Investigating the use of digital solutions in the COVID-19 pandemic: an exploratory analysis of eIR and eLMIS in Guinea, Honduras, India, Rwanda and Tanzania

CERGAS – Centre for Research on Health and Social Care Management at SDA Bocconi & MMGH – MM Global Health Consulting

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Acronyms

AEFI	Adverse Events Following Immunization
ANSS	National Health Security Agency
BMGF	Bill and Melinda Gates Foundation
CDS	COVID-19 Vaccine Delivery Support
CERGAS	Centre for Research on Health and Social Care Management
CNIC	Computerized National Identity Card
CNPRP	Coronavirus National Preparedness and Response Plan
COVAX	COVID-19 Vaccines Global Access
Co-WIN	COVID-19 Vaccine Intelligence Network
CRVS	Civil Registration and Vital Statistics
DHIS	District Health Information System
DIVOC	Digital Infrastructure for Verifiable Open Credentialing
eIR	Electronic Immunization Registries
eLMIS	Electronic Logistics Management Information Systems
EPI	Expanded Programme for Immunization
eSIGL	Système d'Information Electronique de Gestion Logistique
eVIN	Electronic Vaccine Intelligence Network
Gavi	Gavi, the Vaccine Alliance
GDSN	Global Data Synchronization Network
HW	Health Worker(s)
LMIC	Low- and Middle-Income Countries
MMGH	MM Global Health
MoHCDGEC	Ministry of Health, Community Development, Gender, Elders and Children
NIDA	National ID Agency (Rwanda)
PAHO	Pan American Health Organization
PPE	Personal Protective Equipment
RBC	Rwanda Biomedical Center
RI	Routine Immunization
SIA	Supplementary Immunization Activities
SIIS	Sistema Integrado de Información en Salud
SIVAC	Subsistemas de Información de Vacunación
SRMP	Smart Rwanda Master Plan
SMS	Short Messaging Service
TImR	Tanzania Immunization Registry
TMDA	Tanzania Medicine and Medical Devices Authority
UIP	Universal Immunization Programme
UNDP	United Nations Development Programme
USAID	United States Agency for International Development
VIMS	Vaccine Information Management System
wMSSM	Web-based Medicine Supplies Stock Management
WHO	World Health Organization

Commissioned by the Bill & Melinda Gates Foundation (BMGF), with the support of Gavi, the Vaccine Alliance (Gavi) and the World Health Organization (WHO), the Centre for Research on Health and Social Care Management (CERGAS) at Bocconi University and MMGH Consulting GmbH (MMGH) are conducting a comprehensive evaluation of the impact of electronic Immunization Registries (eIR) and electronic Logistics Management Information Systems (eLMIS) on routine immunization in Guinea, Honduras, India, Rwanda, and Tanzania. A supplementary report exploring the use of eIR and eLMIS in these five countries during the past months has also been developed to capture emerging insights on the use of these digital solutions as part of the pandemic response.

The report hereafter includes five exploratory case studies based on preliminary perceptions and available evidence gathered by key informants from Guinea, Honduras, India, Rwanda, and Tanzania. They provide initial insights on how such digital solutions have been adapted at country level. An analysis of the available literature complements the country focus work describing how eIR and eLMIS have supported

COVID-19 vaccination efforts in low- and middle-income countries (LMICs), as well as provides insights, where available, on the impact of these digital solutions on routine immunization during the pandemic.

Executive summary

This report presents a series of brief case studies supported by the existing literature on the deployment of digital solutions during the COVID-19 pandemic. It specifically describes how electronic Immunization Registries (eIR) and electronic Logistics Management Information Systems (eLMIS) have been newly developed and/or repurposed in Guinea, Honduras, India, Rwanda, and Tanzania. Importantly, the findings are influenced by the state of the implementation which, because of the delayed availability of COVID-19 vaccines in the LMICs, is still in its early phase.

Overall, Tanzania and India relied on their existing eLMIS solutions to roll-out the COVID-19 vaccines, however, resorted to the *de novo* development of complementary eIR solutions for tracking of beneficiaries. The latter are to be integrated in the future with the digital infrastructure and systems that currently support routine immunization efforts in these countries, including Civil Registry and Vital Statistics (CRVS) systems. Conversely, Rwanda implemented a separate COVID-19 EIR Tracker as an additional module to its District Health Information Software (DHIS2) platform which also hosts the eIR for routine immunization. Finally, Honduras and Guinea attempted to use the existing eIR and eLMIS systems, respectively, but succeeded only partially in adapting them and did not ensure deployment of all the required functionality across the country, resulting in the need for implementation of multiple parallel solutions.

Several key lessons have emerged from the countries analysed, with support from the literature. The findings in this report clearly highlight the value of simplicity and flexibility in the design of the digital solutions, as well as the need to support local capacity to develop and adapt the tools to the specific context. The roll-out of many concurrent systems to fill gaps in the existing implemented solutions should be avoided as a source of unnecessary complexity. Building local competencies – that is, not continuing to reply upon expensive and time-bound external resources – also emerged as a clear success factor necessary to ensure real ownership and sustainability, as well as the need to strengthen the workforce with extended training and involvement of community health workers in the data collection process to reach zero-dose children. Finally, the need for a strong political commitment and a clear vision for the use of these digital solutions is essential to secure the domestic financing required for sustainable investments.

This report serves as a call to "*keep it simple and keep it local*." Development partners should invest in existing systems and human resources avoiding duplications and ensuring consistency and streamlined processes, wherever possible. Critical observations about the further roll-out of digital solutions over the next six months of the pandemic, coupled with the completion of the broader evaluation on the impact of these solutions, will provide additional information to guide the emerging learning agenda in this area which can further inform future investment decisions on the sustainable scale-up of eIRs and eLMIS as part of integrated health management information systems.

1 Introduction

1.1 Vaccination as a pillar in the fight against the pandemic

The impact of COVID-19, including both the health burden as well as the social and economic consequences of the control measures, has been profound. Vaccination has been and remains a critical pillar of the global fight against the pandemic: the WHO Global COVID-19 Vaccination Strategy lays out an approach that articulates a path to full global recovery which first prioritizes the "*unfinished agenda*" towards vaccination of the most vulnerable populations. The Strategy explicitly notes that vaccination targets should be driven by "*an analysis of what is required to achieve specific goals given local circumstances*" (WHO, 2021).

The delivery of COVID-19 vaccines, however, has faced several challenges in low- and middle-income countries (LMICs), particularly due to continuing constraints in access to sufficient supply, complex and changing policies, human resource availability and financing of the vaccine roll-out, coupled with vaccine hesitancy in some places. As the vaccine supply situation improves and solutions are found to address contextual challenges, the clear identification of and provision of access to target populations, including monitoring of the success in reaching them, as well as the effective management of vaccine supply, will be critical success factors. Tools that can facilitate and strengthen these activities, such as eIR and eLMIS, will bring benefit to this effort and to the health system overall.

1.2 The role of digital solutions in vaccine delivery: opportunities and challenges

Digital solutions have the potential to play an important role in enhancing the efficiency and effectiveness of immunization delivery to respond to both existing and newly emerging needs, constraints and threats, as well as to monitor programme performance and impact. This includes providing critical information across a range of activities such as identifying and prioritizing vaccine recipients, tracking vaccine inventories and supply, ensuring efficient and equitable vaccine distribution, monitoring uptake and adverse events following immunization (AEFI), providing certificates as proof of vaccination, as needed, and analysing and using data to optimize operations.

The contribution of electronic health information systems in improving health service delivery and management is widely recognised, as is the importance of stakeholder engagement in their successful implementation and adoption through change management (Khubone et al., 2020). The scale and complexity of the pandemic has only reinforced the central role of technology across the COVID-19 vaccine delivery lifecycle. As stated, digital solutions can inform and support vaccination from the planning and management phase to post-vaccination monitoring as summarized below in Table 1.

Table 1: *Digital solutions across the vaccination delivery lifecycle as adapted from Eichholtzer et al. (2021)*

	Lifecycle				
	Planning and Management	Supply and Distribution	Programme Delivery		Post Vaccination
Functions	**Prioritization** Identification and prioritization of eligible beneficiaries from existing databases and optimization of outreach with geospatial information systems (GIS).	**Supply Chain** Streamlined management of supply chain and local demand for optimised distribution and minimal wastage.	**Mass Communication** Use of digital tools for community engagement, to inform about campaigns and prioritization strategy, and monitoring of social media.	**Registration** Tools for scheduling and reminding of appointments, and verification of eligibility.	**Monitoring** Adapting surveillance systems for monitoring of events attributable to vaccination and effectiveness of the immunization.
	Analytics Se-up of tools for monitoring and evaluation supporting the performance management of the campaign	**Cold Chain** Control of the cold chain of vaccines to ensure appropriate storage condition requirements are met.	**Records** Set-up of individual-based immunization records, notably keeping track of the type of vaccine received and date, linking to patient ID.	**Trainings** Training of healthcare workers (e.g., vaccine preparation protocols, verification of medical history, monitoring of adverse effects)	**Certificates** Provide verifiable evidence of vaccination status.

As part of their response to the pandemic, many LMICs have leveraged existing digital solutions used for routine immunization (RI), specifically eIR and eLMIS, to manage COVD-19 vaccination more efficiently. Key differences between the delivery of COVID-19 vaccines and RI, however, have necessitated refinement of the technology and reconsidering existing processes relevant for RI.

The focus of most eIRs is on the identification of individual children or adolescents, typically within a health facility catchment area, and on ensuring timely completion of their vaccination as per the national schedules. The systems also facilitate coverage estimation and allow for individualised follow-up of vaccine recipients based on their age (or other target parameters) and geographical location. By doing so, an eIR creates permanent records that can be accessed by the health system when required.

In contrast, COVID-19 vaccine delivery and the broader pandemic response have necessitated expanding the scope of the eIRs to include a much wider target population (de facto the entire population), applying dynamic target groups prioritisation, and registering large numbers of new individuals in a short period of time. Furthermore, the response to the pandemic has required additional activities including testing, tracking, and tracing of contacts, as well as the scheduling of immunization appointments and the reporting and tracking of adverse events following immunization (AEFIs). Unfortunately, most eIRs in use were not designed to seamlessly extend to the whole population, nor to directly support these additional activities and store related information or to have interoperability with other systems tasked with those undertakings. While most eIRs are, in principle, capable of sharing data with other systems, the possibility of such data exchange and integration needs to be actively designed and established, the complexity of which should not be underestimated.

Similarly, for eLMIS, the COVID-19 pandemic has drawn attention not only to the fragile nature of global supply chains, but also to the need for real-time data to track and trace COVID-19 vaccine stock. The demand for vaccines is unprecedented in size and speed and so are the risks. Countries are now required to manage several different vaccines (at times, more than 5) with different storage requirements and shelf-lives, sometimes very short. The complexity of the related tasks (e.g., stock management, forecasting, reordering and cold chain management) is high. Ensuring the ability to track and trace every batch, let alone every vial, becomes a critical aspect. This can be particularly challenging if the eLMIS within a given country is not configured to capture data from barcodes, and if the eLMIS is not interfaced (e.g., with the Global Data Synchronization Network - GDSN) which enables the manufacturers' barcode data (i.e., product name, unique identifier, source, batch, expiry date) to be transmitted to and validated by their customers. In the ideal scenario, to effectively track and trace every vaccine vial, there are serialized barcodes at the vial level, the eLMIS is interfaced with the GDSN and other in-country systems, including eIRs, and networked mobile applications are in the hands of every health worker and in-country supply chain worker. More importantly, those operators are well trained and committed to the use of these digital tools to manage the vaccines. Finally, eLMIS have an important role to play in two additional areas. Avoiding wastage is a first area of critical concern for most countries, particularly in a situation of perduring supply constraints and short shelf lives This necessitates a high degree of visibility throughout the distribution system. A second area of growing focus is the influx of falsified vaccines into the supply chain, as has already been documented in Nigeria and India. To address these risks, several countries are implementing or adapting eLMIS platforms for COVID-19 vaccines as part of a broader effort to use technology to plan and manage vaccine distribution and administration.

2 Methodology

2.1 Desk Review

An initial desk review was performed to gather existing evidence on the use of digital solutions such as eIR and eLMIS during the pandemic. As a first step, the electronic database Web of Science was searched as a key resource for interdisciplinary research publications. Appendix 1 provides a summary of the search terms and strategy as well as the number of articles retrieved at each step. The results from this database search included 7 articles. However, upon examination of the title and abstract, 5 articles were excluded as presenting evidence only on the impact of the pandemic on RI without reference to digital solutions. Two articles met inclusion criteria as they provided information on the use of digital solutions, specifically the use of eIR to maintain RI delivery during the pandemic.

