# In-a-Container: Sustainable Digital Health Solutions for Resource-Challenged Communities

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Abstract: Access to comprehensive healthcare, education, and enterprise services in remote and resource-challenged communities remains a significant global challenge. This paper describes the In-A-Container initiative, a four-stage approach to delivering technology services that support telemedicine, community hospitals, education and community enterprise using secure, battery powered containers, photovoltaic panels and satellite communications. The first stage, for telemedicine, is in a suitcase-sized container small enough to transport in the cabin of a commercial airliner and delivered on-site using an electric bike; the container supporting a community hospital is a quarter-sized shipping container, delivered on an electric tuk-tuk; the largest containers for community education and enterprise are half-sized shipping containers, delivered on an electric truck. The final stage Enterprise-In-A-Container includes a battery bank that provides power for local community enterprises and a rental income that supports the ongoing operations. The first prototype of the Telemedicine-In-A-Container has been developed and tested in the laboratory; the second prototype is due for completion by the end of 2025. First pilots are scheduled for deployment in the first half of 2026 at the Darul Ikram Orphanage in Porto Novo, Benin and the El Roi Inland Missions Hospital in Jos, Nigeria.

## 1 INTRODUCTION

Access to comprehensive healthcare, education, and enterprise services in remote and under-served regions remains a significant global challenge. In sub-Saharan Africa, and other lower-income regions, solar-powered healthcare facilities can have a significant impact on the availability and quality of care (Teklemariam et al, 2025). Case studies from Lebanon (Kapuria, 2024), Kenya (Kaira et al, 2022) and Uganda (Uzorka et al) demonstrate how photovoltaic, solar energy can enhance vaccine cold chains, with solar fridges maintaining the required temperatures consistently. In a similar manner, the introduction of solar-powered telemedicine units has improved access to specialist consultations and diagnostics in under-served and usually off-grid regions, increasing early detection and treatment of diseases (Izuka et al 2023).

Despite successes such as these, significant challenges remain to the widespread adoption of digital health systems, and the improvement of health literacy in rural Africa (Maha et al, 2024).

In-A-Container is a four-stage approach to addressing these challenges, leveraging solar energy, internet and satellite communications, open source software, and telemedicine services to bridge gaps in healthcare service delivery and the inequalities found in the resource-constrained environments in many lower income economies. It will serve as a blueprint for scaling similar projects across the Global South and other regions with comparable challenges, fostering resilience, sustainability, and improved health outcomes.

Success in these volatile regions requires strong, local partnerships with key stakeholders: off-grid communities, community leaders, healthcare professionals, patients, community enterprises, government and Non-Government Organizations (NGOs), as exemplified by initiatives such as Riders for Health (Mbunge et al., 2022).

As a further example, Nigeria's healthcare system faces systemic and multifaceted challenges that undermine service delivery at all tiers (Manyati and Mutsau, 2022). Chief among these is the limited accessibility of care, particularly in marginalized rural areas, exacerbated by a disproportionate concentration of healthcare professionals in urban centres (Adeloye et al, 2017; Khan et al, 2022).

Compounding these disparities are critical deficiencies in infrastructure, including inadequate medical equipment, unreliable power supply, and insufficient basic amenities. Additionally, the prohibitive cost of healthcare further restricts access, especially for economically disadvantaged populations (Emmanuel et al,. 2025).

The first pilot sites for implementation of the Stage One Telemedicine-In-A-Container were chosen to provide a typical cross-section of the challenges that are more widely reported by the literature.

Located in Jos, Plateau State, Nigeria, a region characterized by recurrent political and ethno-religious crises, the El-Roi Inland Missions Hospital is a 20-bed, faith-based, non-profit hospital. Operating in this low-resource, crisis-affected area presents significant challenges: paper-based record keeping across all departments; insufficient funding leading to shortages of drugs and medical resources; a growing patient population; outdated technology, notably obsolete ultrasound equipment; absence of modern laboratory facilities; and lack of a reliable backup power source. This hospital provides the primary Use Case for In-A-Container and will be the site of its second pilot installation.

A simpler pilot will first be installed at the Darul Ikram Orphanage in Porto Novo, Benin. The information management requirements at the orphanage are relatively simple and the primary use of the In-A-Container package will be to support a health record system that stores basic information about children and generates the paperwork required for government reporting.

The remaining sections of this paper outline the vision and objectives for In-A-Container, the first prototype development, plans for the first pilots at the Darul Ikram Orphanage and the El-Roi Inland Missions Hospital, and future directions for the initiative.

