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Bounce Forward Resilience Attributes: Information System Strengthening in Response to Crisis

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Research Paper

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Abstract

Previous information system resilience studies have predominantly focused on analyzing bounce back, return to pre-shock state, resilience. This paper explores the phenomena of bounce forward information system resilience through longitudinal analysis of the COVID-19 responses in Sri Lanka and Sierra Leone. Both of these countries were able to significantly expand their information systems in terms of functionality, scale, and coordination in response to the pandemic. The goal of this paper is to derive new bounce forward attributes that were present in the information system landscapes of these countries prior to the pandemic. Through the analysis of these cases against the previously identified resilience attributes found in the literature, we defined capacity for coordinated agility, configurable and extensible innovation platform infrastructure, and human resource action potential as unique information system attributes that can constitute bounce forward outcomes when systems face shocks or are under stress.

Keywords: Resilience, Information Systems, COVID-19, Attributes, Sri Lanka, Sierra Leone

1 Introduction

The global COVID-19 pandemic has instigated calls from the academic community for further research and understanding of resilience (Rai, 2020). Likewise, amongst information system (IS) practitioners and developers there has been a corresponding focus on the practical properties of resilient IS in response to acute stressors and shocks such as the COVID-19 pandemic (*The Global Fund Strategy 2017-2022: Investing to End Epidemics*, 2016). The purpose of this paper is to respond to calls for and build on existing research into the resilience of IS (Rai, 2020; WHO, 2020).

Our starting point is Heeks and Ospinas' (2019) definition of digital resilience as "the ability of a system to withstand, recover from, and adapt to short-term shocks and longer-term change" (p. 75). From this definition we apply the notion of "bounce back" resilience where there is minimal disruption from the shock and a prompt return to a pre-shock state. However, Marais (2015) points out that there is a concern that resilience of IS could equate to a stagnation or an approach toward preservation of the status quo. In essence, reliant IS is not explicitly well functioning IS and will return to its pre-shock poor quality, dysfunctional, or undesirable state. Based on observations from the prior shocks Ebola and the great East Japan earthquake of 2001, Sakuai and Chughtai (2020) state that, "a recovery as returning to the pre-disaster state was not enough; resilience requires going beyond rebound and must encourage adapting to the existing crisis and then transforming" (p. 587). Here we refer to the phenomenon of an IS strengthening, improving, or developing in response to short-term shocks and longer-term change as a "bounce forward". It is a progression beyond the pre-shock state to a stronger, more developed, and/or scaled state (Heeks & Ospina, 2019).

Yet, there is a paucity of in-depth studies that focus on the characteristics of IS that bounce forward from a shock like COVID-19 (Rai, 2020; Heeks & Ospina, 2019; Sakuai & Chughtai, 2020; Schryen, 2013; Russpatrick et al., 2021). In response to this gap, we propose the following research question: *Are there unique attributes of an information system that can bounce forward when responding to and adapting from a crisis such as COVID-19?* We identify specific system properties, referred to as attributes, that enable a bounce forward of the IS. We derive these attributes through a critical realist, empirical investigation of longitudinal case-studies of the COVID-19 surveillance systems in Sri Lanka and Sierra Leone. Driven by fresh case data and new research, we build on, refine, and fill the gaps of previously identified bounce back and bounce forward resilience attributes (Russpatrick et al. 2021; Amarakoon et al., 2022, Park et al., 2021 Kinkade et al. 2022). We examine in both countries the use of the free and open-source District Health Information Software 2 (DHIS2) platform for COVID-19 surveillance.

The paper is organized as follows. First, we define our conceptualization of resilience attributes through the analysis of the existing resilience attributes from prior research. Next, we present a detailed description of each case-study. From there, we present a cross-case analysis through the lens of established bounce back attributes to explicate the bounce forward outcomes. In the discussion we present new bounce forward resilience attributes through corroboration with the case data and triangulation against existent literature on bounce forward resilience. Finally we briefly recapitulate our findings in the conclusion.

1.2 Conceptual framework

Erol et al. (2010) argue that resilience can be broken down to a set of system properties, which they call “attributes”. These attributes can be recombined to equate to an overall resilient system. Building from this, other scholars have introduced the concept of system properties that equate towards resilience albeit by different names; system attributes, factors, qualities, sub properties, and characteristics (Heeks & Ospina, 2019; Erol et al., 2010; Hollnagel & Woods, 2006; De Florio, 2013; Attoh-Okine, 2015; Magutsha et al., 2022). The attributes of resilient IS, being socio-technical artifacts, point to various human, organizational, and technological aspects.

In this paper, we limited our search for resilience attributes to only those derived from the study of IS. Previous studies by Heeks and Ospina (2019), Park et al. (2021), Russpatrick et al. (2021), Erol et al. (2010), and others, have considered a broad range of resilience attributes presented across many domains including social-ecological systems, economics, engineering, community development, etc. These authors have built on and borrowed from these domains to fabricate their own conceptual frameworks from which they produced their own attributes for resilient IS. Likewise, we build from theirs, presented in table 1.

More pronounced in the literature is the identification of resilience attributes which result in a bounce-back or recovery to a pre-stress or shock state. In table 1, we review these previously identified attributes as a foundation and point of departure for additional exploration of attributes that lead to bounce-forward outcomes. Each of these studies, as presented in table 1, and others introduce bounce-back resilience attributes with some redundancy but less consolidation (Heeks & Ospina 2019; Smith et al. 2011; Erol et al. 2010; Sterbenz et al. 2013).