Based on the limited evidence retrieved from this first database search, a subsequent online exploration of academic and grey literature was performed. Additional research articles, blog posts, and reports from health agencies and international organizations active in the field of immunization were identified providing further information on the use of these electronic tools during the pandemic. Table 2 provides a list of the five focused research articles retrieved from both searches.

Table 2: *List of relevant publications retrieved from the desk review*

Year	Author	Title	Journal
2020	Chandir et al.	Impact of COVID-19 pandemic response on uptake of routine immunizations in Sindh, Pakistan: An analysis of provincial electronic immunization registry data	Vaccine
2021	Siddiqi et al.	Using a low-cost, real-time electronic immunization registry in Pakistan to demonstrate utility of data for immunization programs and evidence-based decision making to achieve SDG-3: Insights from analysis of Big Data on vaccines	International Journal of Medical Informatics
2021	Rana, et al.	Post-disruption catch-up of child immunisation and health-care services in Bangladesh.	The Lancet Infectious Diseases
2021	Gupta et al.	The COWIN portal – current update, personal experience, and future possibilities	Indian Journal of Community Health
2020	Wasswa et al.	Uganda's Public Health Emergency Supply Chain System in the Awake of COVID-19 Emergency Response: Method and Performance	International Journal of Science and Research (IJSR)

2.2 Case studies

The development of case studies in Guinea, Honduras, India, Rwanda, and Tanzania was undertaken with the objective to uncover more detailed insights and specifically: (a) how eIRs and/or eLMIS have been used to support COVID-19 vaccine delivery; and (b) the role these digital solutions have played in supporting routine immunization during the pandemic. To achieve these objectives, a specific set of research questions was developed as outlined in Table 3.

Table 3: *Questions regarding use of digital solutions in support of COVID-19 vaccination and routine immunization during the pandemic*

Theme	Questions
eLMIS	○ Is there an electronic tool used for logistics management of C-19 vaccines? ○ What was the driving factor for the decision for using this tool? ○ What features are included? ○ If an already-existing eLMIS for immunization is used for C-19, were there additional features that needed to be adapted to accommodate the delivery of C-19 vaccines? How was the tool adapted for C-19? ○ What was the cost of rolling-out/adapting the tool for C-19? ○ What is the envisioned future use of the tool (replacement/integration with eLMIS/use for routine immunization)?
eIR	○ Is there an eIR tool used for C-19 vaccination tracking? ○ What was the driving factor for the decision for using this tool? ○ What features are included? If an already-existing eLMIS for immunization is used for C-19, were there additional features that needed to be adapted to accommodate the delivery of C-19 vaccines? How was the tool adapted for C-19? ○ What was the cost of rolling-out/adapting the tool for C-19? ○ What is the envisioned future use of the tool (replacement/integration with eIR/use for routine immunization)?
Routine Immunization	○ How well are RI activities being maintained during the pandemic? ○ What is your perception on the usefulness / effectiveness of eIR/eLMIS tools in maintaining RI service delivery during the pandemic?

Key informants for each country were identified and contacted, including representatives from national immunization programs, development partners and local research institutions. Respondents were asked to provide specific information about the practical deployment of eIR and eLMIS for both COVID-19 vaccination and RI, as well as share their reflections on these tools and their potential future use. During the months of August-October 2021, key informant interviews were conducted as summarized in Table 4. Semi-structured interviews were accompanied by the administration questionnaires through email as well as online using Survey CTO. In addition, during a research visit to Tanzania in October 2021, detailed information was collected in the country during face-to-face discussions.

Table 4: *Semi-structured interviews and questionnaires with key informants*

Country	Timing of responses	Informants
Guinea	30 Sep 2021	Five responders from departments within the Ministry of Health: (1) Strategy and Development Office (Bureau de Stratégie et Developpement); (2) Expanded Programme on Immunization (Programme Élargi de Vaccination [PEV]); (3) Integrated Logistics Management Unit (Unité de Gestion Logistique Intégrée). One responder from the University Gamal Abdel Nasser de Conakry.
Honduras	28 Sep 2021 (3 responses) 01 Oct 2021 (1 response)	Four informants from three agencies within the Government of Honduras: (1) National Health Statistics Unit (Área Estadística de la Salud [AES]); (2) Ministry of Health; Expanded Programme on Immunization (Programa Ampliado de Inmunizaciones [PAI]); (3) Management Planning and Evaluation Unit (Unidad de Planeamiento y Evaluación de la Gestión [UPEG])
India	01 Sep 2021	One responder from United Nations Development Programme (UNDP)
Rwanda	16 Sep 2021, 29 October 2021	Three responders from Rwanda Biomedical Centre (RBC), One responder from HISP Rwanda, One responder from UNICEF, Team from CIICHIN
Tanzania	25 Aug 2021, 28 Sep 2021, 22 Oct 2021	Twelve responders from the Ministry of Health, Community Development, Gender, Elderly and Children (MoHCDGEC), the National Institute for Medical Research (NIMR) Mbeya Medical Research Center (MMRC), inSupply Health / JSI, and PATH country office.

3 Findings on the use of eIR and eLMIS solutions for COVID-19: Current snapshot

3.1 Findings from the desk review

Although limited in geographic scope and referencing a pandemic in full evolution, findings from the desk review provide early insights on 13 countries.

3.1.1 eIR

With routine immunization, eIRs have had a positive impact on data quality and facilitated the use of data for decision-making. The real-time tracking of RI performance with the possibility to implement quick remedial measures emerged as a first important finding.

In **Pakistan**, the Zindagi Mehfooz (Safe Life) eIR (ZM-EIR) was able to detect discrepancies in routine immunization coverage at individual level and across geographic areas (Siddiqi et al., 2021). For example, in Sindh Province, data directly accessed from ZM-EIR indicated that COVID-19 had a significant impact on the coverage of routine immunization with a decrease of 53% in the number of vaccinations administered in the first six months following the pandemic outbreak compared to historical baseline coverage data. The data analysed from ZM-EIR also highlighted differences in vaccination coverage between rural and urban areas, with the lowest levels noted in rural areas followed by urban slums (Chandir et al., 2020).

In **Bangladesh**, similar findings emerged where the District Health Information System 2 (DHIS2) eIR was able to capture more sensitive and specific data which indicated a greater disruption of immunization services in remote rural subdistrict areas (Rana et al., 2021). In both instances, eIRs were used to track and target defaulters to improve immunization service delivery through evidence-based performance management (Chandir et al., 2020).

In these two countries, eIRs have helped ensure equitable delivery of routine immunizations during the pandemic and have also played a substantial role in tailoring catch-up vaccination campaigns for target populations.

A second area of importance refers to the contribution of eIR to more efficient processes for COVID-19 vaccine delivery. For example, **Pakistan** launched an online platform[1] on which citizens could register for vaccination using their computerized national identity card (CNIC). Alternatively, they could also send a SMS to a dedicated number with their CNIC and receive a unique PIN Code which they were requested to show at the vaccination centre for verification. After receiving the vaccine dose, citizens also had access to their vaccination certificates on the same platform. All the data were captured in the National Immunization Management System (NIMS) (Government of Pakistan, n.d.).

The Government of **Jamaica** rolled-out Dimagi's CommCare solution nationwide in June 2021 as a COVID-19 vaccination management platform with the support of UNICEF and the Private Sector Vaccine Initiative (PVSI). The system allowed for registration of individuals for vaccination, tracking of doses administered, and monitoring performance in real-time. Healthcare workers using the software through tablets were able to report at a speed that was three times faster in registering clients than the paper-based tools with which the vaccination drive had started, noting only a two-week transitioning period between the paper and electronic processes (UNICEF, 2021).

The strengthening of vaccine distribution is a third important area where eIRs positively impacted the COVID-19 vaccine delivery. In several countries, the improved tracking of COVID-19 vaccination demand through eIRs also informed the management of vaccine distribution through the available logistics management systems including those with eLMIS technologies, thus optimizing vaccine allocation and minimizing the opportunity costs for travel and waiting times (Hall et al., 2021).

Positive outcomes of the use of electronic tools were often the consequence of a fast-tracked customization of existing systems or the quick roll-out of relatively simple and straightforward digital solutions. In **Lao PDR**, **Sri Lanka**, **Mozambique**, **Guinea-Bissau**, **Cape Verde** and **São Tomé and Príncipe**, for example, the DHIS2 COVID-19 eIR was quickly adopted, offering daily monitoring of COVID-19 vaccination registrations, vaccinations, and AEFI as well as real-time monitoring and supervision. In some of these countries, such as São Tomé and Príncipe, this was the first attempt to roll-out an eIR at a national scale. Its rapid adoption was attributed to its easy customization to local needs and to the support provided by a regional community of practice consisting of users, developers, and implementation partners (DHIS2, n.d.). Similar flexibility to customize to local needs was adopted in Lao PDR which deployed DHIS2 as its digital solution to support both vaccination and case management (DHIS2, n.d.). Sri Lanka also leveraged the DHIS2 platform to include an eIR, as well as stock management and dashboard features. This platform has since also been integrated with India's Digital Infrastructure for Verifiable Open Credentialing (DIVOC) for the provision of certificates (Amarakoon, 2021).

Despite the capacity of eIRs to support equitable and efficient service delivery, one of the limitations observed was the risk of marginalization of those who do not have access to a smartphone or computer and, thus, are unable to utilize the tools and access the services (Mukherji, 2021). Further challenges in India have been noted, including: (i) the availability of the respective App only in English and not in local languages; (ii) the inability of illiterate population groups to use the App; (iii) the uneven internet

[1] https://nims.nadra.gov.pk/nims/

connectivity; and (iv) the limited public health infrastructure, and electricity availability (Sharma, 2021 & Gupta et al., 2021). Similar questions around equitable access to mVacciNation in **South Africa** have also been raised (Abbasi, 2021).

3.1.2 eLMIS

Findings from the desk review also provided examples of how countries have leveraged eLMIS during the pandemic to support the management of COVID-19 health commodities. eLMIS have provided positive contributions to the continued monitoring of the supply chain and the assurance of continuity of supply, reducing the risk of vaccine stock-outs.

In **Uganda**, the pandemic response team used the existing electronic Emergency LMIS (eELMIS) to ensure continuity of medical supplies. This system was introduced as part of the 2018-2019 Ebola preparedness drive and was adapted in 2020 with the support of Management Sciences for Health (MSH) to incorporate and provide a streamlined supply of COVID-19 commodities. Data from the system is used for management and provision of the supplies essential in the COVID-19 response to meet the needs of hospitals and avoid stock-outs (MSH, 2020). The eELMIS has been implemented from the national to the facility level and provides end-to-end visibility in the supply chains for medicines and other health commodities. It has also allowed for the real-time tracking of emergency orders and transactions both from in-country suppliers as well as from external donors and partners. The system reportedly has contributed to building transparency and accountability and for eliminating duplication. Lessons can be learned here particularly about the benefits of early investments in digital solutions as Uganda was able to swiftly leverage its existing system (Wasswa et al., 2020).

A second important area of contribution of the eLMIS use in COVID-19 vaccination is the ability of informing the logistics management of vaccination sessions.

South Africa has been using the Electronic Vaccination Data System (EVDS)[2] based on Vodacom's mVacciNation application. The system offers real time vaccine stock visibility allowing for vaccination sites to plan vaccination sessions accordingly and enables close surveillance and security of the vaccine supply chain thus reducing the risk that the vaccines enter an illegal market.

Similarly, **Mozambique** has adapted its health information and logistics management tools at the district level with the support of the United States Agency for International Development (USAID), to incorporate data tracking from the COVID-19 vaccine delivery, including individual dose administration and vaccine stock monitoring. Reportedly, these tools are used in the microplanning process of the COVID-19 vaccine deployment in which priority groups are identified and targeted (USAID, 2021).

Finally, in **Tonga**, the existing eLMIS (mSupply) has been adapted to support both client registration and vaccine administration for the COVID-19 vaccination roll-out (TechNet-21, 2021) demonstrating the potential for such electronic solutions to communicate.

Some challenges in the use of eLMIS have also started to emerge. **Nepal** relied on its existing eLMIS for the management of COVID-19 commodities with the help of the USAID Global Health Supply Chain Program (USAID GHSC, 2021). However, information provided by the Nepal Ministry of Health and Population suggests that there have been problems in its implementation. In 2020, supply updates were inconsistently submitted, with only 33% of the total laboratories and hospitals providing their reports on

[2] https://sacoronavirus.co.za/evds/

a weekly basis – a fact that renders the forecasting, procurement, and timely provision of COVID-19 commodities difficult (Government of Nepal, 2020).

