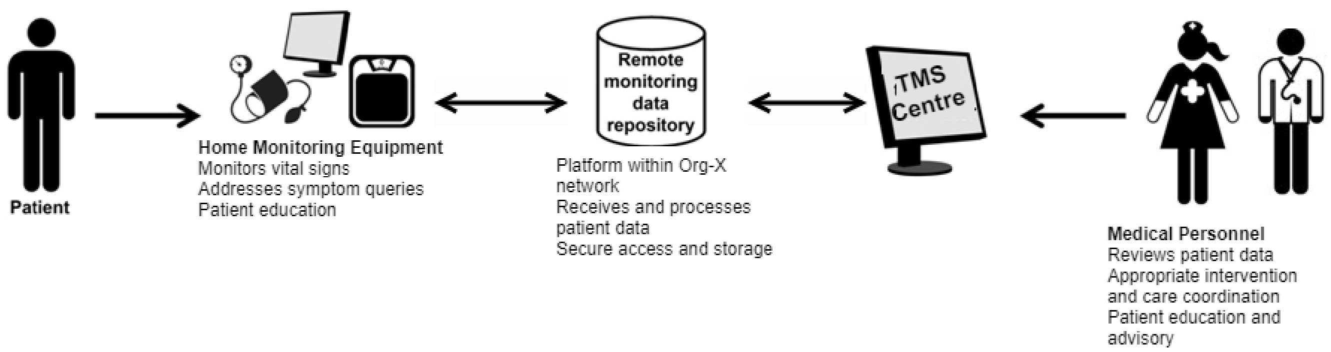
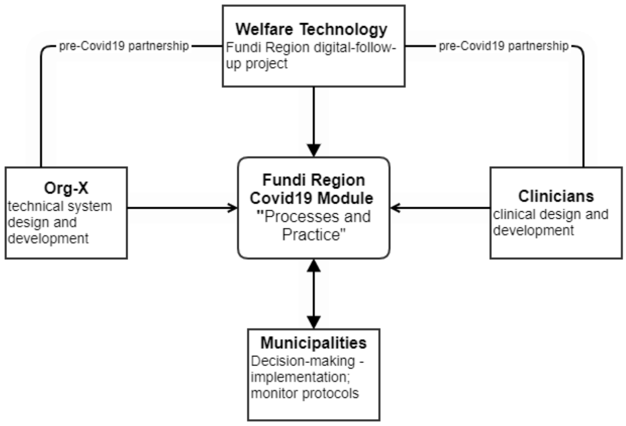


Figure 2
COVID-19 Module Design Collaborators Overview



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

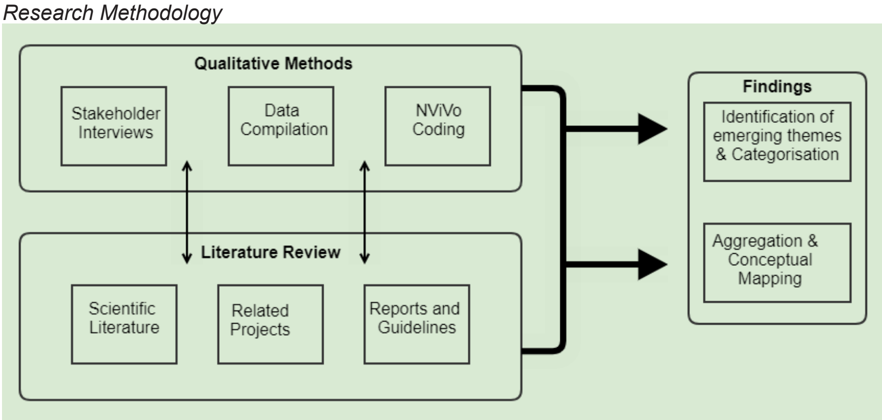


Table 1
Study Informant Profiles

	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.