Attribute:	Definition:	References: (**Bold** denotes source of the definition)
Robustness	“Ability of the system to maintain its characteristics and performance in the face of contextual shocks and fluctuations.”	**Heeks and Ospina, 2019;** Bruneau et al., 2003; Rehak et al., 2018; Wang et al., 2010
Self-Organization	“Ability of the system to independently rearrange its functions and processes in the face	**Heeks and Ospina, 2019;** Rehak et al., 2018; Kim et

	of an external disturbance, without being forced by the influence of other external drivers.”	al., 2020
Learning/Capacity building	“Capacity of the system to generate feedback with which to gain or create knowledge and strengthen skills and capacities necessary to experiment and innovate.”	**Heeks and Ospina, 2019;** Park et al., 2021; Kinkade et al., 2022
Adaptability	“Adaptability is the capacity to adjust responses to changing external drivers and internal processes and thereby allow for development along the current trajectory (stability domain).”	**Folke et al., 2010;** Erol et al., 2010; Lansing, 2003; Rehak et al., 2018; Sakurai and Chughai, 2020
Agility	“Innovation and adaptability during the period when there is the need for rapid institutional change.”	**Park et al., 2021;** Amarakoon et al., 2021
Transformability	“Transformability is the capacity to create new stability domains for development, a new stability landscape, and cross thresholds into a new development trajectory.”	**Folke et al., 2010;** Magutsha et al., 2022
Diversity	A multiplicity of technical solutions built on the existing digital infrastructure (whether in active use or not).	**Park et al., 2021;** Heeks and Ospina, 2019; Sakurai and Chughai, 2020
Plurality	Multiple public and private actors leveraging support to different interventions in an agile manner.	**Park et al., 2021**

Table 1. Bounce back resilience attributes

Introducing the necessity for moving beyond bounce back resilience attributes, Marais (2015), points out that the danger of resilience that does not include the notions of change and adaptation is that low resource communities can become locked into a resiliently poor state. Indeed, the attributes of robustness, self-organization, learning, diversity, and plurality, listed in table 1, point to a return to a pre-shock state, although that state may be inadequate, dysfunctional, or undesirable. Only the attributes of adaptability, agility, and transformability highlight the ability to adjust, change, and create trajectories or institutions which may lend themselves more towards bounce forward outcomes (Folke et al. 2010; Park et al. 2021). However, these attributes have not been specifically grounded in empirical analysis of a bounce forward case. Thus, a limitation of IS resilience in the extant literature is the identification of resilience attributes that relate to coverage of change or adaption / “bounce forward” (Heeks & Ospina 2019; Erol et al. 2010; Sterbenz et al. 2013; Sakurai & Chughai, 2020).

Russpatrick et al. (2021) conducted research on the identification of bounce forward attributes derived from the initial development of the same cases presented in this paper as an inceptive response. Table 2 provides a summary of the initial bounce forward attributes that were identified.

Initial bounce forward attributes	Definition
Local/support expertise	A cohort of individuals, either domestic or international, that are familiar with the country’s health information system(s) and able to adapt and re-configure the information system(s) to new use-cases and requirements. This includes ability to

	rapidly adjust Standard Operating Procedures (SOPs) and training content.
Platform configurability	The technical information system can be rapidly modified and adapted by local/support experts to address urgent needs. Barriers can be purely technical, but also commonly legal or economic for proprietary/commercial information systems.
Local platform infrastructure	Information systems are locally controlled and not dependent on licenses, software vendors, or complicated hardware to make changes.
Local autonomy	Countries can manage and implement the information system as necessary and rapidly as required. They were able to directly respond to the swiftly evolving situation on the ground without direct barriers related to additional global resources or oversight, even if additional resources are required to make it work in the medium or long term.
Long-term capacity building	Long-term investments that the countries had placed in training up cadres of data and disease surveillance officers plus data entry clerks resulted in a pool of distributed health staff who could rapidly utilize the new tools and requirements.

Table 2. Bounce forward attributes

Russpatrick et al. (2021) observed that resilience is inherent in the broader system through these defined attributes. They claim that these attributes enable the IS to be able to rapidly adapt, scale, coordinate increased investment, and actualize new innovations in a time of crisis. IS possessing these attributes are at a steady state of resilience in a time of stability, but in times of stress they can rise to higher levels of resilience enabling bounce forward outcomes.

2 Methods

This article follows two longitudinal case studies (Yin 2014). We followed from their inception the implementation of DHIS2 for COVID-19 monitoring in Sri Lanka and Sierra Leone through two rounds of data collection. The first round of data was captured by the lead author of this paper for a previous, initial investigation of the bounce forward phenomena[1]. This paper is a continuation and refinement of that initial study (Russpatrick et al., 2021). The initial data was collected from four key informant interviews, text analysis from four publicly available case descriptions, presentations of the use-cases from six webinars, and direct observations from communication and activities between the implementation teams in the country and the implementation support staff based at University of Oslo (UIO). Direct observations took place between February 2020 and March 2021.

Data from direct observation (Myers 2020) was gathered from thirteen meetings between the UiO COVID-19 implementation team and Sri Lanka and four between Sierra Leone and the UiO team. The goal of these meetings was to obtain an update on the progress of the implementation, identify issues, provide technical guidance, and capture any software issues. Detailed notes from these meetings were kept for each case-study. These notes include direct quotes from both UiO and country implementers, status of each implementation at the time of the meeting, plans, any encountered issues, points of success, etc. Key informants were identified through the communication between UiO implementation support staff and the implementation teams in the country.