3.2 Findings from the case studies

Both digital solutions, eIR and eLMIS, have been deployed to support vaccine delivery during the pandemic in different ways across the five countries analysed in this report. The setup and use of these systems, as well as their impact, have been dependent on the time and characteristics of the COVID-19 vaccine deployment, which has been very different across the countries: India was the first among the five countries to roll-out COVID-19 vaccine delivery in January 2021, followed by Rwanda and Honduras in February 2021, Guinea in March 2021, and Tanzania in July 2021. Therefore, the state of maturity of each programme is different, and each of the five countries has deployed a mix of vaccines, with variable use of eIR and/or eLMIS in supporting the vaccine roll-out. This is summarized below in Table 5.

Table 5: *Overview of COVID-19 vaccination statistics for the 5 focus countries (WHO, 2021)*

Country	Digital solution used to support vaccine roll-out	C-19 vaccines deployed	First vaccination date	Total # of doses administered
Guinea	eLMIS	Beijing CNBG – BBIBP CorV Gamaleya – Gam-Covid-Vac Janssen – Ad26.COV 2-S Pfizer BioNTech – Comirnaty SII – Covishield Sinovac – CoronaVac	05 Mar 2021	2,441,522 (8 Nov 2021)
Honduras	eIR	AstraZeneca – Vaxzevria Gamaleya - Gam-Covid-Vac Janssen – Ad26.COV 2-S Moderna – Spikevax Pfizer BioNTech – Comirnaty SII – Covishield	26 Feb 2021	7,300,131 (5 Nov 2021)
India	eIR + eLMIS	Bharat – Covaxin Gamaleya – Gam-Covid-Vac Janssen – Ad26.COV 2-S Moderna – Spikevax SII – Covishield	16 Jan 2021	1,068,571,879 (2 Nov 2021)
Rwanda	eIR	Beijing CNBG – BBIBP – CoV Gamaleya – Gam-Covid-Vac Moderna – Spikevax Pfizer BioNTech – Comirnaty SII – Covishield Sinovac – CoronaVac	05 Mar 2021	5,179,627 (26 Oct 2021)
Tanzania	eIR + eLMIS	Beijing CNBG – BBIBP – CoV Janssen – Ad26.COV-2S Pfizer BioNTech – Comirnaty	28 Jul 2021	1,001,610 (29 Oct 2021)

3.2.1 Guinea

3.2.1.1 Context

As of 5 October 2021, there have been 30,681 confirmed COVID-19 cases with 385 deaths in Guinea reported to WHO (WHO, 2021).

Following the declaration of a state of health emergency in response to the COVID-19 pandemic on 27 March 2020, the government of the Republic of Guinea designated the National Health Security Agency (ANSS) to coordinate the response and manage all domestic and external resources. The response has included: prevention and community mobilization; laboratory diagnosis; clinical care; and disease surveillance (Delamou, et al., 2020). Although the country has been able to capitalize on previous experience with the Ebola outbreak, the management strategies of the COVID-19 response have differed from that of Ebola in many aspects.

Guinea received its first COVAX vaccines on 11 April 2021 (194,400 doses of Covishield from Serum Institute of India), with 864,000 doses having been allocated to the country (Gavi The Vaccine Alliance, 2021). As of 8 November 2021, a total of 2,441,522 vaccine doses have been administered. Guinea has used two parallel eLMIS to help support COVID-19 vaccine delivery.

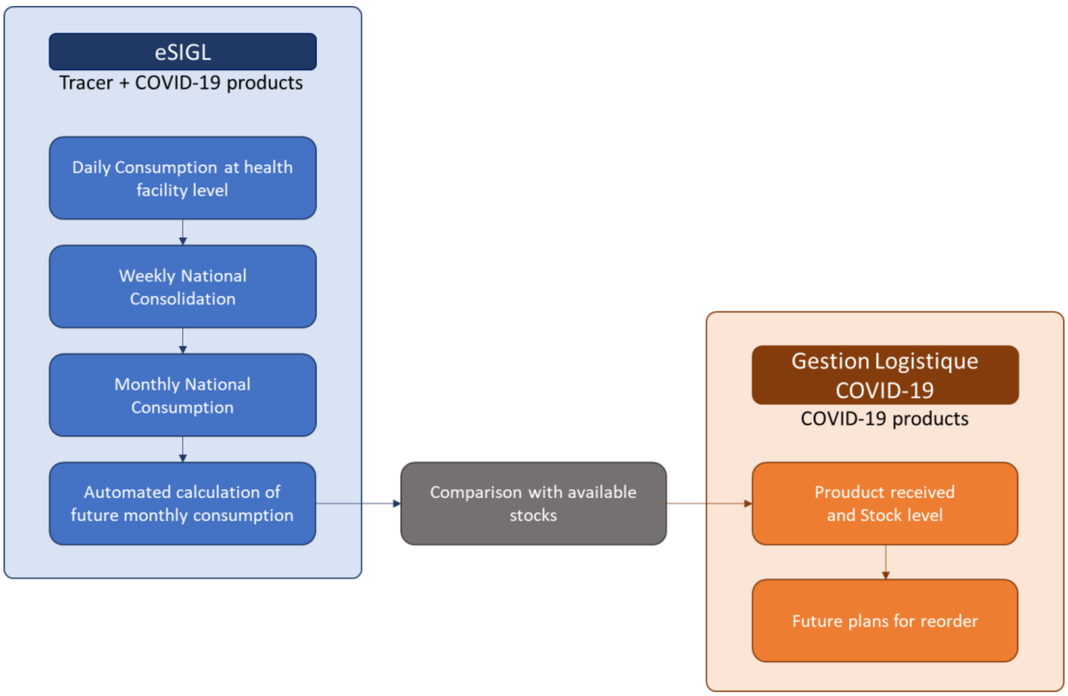
3.2.1.2 Description of digital solutions

Since 2015, Guinea has had in place an eLMIS based on OpenLMIS (Version 2), generically known as eSIGL (Système d'Information de Gestion Logistique), developed with the technical assistance of Chemonics. The system was initially rolled out in 2015 during the Ebola outbreak, covering key health products defined as “tracer products.” The initial system did not include vaccines. The eSIGL was expanded in 2018 with the support of USAID and the Global Fund to support essential medicines including vaccines), family planning, and malaria commodities. The eSIGL currently reports and consolidates information on the consumption of the “tracer products” at national level on a weekly basis and provides information on the monthly consumption quantities of those products (Guinea Technical Committee, 2021). The tool is used to support the automated calculation of the monthly consumption of tracer products and related planning for the next round of supply (USAID GHSC, 2018). While a module for stock management exists for the OpenLMIS 2, this was not adopted in Guinea because the focus, at the time of the implementation, was not on the optimization of the logistic flows nor of the inventory levels.

At the start of the COVID-19 pandemic, there was a pressing need to report and receive information on both stock levels and the distribution of COVID-19 vaccines and protective equipment. As such, a new tool was needed for planning and forecasting demand as the eSIGL could not easily fulfil this function because of its limited adaptability secondary to the fixed workflow of the OpenLMIS 2. The setup allowed only for a limited tailoring of the logistic management functionalities (i.e., forecasting and planning) outside the use for routine health products and did not allow for capturing information at the point of delivery of the health products. Hence, the decision was made to implement a new parallel system to address the urgent needs related to the roll-out of the COVID-19 vaccines.

The ANSS opted for the design of a new module for logistic management. The design and implementation of this module, generally referred to as the Gestion Logistique COVID-19 (COVID-19 Logistics Management System) was assigned to a local firm. The new eLMIS module was developed to provide information on the quantities of COVID-19 products received and available in stock and included a tracking module which allows for stock planning, as well as tracking product distribution and transfers between warehouses. Since the system was not enabled to monitor consumption at the primary health care level, an additional COVID-19 module was integrated into the eSIGL to fulfil this function. The module in eSIGL now allows for the analysis of consumption data of COVID-19 products at the level of health facilities (Guinea Technical Committee, 2021). As a result, two parallel systems (Figure 1) are now in place in Guinea for the management of COVID-19 products: a tool focused on the management of the flow of goods (i.e., the COVID-19 logistics management tool) and a tool capturing the consumption of the products at district and health facility level and consolidating that information at national level (i.e., the dedicated COVID-19 module of eSIGL). Of note, all costs related to the COVID-19 logistics management system are being covered by the ANSS.

Figure 1*: Two parallel eLMIS systems in Guinea*



The management of routine immunization logistics continues to be done using eSIGL with its known limited focus on consumption and without a specific ability to view the flow of goods. No expansion of the COVID-19 Logistics Management System is planned to allow for tracking of routine immunization stocks nor planning for the reordering of vaccines.

To respond to the limitation of scope of the current setup and to allow for an integrated management of the different health product flows, the ANSS is currently planning for the development of an integrated system, based on OpenLMIS 3. This system would be responsible for monitoring the entire supply chain, from the reception of the products to the distribution in the health institutions, and should include the management of stocks and inventory. This system is intended to fully replace the COVID-19 logistics management tool covering all vaccines. However, the monitoring of the consumption of “tracer products” will initially remain with eSIGL. It is planned to eventually integrate the two systems to allow ongoing exchange of detailed information at all levels.

3.2.1.3 Immunization delivery

National trends suggest that the continuity of the routine immunization programme in Guinea was negatively affected by the COVID-19 pandemic with most of the health staff focused on the pandemic response. While vaccination services continued, health facility attendance by the community was low, and there was a scarcity of human resources. In addition, there was also a decrease in immunization outreach activities (e.g., polio campaign, MNT campaign, measles, VAS, etc.) linked both to the measures taken by the government to prevent any regrouping of populations as well as the community's mistrust of immunization. The use of the eSIGL has continued and, at the moment, there is no evidence of stock-out nor an excessive level of wastage of expired products.

In a study on the early effect of the COVID-19 epidemic on administrative vaccine coverage in Guinea, a decline for IPV and Pentavalent was registered with a of drops of 20% for both vaccines. This decrease was the result of the interruption of the vaccination services, with the sharpest impact registered in the prefectures of Yomou, N'Nzérékoré, Macenta, Kankan, Mandiana, Dinguiraye, Mamou, Koubia, Mali, and Conakry (Dabo, et al., 2020) as well as a delay in Supplementary Immunization Activities (SIAs). The performance of the immunization system, however, has steadily recovered during 2021.

In parallel, COVID-19 vaccination in Guinea has progressed in waves (Figure 2). This is linked to the arrival of doses with 11.3% of the population having received at least one dose and 5.5% having completed the vaccination cycle (data as per 3 November 2021).

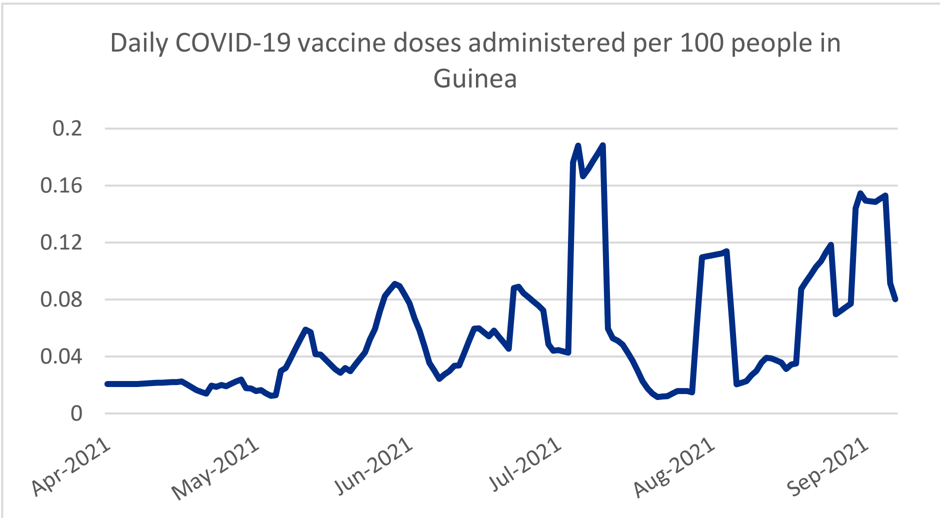


***Figure 2**: COVID-19 vaccination in Guinea (Our World in Data, 2021)*

3.2.1.4 Emerging learning and opportunities

With COVID-19 vaccine uptake in the country significantly hindered by the lack of supply, the learnings to date about the role of eLMIS in support of the COVID-19 vaccine programme are limited. In general, it appears clear that the design of the original eLMIS, the eSIGL, was not appropriate to support the integrated management of the deployment of a new vaccine, in particular, in the event of a pandemic. This is somewhat surprising since the tool was originally deployed to respond to an outbreak – the Ebola epidemic.. The original system design decision to focus only on tracking the consumptions of selected health products and to not cover the management and planning of the flow of goods resulted in the parallel creation of a separate tool to meet the critical emerging needs of the COVID-19 vaccination programme.