# 2 VISION AND OBJECTIVES

The vision of the In-A-Container initiative is to provide a resilient, sustainable solution for telemedicine and digital health in resource-challenged communities, addressing technical, socioeconomic and political barriers. The objectives of the initiative are to:

1. Develop a Sustainable Digital Health Infrastructure; implement a long-term, sustainable digital health system utilizing open-source software to enhance healthcare delivery.
2. Establish Capacity Building Initiatives; empower local communities by providing technical expertise and resources, fostering self-reliance in managing digital health systems.
3. Enable Local Community Enterprise; deploy a swapping station for rechargeable batteries, that can be supplied to power enterprise, homes and transport in the local community and provide long-term revenue streams, quality-of-life improvements and support for the digital health infrastructure.
4. Train Local Technicians; equip local technicians with the skills necessary for the operation and maintenance of solar photovoltaic energy and digital health systems.
5. Implement a Hybrid Training Program; develop a comprehensive training program for healthcare and digital health professionals, at strategic, managerial and operational levels, to enhance the quality and efficiency of healthcare services.
6. Address Policy and Economic Barriers; identify and mitigate economic barriers, infrastructure challenges, and policy constraints hindering the adoption of digital health.

These overall objectives are realised in four stages with increasing sizes of container delivered by electric bike, tuk-tuk and truck, as stylised in Figure 1. The first stage, for telemedicine, is in a suitcase-sized container small enough to transport in the cabin of a commercial airliner and delivered on-site using an electric bike; the container supporting a community hospital is a quarter-sized shipping container, delivered on an electric tuk-tuk; the largest containers for community education and enterprise are half-sized shipping containers, delivered on an electric truck. The final stage Enterprise-In-A-Container includes a battery bank that provides power for local community enterprises and a rental income that supports the ongoing operations.


Figure 1: Four stages of In-A-Container, delivered by electric bike, tuk-tuk and truck.

### 2.1 Stage One: Telemedicine-in-a-Container

The initial stage deploys a compact telemedicine unit, small enough for air transport as cabin luggage yet powerful enough to support full-scale telemedicine consultations. This unit can be delivered on-site using an electric bike and includes an open-source Electronic Health Record system called cityEHR (Chelsom, 2011) running on a local server with dedicated data storage, a cloud-based backup facility, satellite and mobile network connectivity, and wireless interfaces for networked medical devices and terminals. It is powered by batteries supplemented with photovoltaic cells, ensuring functionality in off-grid settings. Configurations such as these have been instrumental in enhancing remote patient monitoring and consultation services in resource-constrained environments, for example the Clinic In A Can initiative in South Sudan (Sworo et al, 2012).

### 2.2 Stage Two: Hospital-in-a-Container

Building upon the telemedicine foundation, the second stage introduces a mobile hospital unit transported by a small electric vehicle, such as an electric tuk-tuk. This unit incorporates the Stage One telemedicine container alongside laboratory test equipment and ultrasound imaging devices, facilitating on-site diagnostics and expanding the scope of medical interventions available in remote locales. The integration of mobile units such as this has previously been shown to significantly improve healthcare accessibility in rural communities (Shaum et al, 2023).

### 2.3 Stage Three: Community-in-a-Container

The third phase extends the initiative's impact by incorporating educational resources and technical training equipment within a half-sized shipping container, thereby transforming the mobile hospital into a community centre. Delivered by a small electric truck, the unit aims to empower local populations through education and skills development, fostering community engagement and capacity building. The inclusion of educational components aligns with broader efforts to enhance health literacy and promote sustainable development in under-served regions.

### 2.4 Stage Four: Enterprise-in-a-Container

The final stage introduces an additional half-sized shipping container equipped with a solar-powered swapping station for rechargeable batteries, designed to power local enterprises, homes and electric vehicles and to generate revenue to sustain the In-A-Container deployment. This enterprise unit mirrors the size of the community container and is also delivered by a small electric truck. By providing a reliable energy source, this stage supports economic activities and ensures the sustainability of the community hub, contributing to the overall resilience and self-sufficiency of the solution.

Overall, the four-stage approach provides a scalable pathway to overall success, starting from the limited, and realistically achievable, first stage of Telemedicine-In-A-Container. By the final stage of Enterprise-In-A-Container the entire solution is sustainable for the long term, on a clinical, technical, environmental and economic basis.

## 3 PROTOTYPE AND PILOT

The first prototype is an implementation of the Stage One, Telemedicine-In-A-Container, with a single board computer as the server running the Electronic Health Record and a network router broadcasting a local Wi-Fi network and enabling the mobile data or satellite internet connection. Several candidate containers were considered, as shown in Figure 2, with the final selection being made on the basis of size, weight and ruggedness.

Figure 2: Assessed Containers and Solar Panel.

To power the server and Wi-Fi router, the main components of the energy supply consist of a FlexSolar 60W portable solar panel, an Eco-worthy 30A PWM solar charge controller (with 12V and 24V output options), and two 4Ah Lithium Iron Phosphate (LiFePO4) 12V batteries (within the total 8Ah limit for carriage on a commercial flight). The batteries are connected in parallel to maintain the nominal 12V for twice the time of a single battery.