The first round of semi-structured, key informant interviews was in early October 2020, one informant from both cases. Following a snowball sampling approach, key informants were asked who

[1] Prior work is cited. Minimal changes in the description of the first round of data capture from previously published paper.

else they recommended be interviewed which led to another round of key informant interviews in late October again with one interview from each case. Each interview was via zoom, 1-1.5 hours long, recorded, and transcribed. For Sri Lanka we interviewed the leader of HISP Sri Lanka, and the Ministry of Health COVID-19 IS Manager. For Sierra Leone we interviewed the principal COVID-19 and disease surveillance system developer and the lead of disease surveillance system at the Ministry of Health. The interviews were semi-structured. Interviewees were asked to tell the story of the key events, and how they responded to COVID-19 focussing on the activities and practices that they engaged in response to the pandemic.

The focus of the second round of data is to capture the continuation of these two cases since the end of the initial data collection in March 2021. The basis for the second round of data collection is the ongoing engagement of the second and third authors in the direct implementation and continued support of the national health IS in Sri Lanka and Sierra Leone respectively, including the design and implementation of the COVID-19 IS. The second author is a key implementer of the COVID-19 pandemic IS at the Ministry of Health (MoH) Sri Lanka. The third author is the lead developer and architect of the electronic Case Base Disease Surveillance (eCDBS) surveillance system in Sierra Leone, which expanded to cover COVID-19 in February 2020. Both authors are able to lend their lived experiences in the continued development of their respective cases through direct observations, analysis of meeting minutes, emails, and the authors' own recollections of key events. Secondary data is also included in this second round of analysis including nascent, complementary research on these cases (Amarakoon et al., 2022; Kinkade et al., 2022).

Data analysis was conducted following a critical realist perspective (Heek & Ospina, 2019; Wynn & Williams, 2012). Critical realism seeks to expose the underlying causal mechanisms, referred to as attributes, that explain a certain event through a retrodictive approach. Critical realist studies promote the use of triangulation and pluralism of methods (Zachariadis et al, 2013; Bhaskar, 2008). First, we conduct a cross-case analysis against established resilience attributes to explicate the bounce forward outcomes as illustrated in section four. Then we applied retroduction to link the explicated bounce forward outcomes to hypothetical attributes. Retroduction is the identification through an inductive, derived from observations, and deductive, derived from theory, processes of the circumstances without which the bounce forward outcomes observed would not have occurred (Wynn & Williams, 2012; Heeks & Wall, 2018). This produced hypothetical attributes many of which had been identified in prior research. These were then combined and refined into the final bounce forward attributes through empirical corroboration and triangulation with the existing bounce back and bounce forward attributes. Both the empirical corroboration and triangulation occurred concurrently as is illustrated in section five.

3 Case Description

The context of this study is the ongoing implementation and use of DHIS2 in Sri Lanka and Sierra Leone. The District Health Information System 2 (DHIS2) is a free and open-source platform serving around 67 low-and middle-income countries in the Global South. Each country manages their own separate instance(s) of DHIS2. The DHIS2 core is an open, web application programming interface (API) and modular components utilized for a suite of generic applications that cover data entry, analysis, and system administration. The HISP Center at the University of Oslo (UiO) develops the DHIS2 core. Beyond the core is an increasing number of third-party developed applications that are developed with little or no involvement from the core development team at UiO. These applications are developed by partners in the global HISP network or by other contributing organizations for needs that are not covered by the core applications. However, these third-party applications are often created by utilizing guides and resources produced by UiO with the specific intent to aid third-party developers to innovate beyond the core applications. Many of these applications are generic and reusable across countries and contexts, and they increase the value of the platform as a whole to all users (Roland et al., 2017; Russpatrick et al., 2020).

Sri Lanka is a middle-income country of approximately 22 million in South Asia. It has a high Human Development Index (HDI) which factors in life expectancy, education levels, and gross national income per capita. Sri Lanka has a life expectancy of 75.5 years which is 10% higher than the global average. Literacy rate is 92.9%, primary school enrollment is 99%, and Sri Lanka has 17 public universities. Sri Lanka provides basic health services to all residents through its universal "pro-poor" health care system (United Nations). In contrast, Sierra Leone is in West Africa, has a population of around 8 million, and a low HDI. The life expectancy is around 57 years, the literacy rate is approximately 43%, and there are only 4 public universities. Medical care is not readily accessible. All residents have the right to free health services, but basic health services often come with a fee as clinicians take advantage of peoples' ignorance of their rights (United Nations).

3.1 Sierra Leone

While Sierra Leone has used DHIS2 as their main Health Management Information System (HMIS) for routine monthly aggregated data since 2008, the use of the software for disease surveillance is relatively recent, following the West African Ebola virus outbreak. From 2016-18, the HMIS was expanded to include weekly aggregated disease surveillance data (eIDSR) for 27 notifiable medical conditions. Around 1,400 Health Facilities were provided with Android tablets to enable them to capture and report their weekly data directly. Before 2016, this data was submitted by phone/paper to the District Surveillance Officer team for capturing into Excel. The HMIS has during the last 8-10 years been hosted by a European cloud provider, but technically administered by the Sierra Leone Ministry of Health and Sanitation (MoHS).