While the scope of digital management solutions must always be driven by the specific context, design decisions should be forward looking and should consider all anticipated needs of the programme they are meant to support. In this case, the country could only rely on limited eLMIS functionalities which required the ad-hoc design and implementation of a new system to address critical programme needs in the middle of a pandemic.

The two systems are currently operational. The selection of a local supplier for the design and implementation of the COVID-19 Logistics Management System appears to have proven successful and may contribute to the building of local capacity which will likely prove useful in future system adaptations.

There are plans for an integration of all vaccines in the COVID-19 Logistics Management System, responding to an unmet need of the routine immunization programme. For the time being, however, the country plans to maintain the two parallel eLMIS. Given the existence of interoperable solutions between eLMIS and DHIS2 for the management of health products and vaccines, it would be important for the MoH to evaluate alternative solutions based on the learning of the COVID-19 vaccine roll-out and on the results of this review (i.e., impact, cost-efficiency, interoperability).

3.2.2 Honduras

3.2.2.1 Context

As of 5 November 2021, there have been 375,983 confirmed COVID-19 cases and 10,285 deaths in Honduras reported to the WHO (WHO, 2021).

In February 2020, Honduras adopted its first National Epidemic and Health Emergency Prevention and Response Plan, as well as the COVID-19 Case Containment and Response Plan (Honduras Ministry of Health, 2021). The COVID-19 emergency response project in Honduras is supported in part by the World Bank's emergency response package using the Multiphase Programmatic Approach (MPA) (Honduras Ministry of Health, 2021). The complete COVID-19 Emergency Response Project is financed in the amount of US$20 million (Honduras Ministry of Health, 2021).

Honduras received its first COVID-19 vaccines in February 2021. Since then, the country has administered 6.8 million doses of COVID-19 vaccine reaching a coverage of 34% of the total population (38% have received the first dose) with a progressive increase in the doses administered (Figure 3).

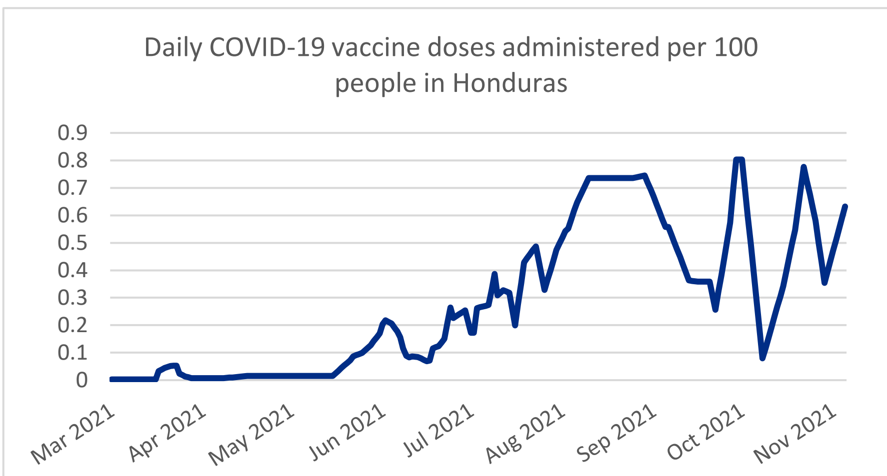
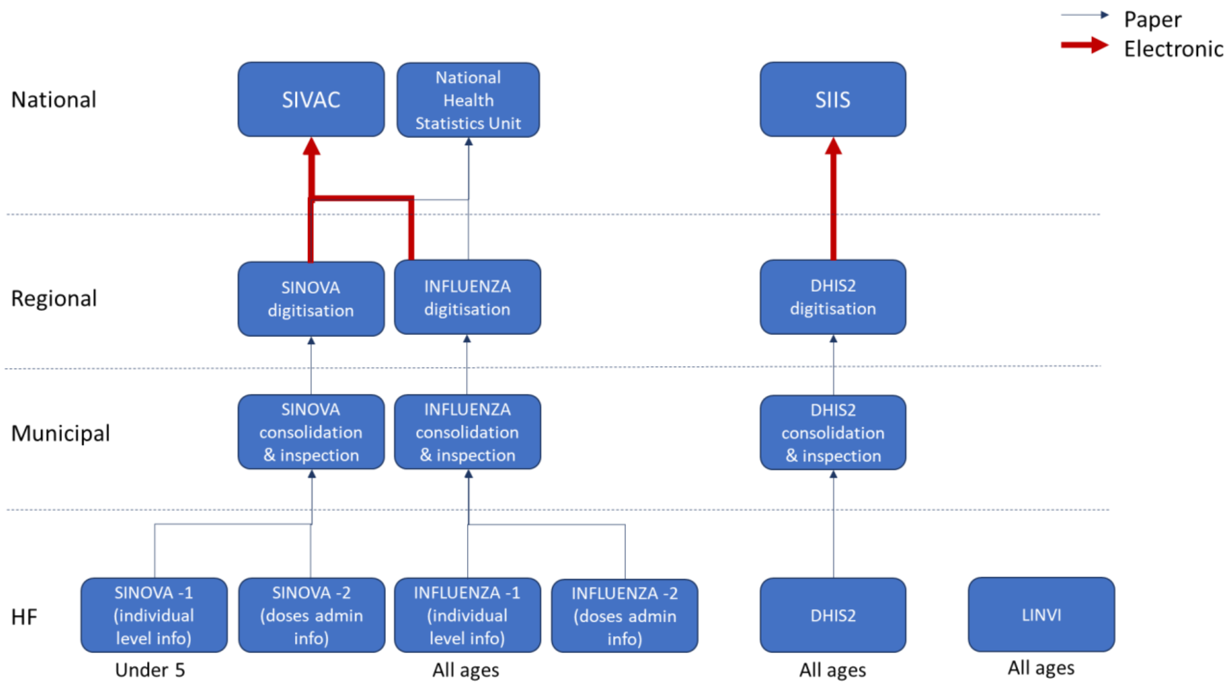


Figure 3: *COVID-19 vaccination in Honduras (Our World in Data, 2021)*

3.2.2.2 Description of digital solutions

To inform the work of the National Immunization Program, Honduras operates a hybrid eIR, the Subsistemas de Información de Vacunación [SIVAC] and a parallel INFLUENZA system with the same design. The two systems operate as follows: (1) paper-based nominal and aggregated form entries are performed at local HF level on a daily basis; (2) the paper forms are sent on a weekly basis to the municipal (i.e., district) level where forms are inspected for completeness; (3) the validated forms are sent to the regional level for digitisation; (4) health regions send both paper and electronic forms to the National Health Statistics Unit (*Área Estadística de la Salud* [AES]). Immunization data gathered through SIVAC include nominal and aggregated data frames, comprising information on administered doses, vaccine manufacturer, vaccination site, demographic data of the vaccine recipients, and RI priority category associated to vaccinated individuals (Government of Honduras, 2021).

Figure 4: *Information flow of multiple EIR system*



As part of the response to the COVID-19 pandemic, the government decided to integrate the existing tools of the Expanded Programme on Immunization (EPI) – SIVAC/SINOVA/INFLUENZA – with the ones of the Regional Departments of Integrated Health Service Networks (*Departamentos de Redes Integradas de Servicios de Salud* [DRISS]), and of the Local Network Coordination Teams (*Equipos coordinadores de redes* [ECOR]) (Honduras Ministry of Health, 2021). A new COVID-19 vaccination information system was therefore designed and developed incorporating it into the SIVAC system at the national level, with the intention that the Honduras EPI would be able to monitor and report immunization progress daily using a designated Excel template (Honduras Ministry of Health, 2021)[3]. In view of the hybrid nature of system, health facilities were supplied with paper-based daily and monthly consolidated registration forms specific to the COVID-19 vaccination effort. COVID-19 vaccination cards were prepared and handed to vaccinated individuals. A full-time systems engineer was hired as the responsible for data management and monitoring specific to the COVID-19 vaccination campaign (Honduras Ministry of Health, 2021)[4].

In parallel to the SIVAC-based system, a COVID-19 module was developed, using the District Health Information Software 2 (DHIS2) platform and the Integrated Health Information System (*Sistema Integrado de Información en Salud* [SIIS]) (Government of Honduras, 2021). Similar to the hybrid SIVAC

[3] We are still investigating if this was carried out by local suppliers or consultants from abroad were contracted.
[4] We required to the Honduras country team to confirm that this is the only human resources improvement.

approach, data collection in DHIS2 is conducted at the health facility level using a paper-based system with data subsequently aggregated and computerized from district to regional and national levels[5].

While implementing those solutions, the MOH outlined a series of multipronged actions to strengthen the National Epidemiological Surveillance System (*Sistema Nacional de Vigilancia Epidemiológica* [SNVE]), with the goal of: (1) implementing an effective, real-time information system (instead of the current weekly – monthly process), based on a well-defined information flow, and capable of supporting evidence-based decision-making, and (2) the creation of epidemiological situation rooms at local, regional and central levels, whereby real-time COVID-19 immunization information could be gathered and channelled (PAHO, 2020).

For the management of the logistics and distribution, the COVID-19 vaccine was integrated at the national level into the Web-based Medicine Supplies Stock Management (wMSSM) – a customized vaccine and supplies inventory control system used for vaccines stock control in the country since 2010 (Honduras Ministry of Health, 2021 & PAHO, 2014).

3.2.2.3 Immunization delivery

The pandemic led to a rapid increase in service demand on the broader health system and, in particular, on the immunization system. The timing, scope, and scale of routine immunization services was disrupted in 2019-2020 (WHO, n.d.) as a result of the COVID-19 pandemic, leading to the implementation of social distancing measures, and aggravated by the avoidance of health care workers and facilities (Honduras Expanded Program on Immunization, 2020). As such, COVID-19 has generated a large population of susceptible (unvaccinated) individuals with a higher likelihood of outbreaks from Vaccine Preventable Diseases (VPD). The Government of Honduras considers it imperative to maintain routine immunization services while ensuring safety precautions for health workers, the eligible population, and their communities at large (Honduras Ministry of Health, 2021).

To this end, the Government of Honduras scheduled National Vaccination and Deworming Days (*Jornada Nacional de Vacunación y Desparasitación* [JNV-D]) from 10-31 May 2021. During this period, health workers and administrative personnel from the Ministry of Health (*Secretaria de Salud* [SESAL]) and the Honduran Institute of Social Security (*Instituto Hondureño de Seguridad Social* [IHSS]) were mobilised across the country to vaccinate[6] the target population as part of a national catch-up campaign (Honduras Ministry of Health, 2021). During the 2021 JNV-D, the COVID-19 vaccine was associated to the EPI programme for the following high-risk groups: (1) health workers, (2) persons aged 60 and older, (3) persons aged 18 to 59 living with comorbidities and (4) persons categorized as essential workers (Honduras Ministry of Health, 2021).

The JNV-D national immunization campaign focused on urban centres with high population concentration and municipalities with high-risk population profiles Honduras Ministry of Health, 2021). The target population was estimated and identified for the catchment area of each health facility, and across municipality networks, in the country adapting the Listing of Integrated Surveillance of Children (*Listado*

[5] We have required to the Honduras country team to inform us about the distinctive role of DHIS vs SINOVA.
[6] The main national priority group in the EPI vaccination schedule is children under five years of age, who receive: (1) Tuberculosis vaccine – Bacille Calmette-Guérin (BCG), (2) Hepatitis B, (3) Inactivated polio vaccine (IPV), (4) Oral polio vaccine (OPV), (5) Pentavalent vaccine (diphtheria, pertussis, tetanus, hepatitis B and haemophilus influenzae type b), (6) Rotavirus, (7) Pneumococcal Conjugate Vaccine (PCV13), (8) Measles, mumps, and rubella (MMR), (9) Hepatitis A and (10) Diphtheria, tetanus, pertussis (DPT) vaccine.

de Niños para la Vigilancia Integral [LINVI]) tool. LINVI is a detection and monitoring paper form independent from SINOVA, used by the EPI to target children and adolescents at the local neighbourhood level. It allows health personnel to establish priorities in the active search for children and adolescents who have not yet started and/or completed their vaccination schedules. Through disaggregated analyses of vaccination coverage yielding lists of children under 5 with pending vaccination status, LINVI was instrumental for the JNV-D's planning and logistics management (Honduras Ministry of Health, 2021). It is estimated that – across vaccine types and target population groups – the JNV-D campaign administered 673,173 doses to reach the target population pending routine immunization (Honduras Ministry of Health, 2021).