In fact, although the nominal output is given as 12V from the solar controller, it does in reality supply around 13.2V (depending on the state of charge of the battery) because the normal operating voltage of a LiFePO4 battery is higher than the 12V standard (and still-used nomenclature) associated with conventional lead acid batteries. As the server requires a 19VDC supply and the solar controller only offers 12V or 24V outputs, it is necessary to include a DC-DC boost converter to raise the voltage from 12V to 19V for the server, while the router is able to run directly off the 12V.

The stipulation that it should be possible to carry the whole package on board a commercial flight imposes limitations on the configuration. Most importantly, no lithium ion batteries are allowed in the cargo hold, so the batteries must be carried on as cabin baggage while the portable solar panel, though small enough for the cabin, may travel in the hold.

To fit in the cabin lockers, the container must not exceed certain dimensions (typically 56 x 35 x 22 cm) and, unless special arrangements are made beforehand, the total capacity of any lithium ion batteries within it is limited to 100Wh (effectively 12V and 8Ah). The maximum allowed weight is usually 10kg, of which the most part is taken up by the batteries. By meeting all these requirements by narrow margins, our prototype maximizes the functional capacity that is possible to achieve from a flight-ready, portable system that is instantly and easily deployable.

Figure 3: Prototype Telemedicine-In-A-Container.

To determine whether this configuration meets the practical demands of its intended initial application, it was tested in the laboratory under typical operational loads, as shown in Figure 3. In real-world operation, the server would normally run ‘headless’ (i.e. without screen, keyboard, or mouse) and would be accessed via a client device (tablet or PC) that communicates with it through the Wi-Fi router (and in pilot operation will also communicate with cloud services over mobile data or satellite connections through the router). It is assumed that the client device will have its own, separate – preferably solar – power supply, so its energy consumption is not relevant to this specific test of the stand-alone sever system.

Table 1 presents the measured data obtained through laboratory testing. On this occasion, the batteries were charged by mains electricity (an option that is often also available in real-world operation), rather than the solar panel, because the charging capabilities are not under scrutiny whereas the discharging rate is the critical factor under investigation. The tests are made on the assumption that the battery/solar is the only available power source (no mains power connection is available).

Test data were used to read, process and write 36 patient records in 5 second bursts of activity. If we assume the clinic is open between 08:00 and 17:00 then the power consumption in each burst equates to 4 patient record interactions per hour. For power capacity calculations it is assumed that the clinic activity is 100 times this level and that 'out of hours' activity is 2 times this level.

The test results show that a total of 433Wh are likely to be consumed over a typical 24-hour period. Even if no processing were carried out on a given day, only about 1% of this would be saved, because although the digital processing adds peaks of server power that can be up four times its background consumption, these are so brief that they barely affect overall energy usage; the vast majority of energy consumed is simply for keeping the system switched on.

Considering that the battery power is restricted to 100Wh (to be carried on a commercial flight) and the lab test shows that 433Wh are consumed over a full 24-hour day, it appears that its capacity is insufficient. However, assuming that the solar panels maintain the battery charge during daylight hours, the battery capacity needs only to be sufficient to keep the system running from twilight in the late afternoon until the sunlight reaches sufficient levels the following morning.

Furthermore, the number of interactions with the server have such an insignificant effect on the overall energy drain on the batteries, that it is almost irrelevant in this calculation. What is important, therefore, is simply keeping the system running through the night, because it is recharged in the morning and kept topped up at a full state of charge for the rest of the daylight hours.

The challenge for the batteries, therefore, is to power the system from around 5pm to about 8am without recourse to solar power, which equates to around 2/3rd of a 24-hour day. This still requires 289Wh of battery capacity, so the question is whether there is scope for improvement, such that the batteries can do the job.

It is noticeable that the losses in the DC-DC boost converter amount to 108Wh, so eliminating this component could bring this overnight energy demand down to about 216Wh, as well as saving, space, weight and cost. However, this still doesn't bring the nighttime consumption down to the required 100Wh, so other options to consider are to find both server and router components that are more energy-efficient and using additional batteries that are sourced or transported separately.