The electronic Case Based Disease Surveillance (eCBDS) was developed as a separate DHIS2 instance in 2018-19, initially aimed at handling individual data (patient profile data, laboratory data, case investigation data, and outcome data) for 20-22 of the 27 notifiable medical conditions. All of them share the same profile data variables, the same lab data variables, and outcome variables, but with different case investigation variables. The remaining conditions, like malaria, are too common for individual tracking. Case based data are likely to replace the separate collection of weekly aggregated data at some stage, but for now this "double capture" works well and Data Quality Assurance activities are increasingly relying on comparisons between the data from the two systems to identify errors or gaps.

While this development work started in May 2018, there were bureaucratic delays as well as delays related to tensions between supporting partners. The MoHS disease surveillance unit worked closely with all relevant partners (WHO, CDC, AFENET, HISP-SA) in the second half of 2019 to update and streamline all eCBDS variables, though, and that process generally resolved tensions. The HISP-SA team provided extensive support to the MoHS in the same period, updating and streamlining their main data sets for routine monthly reporting and ensuring that the duplicated data collection was eliminated. The eCBDS was then successfully piloted in 4 out of 16 districts from Oct-19 to Jan-20, with strong support from all stakeholders working actively with disease surveillance. The key actors driving the pilot was Ministry staff, a team from AFENET (a Ugandan NGO specializing in field epidemiology and disease surveillance), a team from HISP-SA doing advanced technical work and system design, and teams from WHO Sierra Leone and CDC Sierra Leone.

Disease surveillance systems typically diagnose both agents/pathogens and syndromes. Some agents/pathogens are relatively easy to diagnose based on clinical observations and/or Rapid Diagnostic Kit (RDT) tests available to clinicians. Syndromes are typically groups of diseases with similar symptoms where lab tests are required to determine the pathogen. When the COVID-19 pandemic appeared, the eCBDS already included the Acute Respiratory Infections (ARI) syndrome, which typically give symptoms similar to flu, and include pathogens like SARS (caused by a coronavirus) and MERS. Given the similarity of ARIs, it took just a few days to accommodate the additional variables needed for COVID-19. The system was thus in place before the first COVID-19 case was confirmed in late March 2022. There have subsequently been minor changes to the variables collected.

The usage of the existing case-based surveillance system was not a given in the early period of the pandemic as new stakeholders pushed for new systems and applications. The so-called “ICT Pillar” established in Feb 2020 became a hotbed of enthusiastic innovators where anybody could table proposals for new apps or systems or research. MoHS staff were not very active in that forum being too busy using the eCBDS to track the pandemic, so the participants from HISP-SA and AFENET tended to provide “reality checks” vis a vis many proposals. The main driver in the ICT Pillar was the Department of Science, Technology, and Innovation (DSTI, a section under the Presidency). They tended to view the number of new apps and initiatives *in itself* as a success criterion, as “proof” that Sierra Leone was a vanguard in Africa in terms of using ICT to combat the pandemic. But there was one very important caveat: all data must be integrated into the eCBIS as per the Minister’s directive.

Whereas many actors in practice did not prioritize that requirement, it nevertheless became a recognized principle enabling the core teams working on disease surveillance to continue strengthening the eCBDS when most of the fly-by-night apps faded away during 2021. For example, the eCBDS team worked with Dimagi and DSTI to import that data into the eCBDS, but it took a long time, data quality was poor, and the app faded away during 2021 due to negligible use, no support, no sustained funding. The experience from the Ebola epidemic in 2013-14 was decisive in uniting key actors to build on their DHIS2 current systems, HMIS and eCBDS instances.
Once established as the primary COVID-19 reporting system, and with the key teams, MoHS, AFENET, WHO, and CDC, all working together, the eCBDS was rapidly rolled out to the whole country. Although COVID-19 dominated the first few months, all the other conditions were included when the COVID-19 waves subsided. Prior to COVID-19 pandemic the eCBDS was operating in only four districts, but with the rapid need for COVID-19 surveillance the scale of the system was fast tracked and rapidly scaled to all 16 districts in the country. The focus became training, which was done incrementally using a training-of-trainers model from February through May 2020. First district health medical technicians were trained then the district staff trained the facility staff. The training includes data capture and surveillance for all diseases, not just COVID-19. Additionally, a virtual training was provided by external DHIS2 administration experts in March 2020 to the core DHIS2 country administration team on DHIS2 design, management, and database scripting.

During 2021 and 2022, the eCBDS has continued its gradual expansion to cover other aspects of disease surveillance, by adding components covering sentinel surveillance of specific diseases like Influenza like illnesses and Bacterial Meningitis, mortality surveillance of specific diseases (laboratory specimens collected from patients dead on arrival), maternal and perinatal mortality surveillance, event based surveillance, and other components related to disease surveillance response, like emergency team deployment planning and other response-related aspects, are in the pipeline.

3.2 Sri Lanka

DHIS2 was first introduced in Sri Lanka in 2011 as a result of the collaboration with University of Oslo related to the master’s program in Biomedical Informatics which started in 2009. The first implementations were related to vertical health programs as pilot projects, but over time these grew into national program systems designed and maintained by the Ministry of Health (MoH). In 2017, in response to the need for more DHIS2 support for the various MoH programs, HISP Sri Lanka was established as an entity specializing in supporting DHIS2 implementations throughout the country.