3.2.2.4 Emerging learning and opportunities

Honduras has chosen to leverage as much as possible the existing hybrid systems (wMSSM, SIVAC, LINVI; SINOVA and INFLUENZA). During the emergency, no specific focus has been placed on integration nor expansion of those systems. A parallel system based on DHIS2 was, instead, rolled out. The efforts toward the real-time tracking of the COVID-19 response encountered similar operational bottlenecks across the various tools (Government of Honduras, 2021), including: (i) a significant time lag in the flow of information across the local, municipality, regional and national levels, as result of the SIVAC original setup not modified for the COVID-19; (ii) a systematic shortage of data entry personnel and basic computer equipment at the local health facility level, where vaccination takes place; and (iii) the lack of connectivity and access to wireless networks complicating the consolidation of information from different sources at the municipal level. As result, the impact of the system's information flows on decisions and operations remained limited both for RI, as well as for COVID-19 management and response.

The need for strengthening and deploying human resources with health informatics capabilities across the country (Government of Honduras, 2021) emerged as the most pressing need. This is especially relevant when seeking to improve the timeliness of a hybrid system that relies on massive manual and offline data entry across health facilities and vaccination sites. In absence of sufficient trained staff in all health facilities, any system integration will be capable of only delivering partial benefits.

The need to build a performing digital health infrastructure was seen as the second most important factor, especially critical because of the ambition to transform the hybrid system into a fully electronic one – capable of responding to the real-time information demands of an ongoing pandemic. The absence of a well-performing IT infrastructure may greatly limit the return on the investments in systems and human resources.

While engaging with two parallel systems at once, the additional COVID-19 stream of data collection and information flow allowed for iteration, adaptation, and learnings to take place (Government of Honduras, 2021). While it may be too early to appreciate whether a multipronged or an integrated system approach is more advantageous to the national response, the parallel implementation of SIVAC and DHIS2 indicates the willingness to test approaches in real-time. The potential for a more integrated and automated approach which is capable of supporting the daily operations of the routine and emergency immunization efforts should be carefully assessed, though such an evolution will only make sense if investments simultaneously address challenges around the triad of connectivity, equipment, and human resources for health.

3.2.3 India

3.2.3.1 Context

As of 5 November 2021, there have been 34,333,754 confirmed cases of COVID-19 with 459,873 deaths in India reported to WHO (WHO, 2021).

India was severely hit by the COVID-19 pandemic, with the second wave starting from March 2021 causing record numbers of new infections and deaths, peaking at the rate of approximately 400,000 cases and 4,000 deaths, respectively, every day during May 2021 (WHO, 2021). According to experts, this high COVID-19 toll is attributable to the timing of easing restrictions from the first wave, localized waves in epicentres, such as the cities of Delhi and Maharashtra, mass gatherings for political rallies and religious celebrations, as well as public claims by politicians that the pandemic had been beaten (Thiagarajan, 2021a). The second wave hit India during the COVID-19 vaccine roll-out, which lead to straining of the healthcare resources, which had to be allocated for the management and treatment of infections as well for vaccination, resulting in medical supply shortages for treatment and slow vaccination rates (Pandey et al., 2021).

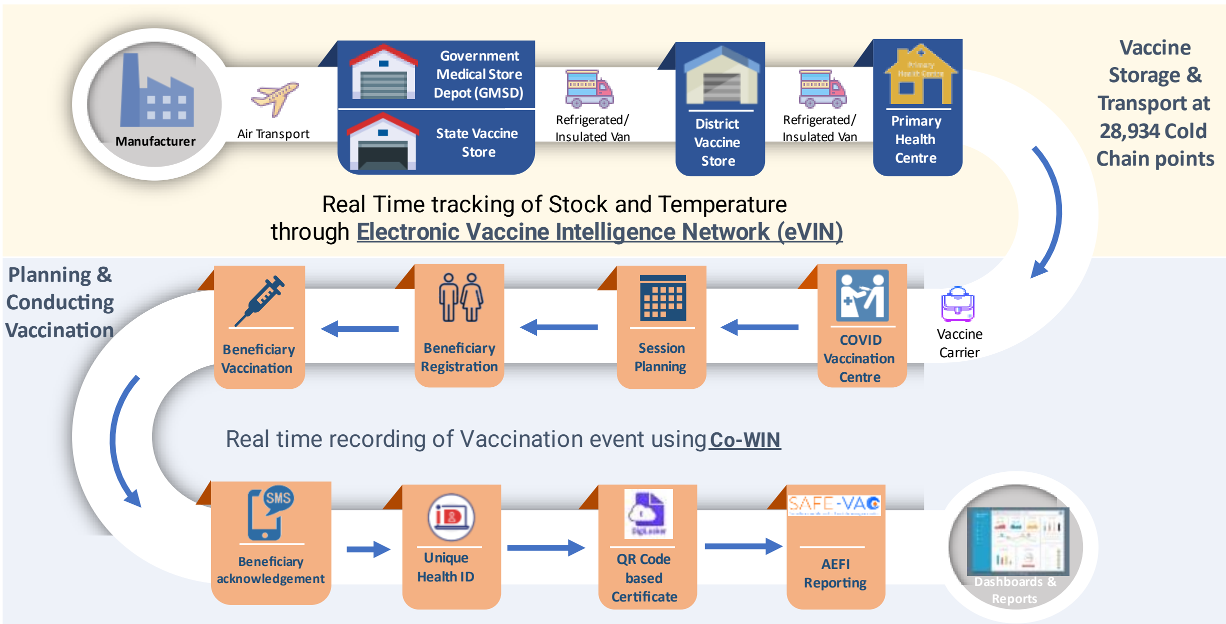
With its longstanding experience in running the Universal Immunization Programme (UIP), which targets 26.7 million newborns and 29 million pregnant women every year, India is currently conducting one of the world's largest vaccination drives against COVID-19. Starting on 16 January 2021, 6 million people were vaccinated in the first 24 days following the Covishield™ (AstraZeneca) vaccine roll-out (Bagcchi, 2021). In the vaccination response against COVID-19, the responsibility for the delivery of vaccination is centralized to the respective state governments. The first phase of vaccine roll-out aimed to reach 300 million beneficiaries by August 2021, starting with health care and other frontline workers. However, it was initially slower than expected, with the country facing vaccine shortages (Pandey et al., 2021). Despite this slow start, India has achieved delivery of more than one billion doses as of October 2021 ramping-up vaccinations in more than 61,000 centres, both public and private (BBC, 2021).

3.2.3.2 Description of digital solutions

Predating the pandemic, India had been using the electronic Vaccine Intelligence Network (eVIN), an eLMIS software developed by Logistimo and deployed with the financial and technical support of Gavi and UNDP, since 2015. eVIN was migrated to a locally developed open-source platform in 2020. The system has been scaled nationally in all public health facilities and oversees the logistics of India's Ministry of Health and Family Welfare's (MOHFW) UIP (Pant, 2021). As a mobile application, it allows for the digitized management of vaccine inventories by cold chain handlers directly from their smartphones, providing real-time information on vaccine stocks and flows, and monitors the storage temperature in those cold chain points (CCP) where it is implemented. eVIN was leveraged when introducing the COVID-19 vaccines, a decision driven by the system's scale and demonstrated effectiveness. To illustrate this, eVIN is operational in all of India's 28,500+ CCPs today ensures >99% availability of routine immunization vaccines compared to <85% before its implementation and has lowered stock-out frequency by 80% (UNDP, n.d.). eVIN did not have to go through an adaptation process to accommodate for the management of the COVID-19 vaccines (Pant, 2021).

India also developed *de novo* the Co-WIN digital application as an eIR for COVID-19 vaccine delivery to complement eVIN. Co-WIN is a cloud-based digitized platform allowing for real-time vaccine supply chain monitoring, including remote temperature monitoring, as well as beneficiary tracking (Kumar et al., 2021). It was launched in January 2021 as an open-architecture software (Pant, 2021). The complementarity of the two systems is depicted below in Figure 5. The primary aim of Co-WIN is to ensure effective targeting and registration of priority groups while ensuring full transparency in vaccination administration tracking (Court, 2021). Of note, in July 2021, the system was made available as open-source to allow for its adoption a global "digital public good" (Ang, 2021).

Figure 5: *COVID-19 vaccine delivery management system* (Pant, 2021)



Co-WIN allows for vaccination appointment scheduling, registration of vaccination events, reminders, AEFI reporting, monitoring and analytics and digital certificate generation (Ang, 2021). The latter is a functionality provided by a software named Digital Infrastructure for Verifiable Open Credentialing (DIVOC) that has been integrated into Co-WIN (DIVOC, 2021). This platform was designed to enable the tracking of over a billion individuals and, to date, is operating across all states in India in over 235,000 public and private vaccination centres. Individuals can register online on the Co-WIN website or via the mobile application with their national identification number to select a location and schedule a vaccination appointment. Alternatively, individuals can physically visit one of the 70,000+ vaccination centres where a health worker will assist them with the registration.

India and its development partners have invested significantly in these digital solutions. The roll-out of eVIN, including its transition from the Logistimo platform, has cost approximately US$ 43m to date. This has been funded by UNDP, Gavi and other NGOs (UNDP, n.d.). Further, India has received financial assistance for the COVID-19 response and vaccine roll-out, namely from UNDP with US$ 4.6m, UNICEF with US$ 6.6m, and the WHO with US$ 10m (Court, 2021). Specifically, for Co-WIN, a Technical Assistance grant of US$ 4.6m was provided by Gavi to support the additional functionalities and infrastructure that needed to be embedded in the eVIN system (Court, 2021). The design and implementation process of Co-WIN lasted 12 months and incurred US$ 10m in costs for software development, hosting infrastructure (cloud-based servers) and backend support/helpdesk for citizens. Due to the nature of the service provided, as the client database grows, the hosting infrastructure requirements grow, primarily due to the storage of data in the cloud driving up costs (Pant, 2021). Since official government approval for evaluating the eVIN is India is not yet obtained, assessment of operational costs for related human resources, including trainings and other activities in the field could not be conducted.

These digital solutions are providing visibility into what's happening in the field in terms of vaccine uptake. However, the data required to make informed decisions about vaccine distribution and administration locations is only now yielding insights that can improve programme planning. For example, data from Co-WIN suggests that most vaccinations are taking place in urban areas and about half of them are walk-ins. This results in crowding in the COVID-19 vaccination centres since systematic demand cannot be determined, unfortunately with the unintended consequence of potentially rendering the mass campaigns to become super-spreader events (Subramanian, 2021).

3.2.3.3 Immunization delivery

Against this backdrop, routine immunization services in India have reportedly decreased with at least 100,000 children missing their BCG vaccination and 200,000 children missing one or more Pentavalent vaccine doses. It is estimated that 49,000 additional child deaths and 2,300 additional maternal deaths could be attributed to the disruption of healthcare services, projecting an overall increase in child mortality of 40% over the next year (Shet et al., 2021). While India currently accounts for 11% of the unvaccinated and under-vaccinated children globally (WUENIC, 2020), it is estimated that 27 million children will miss their pentavalent vaccines following the pandemic (Shet et al., 2021). In order to address this, the Government of India is encouraging states to identify the children who missed essential vaccinations and plan catch-up campaigns under the UIP (MOHFW, 2020). While the UIP's integration of the Co-WIN platform for routine vaccination is still pending, the latter's repurposing is planned to allow for identification of beneficiaries and for keeping an electronic track record of all vaccines provided under the programme (Madaan, 2021).

3.2.3.4 Emerging learning and opportunities

The use of an integrated eIR and eLMIS for COVID-19 vaccination increased visibility, accountability, and transparency and enabled effective programme management. The importance of a digitally trained health workforce that can quickly adapt to new requirements clearly emerged as a key prerequisite for such a platform's success (Pant, 2021). The Co-WIN app enabled beneficiaries to register online and receive an appointment that provided instructions on when and where to report for vaccination, receive reminders and appointments for the follow-up doses and download digital vaccination certificates that enabled travel. The linkage with eVIN ensured vaccine availability at the respective vaccination sites. However, India's effort to digitalize its COVID-19 vaccine delivery has been met with some criticism around equitable access, which is documented in the literature by Mukherji (2021), Sharma (2021) and Gupta et al. (2021). While support was provided to the digitally illiterate and those is rural areas, it was not sufficient to bridge the digital divide and created socio-economic inequities in access to vaccination. Greater attention should be given to training community level volunteers and provide them with incentives to assist community members with the registration process.