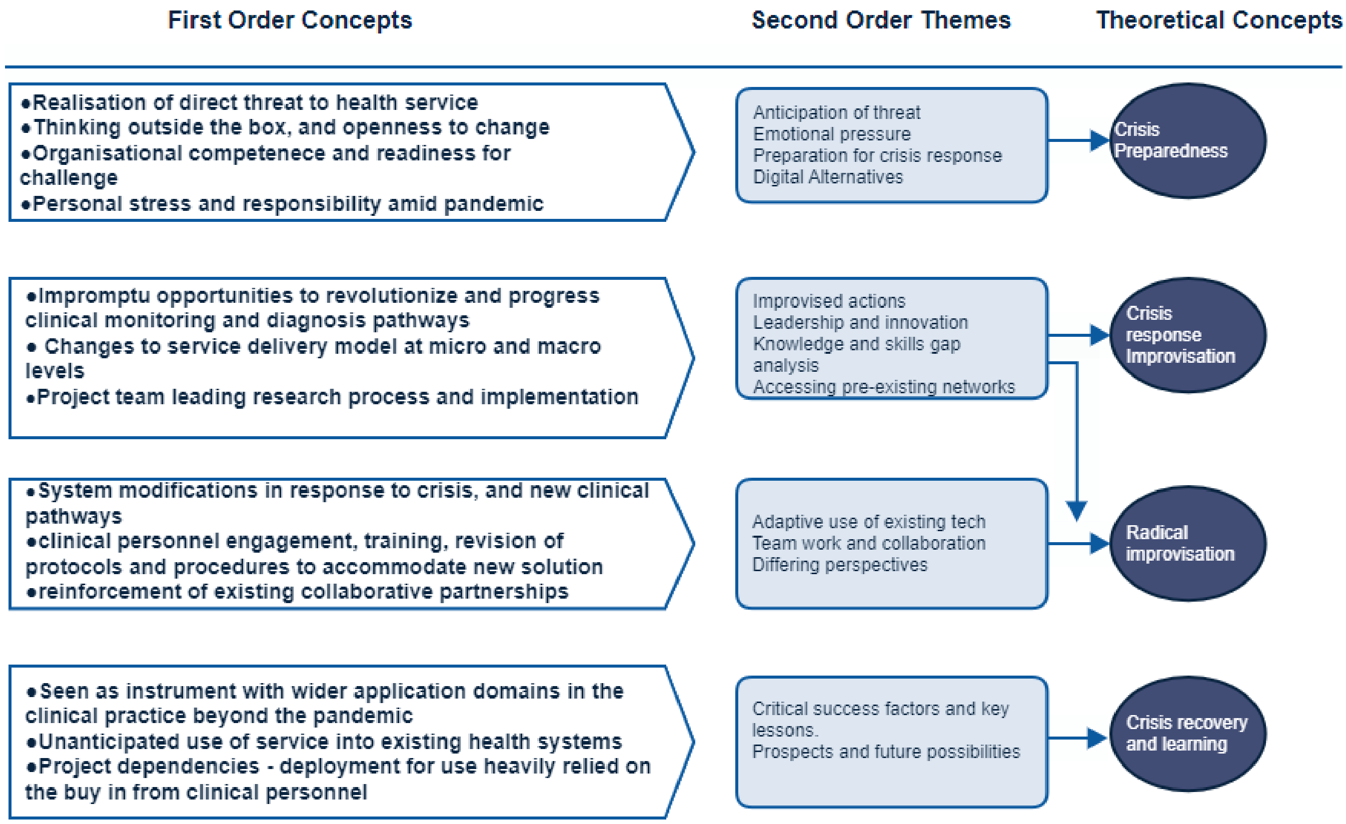
In the following section, a discussion of how radical improvisation of health technology occurs and logical insight into the subprocesses that structure it are proposed.