On the 20th of January 2020 top digital health doctors in the MoH met to discuss the need to collect data on and screen travelers arriving to Sri Lanka from countries with a high prevalence of COVID-19. The first case of COVID-19 was reported in Sri Lanka on the 27th of January 2020. Within two days of that, the digital health doctors in MoH together with support of HISP Sri Lanka had developed a new DHIS2 instance to register all travelers arriving in the country through airports. With the support of the health information unit in the MoH, the solution was presented to the Director General of Health Services who approved the system to be implemented for port of entry monitoring. With the approval, infrastructure, government database cloud hosting, and hardware were rapidly identified through the government ICT Agency. Initially, a small team of three DHIS2 experts at HISP Sri Lanka were able to do the inceptive configuration of the IS, but more human resources were needed to implement it in the entire country with growing requirements. This was addressed by drawing on the large, distributed pool of medical doctors who had completed a government sponsored master's in IS at the University of Colombo. In 2009 the University of Colombo launched a master's in Biomedical Informatics to train medical doctors to be Medical Officers in Health Informatics in the Ministry of Health. Over the last decade, this program has produced a large cadre of medical professions that are able to support the digitization and implementation of ISs.

By early February the port-of-entry (PoE) monitoring system had been implemented at the airport in the country. The cadre of medical informatatitions was called on to train clinicians and PoE screeners. However, it quickly became apparent that to be able to follow-up with travelers and their contacts throughout the country's existing health infrastructure was required. This necessitated a broader active COVID-19 surveillance system that incorporated requirements around quarantine, case surveillance and information of patients receiving treatment at hospitals. Again, the team was called on to develop this system. While analyzing the requirements, it was obvious to the HISP team that all the requirements were not achievable by customization and hence custom developments on the generic DHIS2 platform was required. Due to the limited availability of software developers within the HISP team, they reached out to ICT Agency (ICTA) for development support. ICTA organized a hackathon to obtain support of volunteer developers to contribute to custom developments. The 2-day hackathon organized by the ICTA together with HISP Sri Lanka was supported remotely by the DHIS2 experts from the UiO. Hackathon resulted in several local innovations such as contact mapping visualization app, ICU beds app and several integrations with local information systems.

Prior to COVID-19 Sri Lanka had developed siloed disease or program specific systems. Most of these utilize DHIS2, but there was not a single DHIS2 instance that integrated data across all programs. The unilateral focus to implement the COVID-19 surveillance system spurred deeper connections and collaborations between departments. Prior to the COVID-19 response, the Ministry of Health did not have proper access to the ICTA to work collaboratively on major national implementations due to some internal resistance and politics. During the COVID-19 response the Ministry of Health needed to cooperate with the ICTA for cloud hosting the scaling COVID-19 surveillance system as well as assistance with developing the new applications. HISP Sri Lanka's meta-data configuration for port-of-entry screening was shared with the UiO which then shared it immediately through webinars, the DHIS2 website, and the DHIS2 community of practice with dozens of other countries. This happened in late January almost a full month before the initial WHO interim technical guidelines were published on 28 February 2020. Sri Lanka's port-of-entry meta-data configuration became the initial point of reference for fifty-five countries using DHIS2 for COVID-19 Surveillance as of December 2020.

Towards mid-2020 the COVID-19 surveillance system was more stabilized with several modules implemented and focus was more on strengthening the system. Similarly, further requirements around integrations emerged. The laboratory system called 'Supariksha' for reporting COVID-19 related laboratory testing was developed parallel to the COVID-19 surveillance system. Integration of the laboratory system to the main surveillance system for reporting and visualization was a major requirement. The team from HISP Sri Lanka was able to achieve it with minimal effort following the experience around using DHIS2 web API for development of web apps and integrations in the first half of the year.

In the last quarter of 2020, the global focus was towards COVID-19 vaccination. The HISP Sri Lanka team collaborated with the World Health Organisation (WHO) country office and MoH to produce a module for capturing COVID-19 vaccination information. The designed module was prepopulated with the entire adult population of Sri Lanka converting it to one of the largest DHIS2 based implementations at global level. The system was deployed nationally with the start of COVID vaccination in January 2021. The system also included an aggregated vaccination reporting component and an aggregate vaccine stock reporting in addition to the vaccination registry. Management of the performance of the IS was a major challenge and Sri Lanka collaborated with the UiO core team enhancing performance of the DHIS2 platform which contributed to major performance enhancements to the global product in 2021. The vaccination system was further expanded to produce cryptographically verifiable vaccination certificates by integrating it with DIVOC, a digital tool devised in India to produce vaccination certificates. The design work around vaccination certificates was again based on a collaboration between HISP Sri Lanka and ICTA. The team further expanded the system by producing a vaccination system request platform for submission of digital certificate requests online by providing travel documents. The team subsequently devised data quality assessments to provide insights to the authorities on the quality of data and areas to improve.

4 Case Analysis

The goal of this section is to draw out in both cases the common themes around the bounce forward outcomes observed. These two cases come from very disparate contexts. Given the contextual disparity, this section applies cross-case analysis against established resilience attributes in order to explicate the bounce forward outcomes (Wynn & Williams, 2012). By using established bounce back resilience attributes as a base line, the properties of the bounce forward outcomes are revealed.