Going forward, both Co-WIN and eVIN are envisioned to be integrated into the UIP, thus providing for the functionalities of an integrated eIR/eLMIS with end-to-end visibility of stocks, last-mile delivery and beneficiaries which is seen as favourable for ensuring the most vulnerable are reached. In particular, Co-WIN is planned to be adapted for use as an eIR for routine immunizations, providing also easy integration with other systems, such as vaccine safety surveillance, given its open platform structure. The objective of integrating eVIN with the adapted Co-WIN for use in routine immunization is to reduce the number of zero-dose and partially immunized children and improve immunization coverage through pre-registration of all eligible infants. The MoHFW's plan is to provide the adapted Co-WIN for routine immunization as the interface for recording immunization sessions' data at all immunization delivery sites. A flexible database architecture is envisaged to allow the session site data to flow into eVIN from Co-WIN, enabling programme managers to have access to data on immunization coverage, vaccine consumption and wastage in real time, as well as track key performance indicators.

3.2.4 Rwanda

3.2.4.1 Context

As of 5 November 2021, there have been 99,854 confirmed COVID-19 cases with 1,332 deaths in Rwanda reported to WHO since the first case on 11 March 2020 (WHO, 2021) .

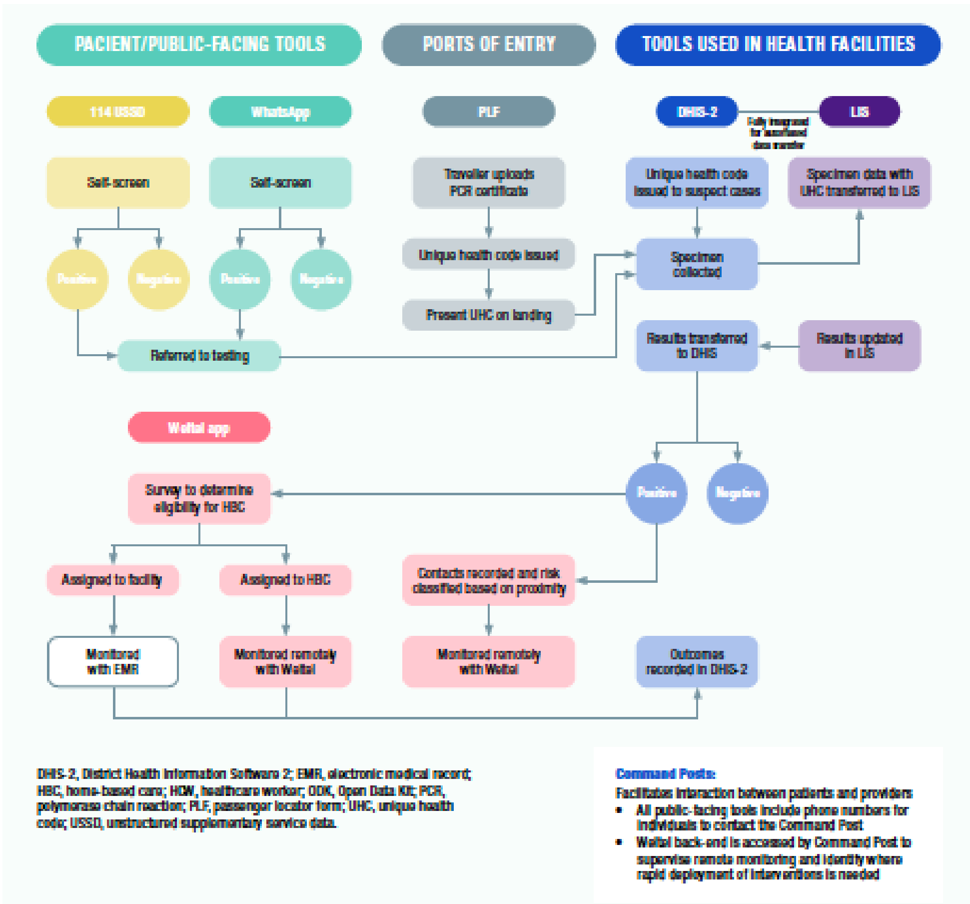
The Ministry of Health (MoH), Rwanda Biomedical Centre (RBC) and the Epidemic and Surveillance Response Division collaborated early in the pandemic to discuss preventive and response measures. A Joint National COVID-19 Task Force (COVID-19 Task Force) was formed to produce and disseminate the Coronavirus National Preparedness and Response Plan (CNPRP) which has different streams, namely: (i) management and operations of COVID-19; (ii) workforce capacity development; (iii) logistics and stakeholder engagement; and (iv) monitoring and evaluation.

Rwanda received its first COVID-19 vaccine batch from Moderna in mid-February 2021, followed by additional doses of AstraZeneca-Oxford and Pfizer/BioNTech through the COVAX initiative in early March 2021 (Nsanzabaganwa et al., 2021). Vaccination sites were set-up across the country with delivery in one health centre per sector and at district hospitals (Binagwaho, 2021). As of 1 November 2021, more than 5.1 million vaccine doses had been administered (WHO, 2021). Rwanda has fully vaccinated 26% of its population against COVID-19 to date, reaching the September 2021 global target set by the WHO. The Government of Rwanda is determined to vaccinate 60% of Rwandans by mid-2022.

3.2.4.2 Description of digital solutions

Overall, the national COVID-19 response in Rwanda has taken advantage of an enabling environment which advocated for the scale-up of technology and innovation. Rwanda's deployment of digital solutions during the pandemic was preceded by investments in broader digital health infrastructure aligned with Rwanda's ambitious Smart Rwanda Master Plan (SRMP) focused on the country's "digital revolution" (MYICT, 2015). Rwanda was, thus, able to leverage pre-existing digital infrastructure on which many COVID-specific solutions could be built. Figure 6 below provides examples of the digital solutions which have been deployed across the pandemic response in Rwanda (FIND, 2021), though the full extent of their quality and interoperability, and thus value, has not yet been evaluated.

Figure 6: *Examples of digital solutions supportive of the pandemic response in Rwanda (FIND, 2021)*



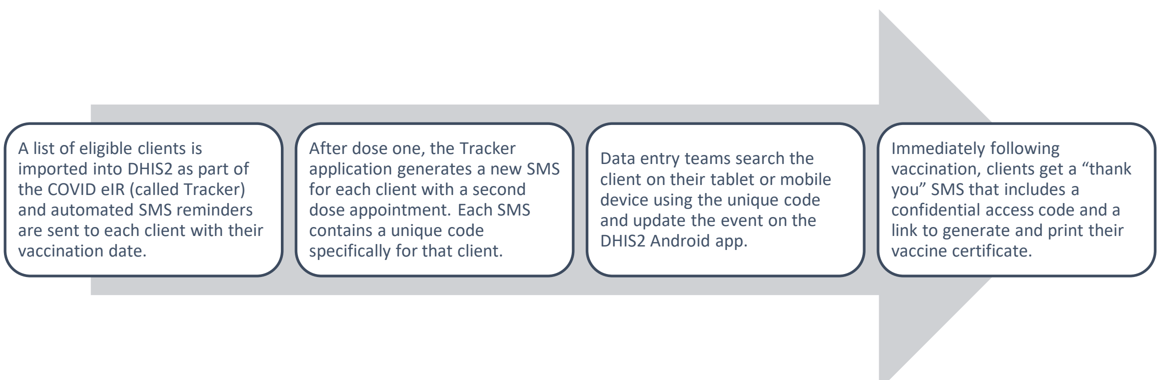
Rwanda's web-based national health information management system, called R-HMIS, had been powered by the DHIS2 software since 2012. Prior to the pandemic, DHIS2 was already operational in all 30 districts with use in 48 public hospitals and 515 health centres, as well as in a number of private health facilities (HISP, 2021).

In 2019, the country's EPI programme made the decision to implement the EPI Tracker module of DHIS2 for routine immunization with collaboration from the national Health Information Systems Programme (HISP), UNICEF, the University of Oslo and WHO. The implementation of the EPI Tracker started in May 2019 with customization and training sessions, followed by a national roll-out in all health facilities delivering routine immunization in September 2019. While the software platform was designed to have several key features such as scheduling of appointments, sending of digital reminders to both parents and community health workers (CHWs), verification of stock levels, staff management and the monitoring of adverse events following immunization (AEFI), the operationalization of many of these features is still in progress.

Based upon past experience with the DHIS2 platform, specifically including the recent deployment of the EPI Tracker, Rwanda was well positioned to respond quickly and effectively to the pandemic. In March 2020, Rwanda customized the DHIS2 COVID 19 Toolkit to support a test-trace-isolate cascade in all health centres and hospitals, both public and private, and enabled information sharing at the district and national level. The creation of the DHIS2 Android Capture App allowed for the harmonization, visibility and management of data and reporting across all health system levels, as well as laboratory sites (DHIS2, n.d.). As infrastructure was already in place with servers hosted by the pre-existing National Data Centre under the Ministry of ICT and maintenance of the system supported by the RBC, systems to support data capture could be adapted and scaled-up to respond to the emerging public health threat.

Rwanda was also able to leverage the DHIS2 platform to support COVID-19 vaccine delivery. DHIS2 was selected over other potential tools because it could be easily adapted and quickly implemented, capitalizing on local DHIS2 capacity to scale-up COVID-19 vaccine delivery at the national level. Prior to the arrival of the first vaccine doses in March 2021, the national EPI reached out to the HISP to request assistance in developing a vaccine management system for COVID-19. HISP supported the MoH to customize the immunization package from the DHIS2 COVID-19 Toolkit for a paperless process from start to finish (Figure 7). This tool was already used in the initial phase of vaccine delivery which targeted high-risk groups and healthcare staff, as well as other frontline staff. The digital solution was deployed at all vaccination sites with data being entered directly on tablets and mobile devices using the DHIS2 Android Capture app.

Figure 7*: Customized features which supported paperless process (adapted from DHIS2 archives)*



Two technical features were particularly important for Rwandan context. First, HISP Rwanda re-purposed the technology developed for the national surveillance system which provided digital certification of negative test results. HSIP was able to use this solution to also generate electronic immunization certificates for first and second doses of COVID-19 vaccines. An interoperable application was linked to the DHIS2 Tracker which enabled the generation of these certificates. Second, HISP Rwanda worked in collaboration with Rwanda's National ID Agency (NIDA), the Ministry of ICT, the Rwanda Information Society Authority, the National Institute of Statistics, RBC and the MoH to integrate the DHIS2 Tracker with the national registry hosted by NIDA to ensure that individuals' information could be pulled from the national ID system as part of an automated registration process. This feature was important because it both eliminated errors in data entry such as incorrect names or dates of birth, as well as made the registration process more efficient. Local stakeholders have specifically noted that since this feature was deployed in August 2021, the time spent on data entry per client at each vaccine centre has decreased significantly and thus more individuals have been able to be processed at each facility. This feature resulted in the rationalization of human resources and could have translated into cost-savings.

Importantly, in making the decision to adopt the purpose-built COVID-19 Tracker for COVID-19 vaccine delivery rather than extending the existing EPI Tracker, Rwanda took into consideration the complexity of pandemic response, requiring additional track and trace features as well as other COVID specific features. Additionally, the modification of the existing tracker system for routine immunizations would have taken time and resources that were not readily available. Utilizing the DHIS2 COVID suite of applications essentially “out of the box” ensured fast setup and importantly, quick access to new features and related modules as they became available to meet changing and expanding requirements. As both systems are deployed on the same platform, while not integrated currently, it should be relatively straightforward to connect the two systems, or even to migrate data in the future to use a single application.

3.2.4.3 Immunization delivery

The concurrent use of the EPI Tracker and the introduction of the COVID-19 Tracker enabled the country to continue to deliver routine immunizations and introduce COVID-19 vaccines during the pandemic. While Rwanda has had steadily high immunization coverage over the past few years, it did experience a decrease in routine vaccination with an average of 6% across selected antigens (Penta3, MR1&2) between 2019-2020 and 2020-2021 (HMIS, 2021). It is possible that having an EPI Tracker in place contributed to maintaining immunization delivery services and/or in avoiding coverage rates to plummet further. This is an area for further exploration.