Table 1: Laboratory Test Results of the First Prototype Telemedicine-In-A-Container.

| **Component** | **Process** | **Current,** *A* | **Duration,** *s (h)* | **Mean current,** *A* | **Occurrence during daylight hours,** *n* | **Occurrence overnight,** *n* | **Energy per day (with solar charge controller providing 13.2V),** *Wh* |
|---|---|---|---|---|---|---|---|
| Server (includes parasitic losses of DC-DC power supply) | Standby (i.e., on, but not processing) | 0.8 – 1.1 | Continuous (24) | 0.85 | Continuous | Continuous | 0.85 * 13.2 * 24 = 270 (of which 108 Wh are power supply losses) |
| | Searching, retrieving, editing, updating 36 records | 0.8 – 4.5 | 5 ($1.39 \times 10^{3}$) | 2.5 | 100 | 2 | 2.5 * 13.2 * ($1.39 \times 10^{3}$) * (100 +2) = 4.65 |
| Wi-Fi router | All operations (sending, receiving, standby) | 0.5 | Continuous (24) | 0.5 | Continuous | Continuous | 0.5 * 13.2 * 24 =158 |

Connecting additional batteries in parallel to the two already contained in this prototype provides larger energy capacities and longer operational times. Indeed, even in the sunniest parts of the world, there will occasionally be days without strong sunshine, which requires this system to have a bigger battery capacity than is possible in this flight-ready package. However, this is easily accommodated by adding further batteries as and when required, so the system is very flexible and is expandable from the initial base unit.

The second prototype is being built with replacement components for the server and router. In particular the single board computer used for the server (HP EliteDesk 705 Mini PC 16GB RAM 128GB SSD) is being replaced by a more rugged unit that runs off a 12v power supply, allowing the removal of the DC-DC converter.

The move from prototype to pilot involves the configuration and installation of the cityEHR open source health records system on the server hardware in each container delivered to the pilot sites. cityEHR is a model-driven system, whereby a clinical information model is developed for each deployment, conforming to the ISO-13606 and HL7 CDA standards. This approach ensures that the system meets the local requirements for clinical information, using a model that is developed "bottom up" by local clinicians.

This contrasts with "top down" approaches such as the Digital Health Platform (DHP) proposed by the World Health Organization Africa Regional Office, which is based on the open source MRS health records system (Ibeneme et al, 2022). Both approaches are valid, each with advantages and disadvantages, and the common factor is the use of open standards for the representation and exchange of healthcare information, which ensures the potential interoperability of any systems that are deployed.

Using the model-driven approach of cityEHR, the first step in any implementation is the development of a clinical information model that is designed to meet the specific local needs. Separate models have been developed for the needs of the Darul Ikram Orphanage and for the El-Roi Inland Missions Hospital, the former being quite simple and the latter a more comprehensive information model of data and services typical of a community hospital .Although developed specifically with staff from the two locations, these models could now be used, or adapted, for deployment at similar facilities in different locations.

One major concern in the deployment of any clinical information system is to protect the security and confidentiality of patient data. When those systems are deployed in volatile environments using portable technology such as In-A-Container the concerns assume even greater significance. The access control features of cityEHR ensure that authenticated users gain access to data only for patients with whom they have a "legitimate relationship". To achieve this requires robust identification of each clinical user and a digital identity for each patient, usually using a unique patient identifier. In the two pilot locations the identity management for clinical users and patients (or children, in the case of the orphanage) is currently paper-based and must be transferred to digital management in cityEHR as a first step.

Clinical data security is ensured on several levels. The disks on the servers within the container are encrypted so that they are protected in the event that the physical devices are lost or stolen. In addition, the database used for storing patient data in cityEHR uses database field encryption for all "data at rest" which ensures protection in case the access control of cityEHR is bypassed by cyber intruders. This is important, since the container does not include a stand-alone security appliance for implementation of a network firewall.

The satellite or mobile data internet communications in the container can be used to configure cloud-based backup which can be configured to run overnight or during other periods of low database activity. The backup can be used to restore the local database in the case of data corruption, physical damage or theft of the server (or the whole container). The communications link can also be used for remote monitoring, maintenance and support of the server and database, although the intention is that the data are held locally within the container. This is necessary to ensure that patient information is always available, even when the internet communication link is not.

# 4 CONCLUSIONS

The In-A-Container initiative sets out an ambitious vision for delivery of a resilient and sustainable infrastructure to support digital health solutions in lower-income countries. The first prototype has demonstrated the technical feasibility of the Stage One Telemedicine-In-A-Container. The second prototype will simplify the power requirements of the server and upgrade the capabilities of the router.

This second prototype will then be used for the pilot installations at the Darul Ikram Orphanage and the El Roi Inland Missions Hospital in the first half of 2026. The orphanage provides a relatively simple environment for the first installation and will test the logistics of delivering the smallest sized container. There are few technical challenges here and the Telemedicine-In-A-Container should be sufficient to meet the long term needs, hence the site can be used for iterative refinement of that first stage container.

The pilot installation at the El Roi Inland Missions Hospital will provide the platform for developing the vision to its full potential. Once the Telemedicine-In-A-Container has been established there, staff have provided feedback and are comfortable with its use, then the hospital provides the perfect environment to pilot the more advanced stages of the In-A-Container initiative.

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