Learning - building on instead of building new: Heeks and Ospina (2019) identify *learning* as a key resilience attribute, and a key lesson in the aftermath of the 2014 Ebola outbreak in West Africa was that a more effective response to the next health challenge or public health emergency should be working with existing ISs instead of replacing them or introducing uncoordinated, parallel systems (Keiny & Dovlo, 2015; Kinkade et al., 2022). In the cases of Sri Lanka and Sierra Leone it is evident that this lesson was actualized; however, in different ways and at different points in their respective responses to COVID-19. In the early days of the pandemic, Sierra Leone made the strategic decision to incorporate COVID-19 surveillance into their existing, but yet to be scaled, electronic case-based disease surveillance (eCBDS) system which already covered other acute respiratory infections such as SARs and MERS. The necessity for national COVID-19 surveillance prompted the eCBDS to scale to national level beyond its initial pre-pandemic pilot scale.

Sri Lanka on the other hand, did introduce a new DHIS2 deployment for port-of-entry (PoE) screening as well as broader COVID-19 surveillance system. Sri Lanka did not have existing PoE or case-based surveillance systems, unlike Sierra Leone, to build on at the start of the pandemic. They did, illustrating *plurality*, already have the DHIS2 configuration and hosting resources from implementation of other DHIS2 instances, so while they were not building on existing systems they were building from existing knowledge and capabilities spread over a diverse set of actors. When Sri Lanka needed to begin to track COVID-19 vaccinations they were able to expand their DHIS2 based, existing immunization registry to include COVID-19 vaccinations and scale it to the entire population.

Bounce forward outcomes reveal themselves from this analysis. A purely bounce back resilient response would suggest that the nature of the system that existed prior to the pandemic would not be significantly different from after the COVID-19 response. However, in each of these cases the existing IS were substantially, permanently modified and scaled, and in Sri Lanka several new IS were developed and rapidly deployed. To-date, the IS that existed before COVID-19 are significantly expanded and have not shown a movement back to a pre-response state.

Capacity, plurality, and self-organization: Park et al. (2021) point to the necessity for robust IS to be able to leverage a *plurality* of actors in their response to a shock or stressors. Correspondingly, Kinkade et al. (2022) highlight the importance of leveraging and building on existing technical and implementation *capacity* for effective IS responses to global pandemics. In Sierra Leone both of these attributes played out in the COVID-19 response. First, a diverse set of technical experts contributed to the expansion of the eCBDS system. The leadership and decision to expand the eCBDS instead of building a parallel system came from the Ministry of Health while the lead system developers were HISP-SA that had a long history of providing technical support to the eCBDS. Cascading implementation and use capacity became a key focus to scale the eCBDS. Subsequently, district health medical technicians, district staff, and facility staff were trained following a training-of-trainers approach in addition to a virtual training to build DHIS2 administration expertise within the Ministry of Health team.

In Sri Lanka a large cadre of DHIS2 administration and implementation capacity had been cultivated in the IS program at the University of Colombo prior to the pandemic that were utilized to develop the PoE screening system, the case-based surveillance system, and the expansion of the immunization registry. Demonstrating the *self-organization* and *plurality* attributes, a coordinating task force was established including ministry of health, partnerships with NGOs, namely HISP Sri Lanka, as well as cross departmental and ministerial collaborations forming. Sri Lanka utilized a diverse set of actors that contributed in a coordinated manner to expand the system functionality. Sri Lanka embarked on a massive training program, again leveraging the cadre of IS experts, for front-line PoE screeners, COVID-19 testers, and vaccine administrators.

Bounce forward outcomes are evident in this analysis as well. In both cases the IS response to COVID-19 prompted a closely coordinated, enormous expansion of implementation and technical expertise throughout the entire health system. In both cases, lasting linkages and cooperation between previously siloed governmental departments and partners were established. These new collaborations additionally support the continued expansion and scale systems in these countries.

Transformability, adaptability, and agility: Folke et al. (2010) indicate that *transformability* or the capacity to create new stable domains and to cross thresholds into new trajectories is a principal attribute of resilient IS. Their notion of new trajectories suggests that resilience is more than a static, rigid state. They see that resilience should have a degree of flexibility and *adaptability* given new inputs. Amarakoon et al. (2021) also stress the necessity for rapid institutional change and *agility* as a tenant for innovation. In these cases, we see the ability of the IS in both countries able to rapidly change and produce new innovations as the needs evolved over the course of the pandemic response. Sierra Leone's innovation is centered in their incorporation of COVID-19 case surveillance into their existing eCBDS. Here we see Sierra Leone's eCBDS demonstrated *robustness* as the broader eCBDS was able to maintain its characteristics and performance. We also see evidence of *adaptability* and *agility* as the eCBDS has continually been able to rapidly develop and incorporate new reporting and analytics functionalities.

Sri Lanka has displayed many examples of innovation, *adaptability*, and *transformability* over the course of their pandemic response. Particularly, Sri Lanka pioneered a PoE screening and case-based surveillance systems before WHO had released any official guidelines. A component of Sri Lanka's case-based system was the agile development of new applications. *Transformability* became apparent as Sri Lanka's IS and those supporting them pivoted from PoE screening to case-based surveillance to vaccination registries, utilizing DHIS2 for each case. Highlighting the technical *diversity* of Sri Lanka's pandemic response, where the various other non-DHIS2 systems that were established and then connected to their various DHIS2 instances.

Bounce forward outcomes are clear in both bases as systems have incorporated innovations and increased functionality in reaction to the pandemic response. In Sri Lanka, specifically, the diversity of systems has increased, and the interoperability of all systems required for the pandemic response has been established.