3.2.4.4 Emerging learning and opportunities

Rwanda presents a particular case study for the understanding of how enabling factors such a political will and strong investments in IT infrastructure enabled the implementation of an eIR for RI at national scale in a short period of time, as well as rapidly adjusting it during the unfolding of the COVID-19 pandemic. Like in the other countries, there is the potential for formative learning around how an eIR can monitor the impact of unforeseen ‘shocks’ to the health system on routine immunization, as well as inform the planning of any needed catch-up of immunization services to restore coverage. Similarly, Rwanda also represents an opportunity for further exploring the benefits of leverage the DHIS2 platform for the COVID EIR Tracker which has enabled the health system to rapidly capture data to specifically monitor and evaluate the introduction and uptake of COVID-19 vaccines. This may also provide a lens on further understanding critical equity issues with COVID-19 vaccine delivery across districts and across all layers of wealth index categories.

While it may be too early to draw any definitive conclusions, country level stakeholders have cited several important lessons learned to date. Perhaps most notable is how the enabling environment in Rwanda allowed for the rapid adaptation and scale-up of both repurposed and new technologies during the pandemic. Favourable governance structures, policies and existing digital infrastructure together enabled simple, interoperable, and adaptable digital solutions to be designed and deployed rapidly at scale to support COVID-19 vaccine delivery. The specific case of Rwanda may suggest that a necessary condition for the successful deployment of digital solutions is the match of strategic vision, strong governance, local technical competencies, and fit-for-purpose tools.

3.2.5 Tanzania

3.2.5.1 Context

As of 5 November 2021, there have been 26,196 confirmed COVID-19 cases with 725 deaths in Tanzania reported to WHO (WHO, 2021) .

The COVID-19 pandemic response through vaccination was not initially recognised by the senior country leadership and in February 2021, the country did not accept an initial allocation of COVID-19 vaccines (Makoni, 2021). Other preventive measures against the disease were only slowly introduced (Buguzi, 2021), however, with the recent change in government, Tanzania's stance on the pandemic was reversed (Mohammed & Kasolowsky, 2021). The country applied for COVID-19 vaccines through COVAX in June 2021 and in July 2021, it received 1,058,450 doses of the Johnson & Johnson single-dose vaccines (Mwengee & Kileo, 2021). Further, on 11 October 2021 1,068,600 doses of Sinopharm vaccine arrived in the country and 500,000 Pfizer doses are expected to be received in early November (IVD & NIMR interview, 2021). Initial scepticism and denial of the disease with later reversal has affected perceptions and attitudes of the population (Buguzi, 2021). However, the country is facing fewer challenges with COVID-19 vaccine deployment today.

By 20 October 2021, more than 950,000 doses of Johnson & Johnson vaccine had been administered and almost 9,000 doses of the Sinopharm vaccine. Initially health workers, the elderly (> 50 years of age) and persons with comorbidities were prioritized, but vaccination was opened for all adults (> 18 years of age) in mid-August 2021. Coinciding with the arrival of the first vaccines, 550 COVID-19 vaccination sites were established across the country (Makoye, 2021). COVID-19 vaccination is now offered in all 6,784 routine immunization sites in the country following the initiation of the "Participatory and Immediate Community Immunization Program" in September 2021 (Makwetta, 2021). To date, COVID-19 vaccine coverage has reached 1.6% of the adult population (IVD & NIMR interview, 2021).

All health facilities are required to keep a record of the number of COVID-19 vaccine doses delivered, either on paper or using electronic tools where in use, as per the Ministry of Health, Community Development, Gender, Elderly and Children (MoHCDGEC) guidelines which outline the data recording and reporting protocols in detail (MoHCDGEC, 2021).

3.2.5.2 Description of digital solutions

Tanzania had developed a National Immunization Strategy (NIS) for the period 2021-2025 which is to be officially endorsed in late 2021. Its two main objectives, to ensure everyone is protected from vaccine preventable diseases throughout the life-course with high quality, effective, efficient and equitable immunization services and to ensure an effective, efficient, and resilient immunization programme as an integral part of the primary health care system (IVD Program, 2021) are driven by the recognition of the need for greater equity in access to and utilization of health services. In achieving these aims, digital technology will continue to play an important role as the use of electronic solutions for immunization in Tanzania predates the COVID-19 pandemic. Tanzania has been in the process of rolling out an eIR for routine immunization, called Tanzania Immunization Registry (TImR) since 2015, while a specific eLMIS for vaccines, the Vaccine Information Management System (VIMS), has been in place at national scale from the district level upwards since 2018.

As part of the preparatory activities for the roll-out of the COVID-19 vaccine in July 2021, the MoHCDGEC reached out to the developers of the TImR to discuss opportunities to accommodate additional features for registration and booking of COVID-19 immunization appointments. The relatively abrupt shift in attitude toward the pandemic resulted in tight timelines and prevented a lengthy customization of the TImR which would have involved external assistance for its development by Sante Suites, Canada. In a situation requiring immediate solutions, an agreement with the provider of technical assistance for TImR could not be reached. In addition to the short timelines for technical design and development, the non-availability of subcontractors, financial issues (several partners were unable to provide immediate funding), coupled with the firm requirement for hosting all data on local Tanzanian servers prohibited its further development (Bulula, 2021).

As an alternative solution, the DHIS2 Covid tracker module was quickly accepted, which was already partly in use for the management of the COVID-19 vaccination efforts by health workers in static clinics. In addition, a public-facing COVID-19 vaccination appointment booking site was created within a few days by the University of Dar Es Salaam, based on the already available Pima Covid[7] tool used for managing appointments for COVID-19 antigen tests and the provision of test certificates. The decision to pursue this technical solution was based on positive experiences with the Pima Covid testing app, considered to be leaner and more flexible than TImR and, being locally developed and expanded, deemed more adaptable in supporting the COVID-19 vaccination scheduling and certification processes. After customization of this system, it was finally converted into the 'Chanjo Covid Tracker` as a web-based app in use since early August 2021 for booking and registering COVID-19 vaccinations[8]. Gavi COVAX funding of USD 598,384 USD had been made available as part of approved COVID-19 Vaccine Delivery Support (CDS) funding for the electronic system development, procurement of devices and related training efforts. Out of this, USD 282,832 were budgeted for the actual development of the Chanjo Covid Tracker application.

The tool captures the following information during registration: Full name, age, sex, residence, occupation, history of COVID-19 infection (if any), comorbidities including allergies as well as information on date and location of vaccine doses received (MoHCDGEC, 2021). Registration for vaccination is possible by using the national ID but can also be done using a passport or driving license. The system creates a unique number to which the vaccination certificate is linked. Smartphone registration is possible, and the client is able to select a preferred vaccination site. The tool sends automatic acknowledgments of booking a vaccination appointment, a statement of vaccination following the first dose, SMS reminders for second doses (for Sinopharm and Pfizer vaccines) as well as reminders for no-shows (within 3 days). Vaccination certificates are also automatically issued once clients are fully vaccinated. The Chanjo Covid Tracker has substantially improved registration for COVID-19 vaccination which had been started on paper. The initial long queues for registering vaccinees in person were reduced with registration time condensed to 15 minutes (Wambura, 2021). At the same time, the DHIS2 Covid tracker is being used by health workers to register any walk-in COVID-19 vaccinees.

Distribution of all vaccines in the country is done via an informed push system down to the facility level. Supply chain and logistics management are being maintained through the existing VIMS at the regional and district levels. Health facilities capture the number of COVID-19 vaccines delivered; however, no detailed data is yet available on the number of doses administered at facility level. As an interim measure, the Chanjo Covid Tracker will be updated to keep track of the vaccine stock at the health facility level, a function which is expected to be available before the end of 2021.

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[7] https://pimacovid.moh.go.tz
[8] https://chanjocovid.moh.go.tz/#/

Further, COVID-19 vaccine-related AEFI are not yet reported through the Chanjo Covid Tracker but are captured in paper format on the Tanzania Medicine and Medical Devices Authority (TMDA) template (MoHCDGEC, 2021) as well as through the TImR AEFI forms used in routine immunization. The TMDA template is now being customized to be included in the Chanjo Covid Tracker.

3.2.5.3 Immunization delivery

The use of TImR and VIMS in RI has continued as before the pandemic. In particular, TImR supported the continuity of immunization service delivery throughout the pandemic through the timely scheduling of vaccination appointments and SMS reminders to avoid overcrowding in health facilities and reduce the risk of COVID-19 contamination (PATH, 2021). Like many countries across the region, Tanzania has faced challenges with RI during the pandemic and TImR's ability to provide real-time routine coverage, dropout data as well as to issue SMS reminders to parents and health workers have been noted as particularly useful during the first wave of the pandemic, specifically for defaulter tracking. The SMS reminder functionality of TImR was transferred to the Covid Chanjo Tracker as a best practice.

3.2.5.4 Emerging learning and opportunities

Further plans for TImR include its national scale-up by the end of 2022 and its integration with the Civil Registration and Vital Statistics System (RITA) to allow for exchange of information between the two systems. As demographic data are not currently shared across systems (i.e., by ID), TImR's link to RITA could aid in the identification of children who are registered in only one system and thus in reducing the number of zero-dose children, while its link with the Chanjo Covid Tracker could allow identification of more eligible beneficiaries for COVID-19 vaccination in the future. An integrated system would also allow TImR to provide birth certificates at the health facility level (IVD Program, 2021).

For stock data management, VIMS was customized to accommodate the COVID-19 vaccines, however challenges quoted by the developers pertain to its integration with the DHIS2 Covid Tracker (inSupply Health, 2021). VIMS depends on an interface with TImR which is linked to DHIS2 through a Health Information Mediator level to share information with DHIS2. As the Chanjo Covid Tracker is not directly linked to the TImR, information sharing with DHIS2 on COVID-19 vaccine stock and dose administration data is not presently possible. This is illustrative of the complexity of achieving data exchange between two separate systems, which has both a syntactic (i.e., one system knowing how to technically "talk" to another system via the establishment of an interface) as well as a semantic (i.e., each system "understanding" what the data means) dimension. The latter is much more complex and requires standardising the actual data exchanged via the alignment of the data model, a process that requires expertise, consensus, and time. Under urgent circumstances, as in the pandemic, achievement of such a result is proving especially challenging resulting in the dual use of eIR.

Given the rapid development of the Chanjo Covid Tracker, some lack of proper training and preparation of health workers in its use was acknowledged which led to an initial inability to troubleshoot properly. In response, the MoHCDGEC initiated intensified training sessions through remote virtual meetings while further trainings are being developed through a standard cascade approach with a specific budget earmarked for this activity. Procurement of tablets and training has overall been slow but is improving (Bulula, 2021).

National stakeholders cite several key lessons learned from the experience in Tanzania, including the following: (i) the rapid local adaptation of the existing DHIS2 tracker with the addition of a public facing app for making appointments is considered a major success; (ii) linking this tracker with the existing eIR

(TImR) and eLMIS (VIMS) as well as with the CRVS and AEFI notification system is deemed very important and should be implemented in steps; (iii) appropriate and intensive training of health workers is imperative and should include more than one staff per health facility; and (iv) advocacy and buy-in of the senior officials at the district and regional levels will enhance ownership of any innovative technical solutions. The latter has been cited as critical for the sustainability of the necessary budgets, specifically as this pertains to the purchase of internet bundles and other commodities at the health facility level. Close follow up and endorsement by the district, regional and national level will be needed here.

4 Lessons learned

A wide range of customized digital solutions have been deployed to support COVID-19 vaccine delivery and routine immunization throughout the pandemic. The case studies of Guinea, Honduras, India, Rwanda and Tanzania collectively provide further insights on how eIR and eLMIS have been used over the past few months, highlighting both challenges and opportunities. A complementary review of the literature published so far, while limited, positions the case studies within a more general view of the overall landscape, as well as highlights some additional country examples with a good breadth of information.

Overall, the findings provide a preliminary indication that digital solutions have been widely used during the pandemic response in support of the delivery of routine immunization, the identification and monitoring of the COVID-19 target populations, and the roll-out of COVID-19 vaccine delivery. However, countries have adopted different approaches to system design, with varying success.

Tanzania and India relied on their existing eLMIS solutions to manage COVID-19 vaccines. Uganda, Nepal, Bangladesh, and Pakistan also made use of existing eLMIS as part of the pandemic response, generally with success, while Guinea expanded the functionality of its existing eLMIS with the addition of a new module.