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



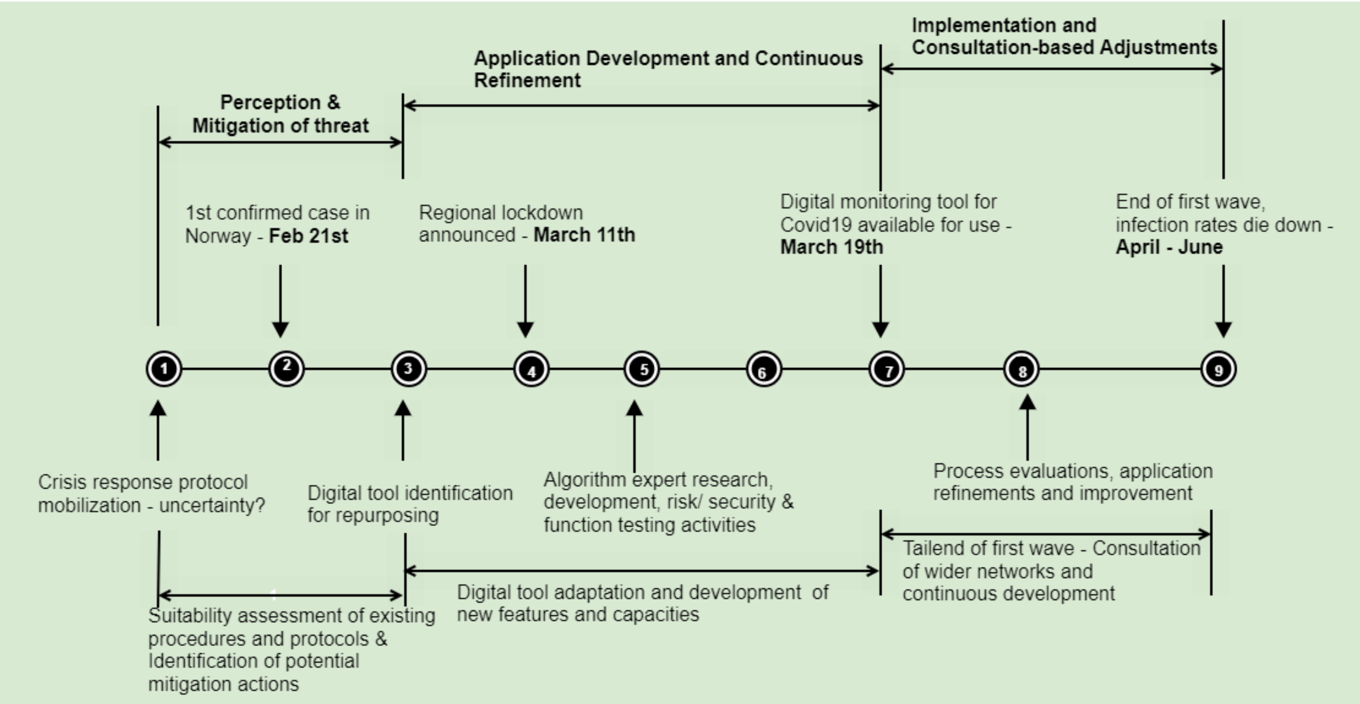
development procedure and make concessions, for instance- when Org-X undertakes to design the web user interface (a service they ordinarily do not provide at all) out of necessity. Therefore, additional scrutiny was applied to identify changes in pattern, enactment, and ordering of the known and novel 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

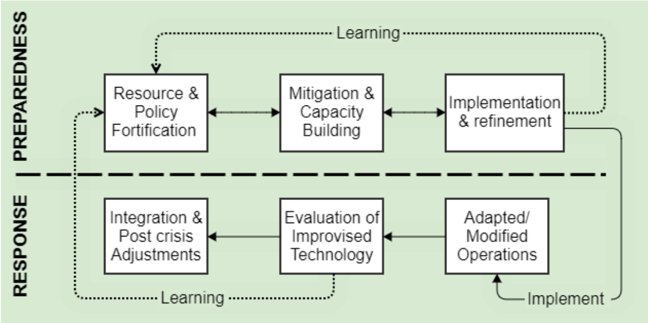


Table 2

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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