5 Findings: Bounce forward attributes

Consistent with the critical realist approach, we seek to instantiate the bounce forward resilience attributes that are connected to outcomes observed in these cases. These attributes are not intended to replace the resilience attributes described already in the literature as we have illustrated that these are present in the cases. This section further illustrates that the existing bounce forwards attributes are insufficient, thus we introduce new hypothetical attributes through the retroduction process (Wynn & Williams, 2012). New hypothetical attributes and present, established bounce forward attributes, through empirically corroboration and triangulation, are refined and where possible combined into new bounce forward resilience attributes that offer sufficient explanatory power over the outcomes observed.

Many countries lack the governance mechanisms that are effective at mitigating technical and institutional fragmentation. In countries with limited capacity for coordination, plurality is a double-edged sword. It often results in fragmentation with limited sustainability, in reality a “bounce backwards” (Sahay, Surdararaman, & Braa, 2017). This was observed to be the exact outcome in several countries following the Ebola pandemic in 2014 (Kieny et al., 2015). Russpartrick et al. (2021) in their initial analysis and reemerging as a hypothetical attribute through the retroduction process of these cases point to local/support expertise as a bounce forward attribute. Russparrick et al. (2021) confine those capacities to only technical i.e., translating requirements into generic features and proficiency in DHIS2 functionality, data models, and components. While these capacities certainly exist in these cases, we also see clear existing capacity for coordination and leadership evident as additional hypothetical attributes. IS knowledge is not confined to the purely technical. Arguably more important is the knowledge to be able to manage the direction, implementation, and coordination of IS through the development of standard operating procedures and high-level coordinating bodies such as working groups or taskforces (Russpatrick et al., 2019). In Sri Lanka a high-level, cross-sectoral, and departmental taskforce, which had been historically difficult to achieve, was established to coordinate the IS response to the pandemic. In Sierra Leone key personnel in the ministry of health and technical advisors from the CDC and WHO cooperated to build a clear vision for and management of the eCBDS expansion. That vision for the eCBDS included a long-term strategy to continually integrate new disease surveillance and reporting components whenever possible. This strategy was based upon the hard lessons learned from their experience during the 2014 Ebola pandemic.

Agility and adaptability are key in a time of crisis response and arise as hypothetical attributes in this analysis (Amarakoon et al., 2022, Folke et al., 2010, Erol et al., 2010). However, somewhat paradoxically, Janssen & Voort (2020) note that government bureaucracy can bolster adaptability. They argue that “adaptivity requires new forms of collaboration and shared decision-making and accountability by government and non-government actors” (p. 6). Adaptability is driven by the coordination of existing government institutions. Supporting this notion, the self-organization and plurality resilience attribute also points to the fact that close coordination between a diverse set of actors leads to increased adaptability (Heeks & Ospina, 2019, Park et al., 2022). Agility and adaptability are not the same, however. Janssen & Voort (2020), also highlight that agility can hinder adaptability. A rapid, agile process to address problems can lead to lock-ins where some ideas and approaches receive the majority of focus at the expense of others. Hyper fixation on a single solution can hinder the ability to coordinate between a diverse set of actors. Conversely, without agility innovation may be limited. A degree of agility is required for non-standard solutions to be identified, refined, and implemented (Amarakoon et al., 2022). The key lesson is that agility must be allowed while coordinated, stable adaptability is maintained at the same time. These two cases both exemplify this lesson. The rapid agile expansion of the eCBDS in Sierra Leone followed a long-term strategy and was closely coordinated by the Ministry of Health. Various actors were blocked from implementing their own parallel systems and were instead directed to contribute their ideas and innovations into the adaptable eCBDS. Similarly, in Sri Lanka agile innovations were incorporated into the existing, closely coordinated case-based detection and immunization registry systems.

We have established that coordination is key to adaptability, and agility is an essential process for innovation and bounce forward outcomes. We have also argued that in both cases there existed the coordinating mechanisms and capacity to be adaptable and incorporate innovations as they were needed. Therefore, we introduce ***capacity for coordinated agility*** as a critical bounce-forward attribute.

A key ingredient in both Sri Lanka's and Sierra Leone's IS development and innovations expansion are the configurability of the DHIS2 platform (Russpatrick et al., 2021, Amarakoon et al., 2022, Kinkade et al., 2022). Configurability, as applied to DHIS2, means that system administrators can adapt the generic, existing features to specific data capture and analysis needs without modifying the codebase (Li & Nielsen, 2019). Both cases were able to rapidly configure existing DHIS2 instances to incorporate new reporting needs, adding COVID-19 to the eCBDS system in Sierra Leone and expanding the vaccine registry in Sri Lanka. Beyond configurability, extensibility is evident as a new attribute in new case analysis. Extensibility means that a user can extend the software platform, create new features or applications, and connect with other platforms without having to modify the original codebase (Rytter & Jørgensen, 2010). Exemplifying the extensibility of the DHIS2 platform, Sri Lanka's hack-a-ton was able to rapidly develop new applications that were necessary for COVID-19 surveillance. We introduce the concept of extensibility in order to refine Park et al. (2022)'s diversity attribute as well as Russpatrick et al. (2021)'s platform configurability attribute. As originally defined, the platform configurability attribute included Sri Lanka's development of new DHIS2 applications. Configurability is not extensibility, and therefore Russpatrick et al. (2021)'s definition of this attribute was too broad. Likewise, Park et al. (2021) point to the need for a diversity of digital solutions to be built on shared infrastructure; however, extensibility not only stresses diversity but also the ability for systems to interoperate, connect and share data, to meet end-user needs. Sri Lanka's IS landscape is significantly more connected and interoperable than prior to the pandemic, so therefore by reframing the concept of diversity to extensibility, we expand the notion to include the increased IS connectivity.