With respect to eIR system design, both Tanzania and India resorted to the *de novo* development of complementary eIR solutions for tracking and certification of beneficiaries. The latter are planned to be integrated with the digital infrastructure and systems that currently support routine immunization efforts in these countries, including birth registration and CRVS systems. At the same time, Rwanda implemented a separate COVID-19 Tracker as an additional module to its DHIS2 platform which also hosts the eIR Tracker for routine immunization. Lao PDR, Sri Lanka, Mozambique, Guinea-Bissau, Cape Verde and São Tomé and Príncipe similarly leveraged DHIS2. Jamaica, by contrast, introduced a new eIR, while Honduras deployed its existing hybrid eIR, though experiencing several shortcomings.

While little quantitative evidence is available to date about the impact of these digital solutions as part of the COVID-19 response, several insights about the application of existing and/or new digital solutions have emerged.

eLMIS have been successfully used for routine immunization and now also for COVID-19 vaccine supply chain monitoring. They have been instrumental in providing real-time stock data and, thus, have played an important role in reducing vaccine stock-outs. The learning from Uganda and Guinea demonstrates how eLMIS can be used for monitoring the flow of goods and reordering, while the experience in South Africa and Mozambique reveal how eLMIS can be leveraged to support microplanning for immunization sessions. The use of eLMIS will continue beyond the pandemic, and these tools will need to be flexibly adapted to emerging vaccine logistics and management needs.

For eIR, Pakistan and Bangladesh were both able to use their eIR for the monitoring of routine immunization performance during the pandemic, as the ability to obtain real-time data allowed for timely remediation of emerging problems. The ongoing work in Tanzania on integration of TImR and RITA provides learnings about the mechanisms of linking an eIR to a CRVS to capture zero dose children in support of routine immunization delivery. Rapid adaptations to eIRs to accommodate COVID-19 vaccination during the pandemic allowed for the introduction of new functionalities, including both the registration and tracking of vaccinations, as well as the issuance of vaccine certificates. Importantly, DHIS2 appears to be a solution which is now widely used in more than 70 countries. Although it may not be the digital solution with the most elaborate 'technical' standards and capabilities, many countries, including Rwanda, Lao PDR, Sri Lanka, Mozambique, Guinea-Bissau, Cape Verde and São Tomé and Príncipe, for example, successfully designed and implemented their eIR for COVID-19 vaccine delivery on the DHIS2 platform.

Several learnings and recommendations can be drawn from this early learning on the use of eIR and eLMIS during the pandemic, as well as suggestions posited as to where further research would be required before investment decisions can be made in relation to their sustainable scale-up and spread.

Firstly, **context-sensitive system design** is critical. The design of 'simple' digital solutions should reflect contextual constraints, such as IT infrastructure and digital literacy and access, as well as local needs. Criticism documented from India and South Africa suggests the need to ensure an equitable design of digital solutions given socioeconomic disparities. These solutions are most effective when they are informed by end users, and specifically respond to the needs of the frontline health workers, as well as those of the community they serve. There might be an evolving preference to go for simplicity in design of systems rather than for the highest level of technical capabilities which would enable local developers to continuously adapt the tools to changing environments. The example of Guinea, where the existing eLMIS covered only a part of the information needs (i.e., consumption) leaving important aspects uncovered (i.e., stock levels and flow of goods), further emphasizes the need for a thoughtful and forward-looking approach to the design of those systems.

Secondly, **utilization of local developers and investment in building national capacity** is suggested as a key success factor and critical to ensure sustainability. The experience in Tanzania demonstrates the potential risks of an overreliance on external technical assistance. Building local capacity can be done by supporting the establishment and development of local communities of practice of developers and users and by fully capitalizing existing South-to-South relationships. In addition, local developers and locally designed solutions together should enhance flexibility in adapting solutions to the local context and promoting ownership of the data. In the development of digital solutions, development partners should not be tempted to continue to rely on (and finance) international developers but rather focus on capacity building of local IT developers (e.g., with stipends for on-the-job training abroad) for the development and further adaptation of the electronic systems.

Thirdly, **digital solutions already in place should be leveraged** whenever possible, encouraging adaptations, fostering interoperability, and avoiding duplications. DHIS2 as a shared platform offers such practical solutions, as evidenced by the experiences in Bangladesh and Rwanda. At the same time, a proliferation of digital solutions has complicated and fragmented the landscape, leading to siloed operation of systems as experienced in the case of Honduras. There is a need to better understand which solutions can be useful and in which conditions, as well as how they can be consolidated to enable simple solutions to talk to each other. From a programmatic lens, there is the need for more targeted support for the development of practical solutions to establish interoperability, specifically including linking eIR to CRVS to allow zero-dose children to be reached. However, one cannot underestimate the difficulties of achieving such interoperability, once systems are set up and running. This will ideally need to be done in the design phase. Also from an economic perspective, it is reasonable to assume that adding or designing context-specific tools that can be readily integrated into already existing systems can contribute to quicker implementation as well as reduced costs compared to ex-novo development of tools. For example, potential savings may originate from existing knowledge capital and economies of scope, including lower software development costs; lower need for trainings and mentorship at different administrative levels; shared capital equipment such as servers and other IT infrastructure; shared use of software and durable equipment (e.g., software licences and tablets); and shared personnel costs (e.g., software developers).

Fourthly, **strong political commitment and a clear vision** are necessary to support the rapid and agile development and deployment of digital solutions. Investments need to be made to increase the level of preparedness as demonstrated in the case of Uganda. National ownership manifest in political will, like in Rwanda, ensures an enabling environment which prioritizes resources for digital health and favours a strategic and coordinated approach to thinking about critical issues around scalability, interoperability, and sustainability. Equally important is the advocacy and buy-in of senior leadership at the subnational level to further enhance the ownership of these solutions and pave the way for their decentralized financing.

Fifthly, **investments in human resources and digital infrastructure** are preconditions for success. Without sufficient and adequately trained staff, even the best performing systems and best designed tools will experience delays and shortcomings as evident in the case of Tanzania and Honduras. There is need for intensive training and re-training of local health workers, who need to be capacitated to use the systems daily and feel as comfortable using these as they are using their smartphones. It is pertinent to train all potential users, and this will likely not be achieved in this case through a Training-of-Trainers cascade approach.

Finally, strategic investment decisions about the scale-up of digital solutions should not be based solely on their direct expected return on investment. Rather, these decisions should incorporate broader considerations about the potential spill-over effects on other key areas of public health, such as the capacity to promptly respond to unforeseen situations. For example, critical areas of further exploration include: the extent to which a larger diffusion of digital solutions has favoured a more widespread and equitable access to COVID-19 vaccines; the resulting impact in terms of health and other societal outcomes; and the economies of scope reached by exploiting the existing digital infrastructure and digital knowledge capital.

This learning, while nascent, has the potential to make an important contribution to the larger dialogue on digital health. eLMIS have been useful for COVID-19 vaccine management and have been easily adapted; by contrast, eIR have been more difficult to modify given the technical issues with expansion of target groups, technical interoperability, need for including appointment scheduling and issuance of certificates. Both solutions, however, have great potential. There is emerging clarity about the way forward which includes increased investments in simple, open-source technical solutions, such as DHIS2, and greater support for the broader user and developer community of practice.

5 Conclusion

While every country context is unique, the pandemic has accelerated the pace of the digital evolution in health systems by exposing the need for integrated information management systems. The need to enable client registration, to track vaccines and vaccinations, to generate secure vaccination certificates, and to track AEFIs in real time has driven demand for both new and repurposed technologies. Countries and technology partners have stepped up, quickly developing new applications or new functionality in existing software to support COVID-19 vaccination efforts. This has been clearly demonstrated in the case studies presented for Guinea, Honduras, India, Rwanda, and Tanzania. While not a panacea, digital health applications are now seen as essential tools and enablers in any health system. Not every innovation deployed for COVID-19 will succeed, but the many different approaches have already begun to yield lessons learned. Many of the newly deployed technologies are platforms on which health systems can build to support routine immunization and other programmes. At the same time, the investments into existing technologies that have been adapted to support COVID-19 are legacies that strengthen health system resiliency for the future.

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Appendices

Appendix 1: *Search strategy on Web of Science performed on 08 October 2021.*

Set	Hits	Search strategy
#10	7	#9 AND LANGUAGE: (English OR French OR Spanish) Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI Timespan=2020-2021
#9	79	#7 AND #8 Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI Timespan=2020-2021
#8	7	#1 AND #2 AND #3 AND #6 Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI Timespan=2020-2021
#7	79	#1 AND #2 AND #6 Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI Timespan=2020-2021
#6	162,830	TS = ((("low" OR "middle") AND ("income" OR "resource") AND ("countries" OR "country" OR "context")) OR "LMIC" OR "LIC" OR "MIC" OR ("poor" AND ("countries" OR "country" OR "nation" OR "context")) OR Afghanistan "Albania" OR "Algeria" OR "Angola" OR "Antigua and Barbuda" OR "Argentina" OR "Armenia" OR "Azerbaijan" OR "Bangladesh" OR "Belarus" OR "Belize" OR "Benin" OR "Bhutan" OR "Bolivia" OR "Bosnia and Herzegovina" OR "Botswana" OR "Brazil" OR "Burkina Faso" OR "Burundi" OR "Cabo Verde" OR "Cambodia" OR "Cameroon" OR "Central "African Republic" OR "Chad" OR "China" OR "Colombia" OR "Comoros" OR "Democratic Republic of Congo" OR "Congo" OR "Costa Rica" OR "Côte d'Ivoire" OR "Cuba" OR "Djibouti" OR "Dominica" OR "Dominican Republic" OR "Ecuador" OR "Egypt" OR "El Salvador" OR "Equatorial Guinea" OR "Eritrea" OR "Eswatini" OR "Ethiopia" OR "Fiji" OR "Gabon" OR "Gambia" OR "Georgia" OR "Ghana" OR "Grenada" OR "Guatemala" OR "Guinea" OR "Guinea-Bissau" OR "Guyana" OR "Haiti" OR "Honduras" OR "India" OR "Indonesia" OR "Iran" OR "Iraq" OR "Jamaica" OR "Jordan" OR "Kazakhstan" OR "Kenya" OR "Kiribati" OR "Democratic People's Republic of Korea" OR "Kosovo" OR "Kyrgyzstan" OR "Lao People's Democratic Republic" OR "Lebanon" OR "Lesotho" OR "Liberia" OR "Libya" OR "North Macedonia" OR "Madagascar" OR "Malawi" OR "Malaysia" OR "Maldives" OR "Mali" OR "Marshall Islands" OR "Mauritania" OR "Mauritius" OR "Mexico" OR "Micronesia" OR "Moldova" OR "Mongolia" OR "Montenegro" OR "Montserrat" OR "Morocco" OR "Mozambique" OR "Myanmar" OR "Namibia" OR "Nauru" OR "Nepal" OR "Nicaragua" OR "Niger" OR "Nigeria" OR "Niue" OR "Pakistan" OR "Palau" OR "Panama" OR "Papua New Guinea" OR "Paraguay" OR "Peru" OR "Philippines" OR "Rwanda" OR "Saint Helena" OR "Samoa" OR "São Tomé and Príncipe" OR "Senegal" OR "Serbia" OR "Sierra Leone" OR "Solomon Islands" OR "Somalia" OR "South Africa" OR "South Sudan" ORvSri Lanka" OR "Saint Lucia" OR "Saint Vincent and the Grenadines" OR "Sudan" OR "Suriname" OR "Syrian Arab Republic" OR "Tajikistan" OR "Tanzania" OR "Thailand" OR "Timor-Leste" OR "Togo" OR "Tokelau" OR "Tonga" OR "Tunisia" OR "Turkey" OR "Turkmenistan" OR "Tuvalu" OR "Uganda"OR "Ukraine" OR "Uzbekistan" OR "Vanuatu" OR "Venezuela" OR "Vietnam" OR "Wallis and Futuna" OR "West Bank" OR "Gaza Strip" OR "Yemen" OR "Zambia" OR "Zimbabwe") Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI Timespan=2020-2021
#5	23	#4 AND #3 Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI Timespan=2020-2021
#4	591	#1 AND #2 Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI Timespan=2020-2021
#3	5,432	TS=(("routine" OR "regular" OR "schedul*" OR "essential") AND ("immuni$ation" OR "immuni$e" OR "vaccin*")) Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI Timespan=2020-2021

#2	18,261	TS=(("electronic" AND ("logistics management information system*" OR ("immuni$ation" OR "vaccin*") AND "regist*")) OR "eLMIS" OR "eIR" OR "information system*") Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI Timespan=2020-2021
#1	200,136	TS=("COVID*" OR "coronavirus" OR "C-19" OR "pandemic") Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI Timespan=2020-2021