A technical platform classification has been surprisingly lacking in all IS resilience attributes. To fill this gap, we bring in the concept of innovation platforms. Innovation platforms are the foundation in which implementers can build complementary applications, services, or technologies (Gawer, 2014). Innovation platforms are extensively described in the existing literature as having layered architecture, an open application programing interface (API), modular components, and other technical resources such application programing kits (APKs) (Russpatrick et al., 2020; Gawer, 2014; Bonina et al., 2021). The advantage with being modular and application based is that Sri Lanka's new functionalities were able to be bundled into new applications as opposed to editing core or existing functionalities. Additionally, innovation platforms enable multiple actors to contribute at the same time. Again, we observed this as a loose collection of globally distributed developers all contributed to multiple, new applications in Sri Lanka by utilizing the DHIS2 platform technical resources and API. In their analysis of these same cases both Kinkade et al. (2022) and Amarakoon et al. (2022) specifically point to the utility of the DHIS2 open API in facilitating the extensibility observed. Therefore, it is evident that the inherent properties of DHIS2 as an innovation platform are a large factor in the bounce forward outcomes observed.

Locally managed platform infrastructures are revealed as a hypothetical attribute which are critical technical factor for bounce forward outcomes. Here we refer to infrastructure as the technical building blocks of the IS in these cases. These are locally managed server hosting and access, ownership of DHIS2 instances, managing reporting devices, and managing data analytics feedback mechanisms, i.e. dashboards, reports, etc. In prior analysis of these cases and in our own data analysis, we see that national control over infrastructures enabled a diverse set of actors and contributors to provide inputs to these systems (Russpatrick et al. 2021). However, it should be noted that national ownership of physical servers is not necessary as Sierra Leone's IS are hosted in the cloud because there is not a data center in the country. Amarakoon et al. (2022) notes that the agility at which Sri Lanka was able to respond to the rapidly developing needs was in part since they were able to host their own instances of DHIS2. The government was not dependent upon third-party hosting providers, proprietary systems, or service provider vendor lock-in. Similarly in Sierra Leone, the government has complete control of their DHIS2 instances, whether hosted by a European cloud provider (Dediserve) or in a South African data center (HISP-SA). This allowed system administrators to quickly make changes, update versions of DHIS2, and scale new reporting pathways. They are also easily able to change and scale server resources when needed because the servers are cloud hosted and not on-premises as is the case in Sri Lanka.

Configurable, extensible innovation platform infrastructure is a culminating attribute that describes and combines the various IS technical properties and platform classification that enabled both Sri Lanka and Sierra Leone to advance their systems beyond a pre-COVID-19 state.

Many studies and several existing resilience attributes stress the necessity for long-term capacity building and learning. Without question, these are critically important in our own case analysis (Heek & Ospina 2019; Russpatrick et al., 2021; Kinkade et al., 2022; Amarakoon et al.,2022). However, to evaluate the bounce forward outcomes observed we must ask ourselves if this is sufficient.

For this attribute description we repurpose and draw an analogy with the biological term “action potential” to describe the nature of human resource availability in these cases. In biological systems, action potential is the molecular process of cells passing ions between each other. The exchange of ions is the underlying biological process that coordinates the contraction of the heart, muscle contractions, and neurotransmitter molecules passing between neurons (Hodgkin & Huxley, 1952). Essentially, action potential is the fundamental process that enables us to move our bodies, keeps our hearts beating, and develop thoughts. In ISs, human resources, as opposed to ions in biological systems, drive change, movement, and create new thoughts. The body must contain a sufficient reserve of various ions to enable action potential even in a time of biological stress, injury or illness. Similarly, the IS must have sufficient human resources to maintain functions not only in a time of calm, but also in a time of stress, e.g., pandemic response. Ions unto themselves do not produce action potential. Ions must be incorporated into a biological system that has the organization and processes to utilize them for action potential (Williams, 1981). Likewise, isolated human resources that may have capacity but lack the process and organization to act are essentially inert, ineffectual.

Sri Lanka had an extended network of informatics and DHIS2 experts in reserve that were able to be unleashed to rapidly scale new systems and massively expand capacities through training across the country. Sri Lanka was able to create the structures to channel this reserve of human resources into positive outcomes. In Sierra Leone, a highly structured capacity building approach was implemented to rapidly cascade training down to all levels. We see the processes that were established in Sierra Leone were able to harness existing human resource capabilities to quickly expand them to thousands of new eCBDS users. In summary, action potential, as applied to IS, is having sufficient human resources and the means to coordinate their actions for change. Thus, we introduce ***human resource action potential*** as a bounce forward attribute.

6 Conclusion

This paper explores the bounce forward outcomes of the IS in response to COVID-19 in Sri Lanka and Sierra Leone. We note that both Sri Lanka and Sierra Leone went into the pandemic response in very different places, but we observed in both countries that the IS and the capacity to use those systems were significantly expanded due to the shock of the pandemic. The goal of this paper is to derive new bounce forward attributes that were present in the IS landscape of these countries prior to the pandemic. In this paper we have extended the analysis of Sri Lanka and Sierra Leone IS response to the COVID-19 pandemic through fresh data analysis as well as incorporating recent analysis of these cases and others in relevant peer-reviewed literature. Ultimately, we defined capacity for coordinated agility, configurable and extensible innovation platform infrastructure, and human resource action potential as these attributes.

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