Enabling sustainable behaviors of data recording and use in low-resource supply chains

Arun Ramanujapuram
Logistimo
Bangalore, Karnataka, India
arun@logistimo.com

Charan Kumar Malemarpuram
Logistimo
Bangalore, Karnataka, India
charan@logistimo.com

ABSTRACT

Public services, such as public health supply chains, in low- and middle-income countries can be characterized as *low-resource environments*, where both infrastructure and human capacity are limited. There is no strong culture of data recording or use, with ad hoc reporting practices, poor planning and lack of coordination. All these lead to poor supply chain performance, thereby restricting access to medicines, and eventually resulting in poorer health and mortality.

We describe the ground-up design of Logistimo SCM, a supply chain management software, offered as a service, that has enabled a transformative change in public health supply chains, leading to improved performance. Our approach is rooted in bottom-up empowerment of the human value chain, based on the principle that higher self-efficacy amongst health workers and managers can lead to sustained changes in data recording and use behaviors. This is achieved through a service that optimizes data collection effort, maximizes supervisory bandwidth, promotes proactive and collaborative operations, and enables frictionless performance recognition. We describe the guiding principles of inclusive software service design and four mechanisms that enable the appropriate conditions for stimulating a behavior of data recording and use. We demonstrate their effectiveness in achieving good supply chain performance through case studies in India and Africa. The principles and methods discussed here are generic and can be applied to any low-resource environment.

CSS CONCEPTS

• Human-centered computing ~ Human computer interaction (HCI) ~ Interactive systems and tools • Information systems ~ Information systems applications. ~. Mobile information processing systems

KEYWORDS

Data collection, data use behavior, culture of data use, supply chain, public health, low-resource environment.

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1 Introduction

One third of world's population lacks regular access to essential medicines, and in the poorest parts of Asia and Africa, this figure increases to 50% [27]. To achieve good health outcomes, access to essential medicines and related consumables is crucial. The weakness of public health supply chains has remained a constant barrier across a range of low- and middle-income countries. Despite major investments over many decades, efforts to strengthen National supply chains have not succeeded, placing health outcomes at risk [9].

In low- and middle-income countries, districts and below can be considered as *low-resource environments*, where both infrastructure and human capacity are limited. Physical infrastructure, such as building and roads, are lacking and health centers tend to be poorly equipped. Digital infrastructure such as computer and Internet are only intermittently available. Many centers are short-staffed, with overburdened resources and insufficient capabilities. These impose significant stress on district managers and health center staff, leading to low performance and motivation.

The onset of software systems has now afforded an opportunity to achieve better visibility into operations, process automation and decision support using data. However, public health systems have not been able to create the transformation required to achieve the necessary behavior changes in data collection and use. Data quality has perennially been a challenge in these environments, possibly due to top-down paradigms of system strengthening that do not holistically consider the needs and constraints across the value chain, especially at the last-mile. Consequently, these efforts have been *supportive* at best, resulting in incremental improvements rather than transformative ones.

Logistimo SCM is a supply chain management software, offered as a *service*, which has enabled sustained behavioral changes in data recording and use, leading to improved performance. In this paper, we highlight the importance of inclusive design of information systems that can adapt to organizational and resource constraints in low-resource environments, while empowering people bottom-up. With good system design, easy-to-use tools and easy-to-interpret data, the effort and friction in

data entry and use can be reduced, thereby improving adoption and performance.

We first describe the challenges in low-resource health supply chains that lead to poor data quality and performance. We provide an overview of the Logistimo SCM platform. Subsequently, we describe the guiding principles of design and four mechanisms in the service that enable sustained changes in data recording and use behaviors. We finally share case studies from successful deployments of Logistimo in India and Africa that illustrate the effectiveness of this approach.

2 Challenges in low-resource environments

Low-resource environments face a variety of challenges including organizational, infrastructure and human resource challenges. The public health sector depends heavily on people to carry out its mission, but is also the one plagued by shortage of capable human resources [3]. Organizational hierarchies and divisions create additional bottlenecks that can only be addressed through systematic restructuring and decentralization, both of which are challenging. The Primary Healthcare Centers (PHC) and Sub-Centers (SC) are the last-mile service delivery points. Being remote, they are the most hard pressed for infrastructure and resources, and difficult to monitor [21]. It is critically important to have good visibility at the last-mile to be able to optimize the supply chain.

In this section, we review four challenges in low resource environments that limit adoption of technology for data recording and use, especially below district. These include: (1) resource unavailability, (2) limited technology capability, (3) no culture of data recording and use, and (4) limited management capacity.

2.1 Resource unavailability

There are significant inequities in the distribution of health workers between countries and within countries, with a larger proportion of the workforce concentrated in urban areas. Many positions in rural PHCs, including those of doctors, nurses, midwives, pharmacists and lab technicians remain vacant for long periods. For instance, Sub-Saharan Africa has about 11% of the world's population and bears over 24% of the global disease burden, but has only 3% of the global health workforce [4]. In India, the aggregate density of doctors, nurses and midwives was found to be 2.06 per 1000 population, which was lower than World Health Organization's (WHO) critical shortage threshold of 2.8 [14]. Attrition rates amongst health workers are also high, and retention has been a problem. Public health supply chains in low-income countries tend to have fewer pharmacists, on the average about 6 pharmacists per 10,000 population, leading to inequities in access to medicines and pharmaceutical expertise [7]. Resource unavailability poses a real challenge for administrators at the PHCs and districts to ensure sustained improvements in data quality and performance.

2.2 Limited technology capability

Computer systems and data have become a strong part of public health systems. However, many health workers at the last-mile have limited capability to use information and communication technologies. Studies have shown that knowledge and utilization of computers is very low amongst health workers [1][2]. For instance, [2] indicated that only 18.4% of health workers in Ethiopia utilized computers with 3.4% having adequate computer knowledge. Across 12 states in India, 40% of cold-chain staff managing vaccine inventory were over 50 years old, and some had never used a mobile phone application [17]. Due to these reasons, there is no consistent adoption of information systems and data reporting continues on paper in non-standard formats. Frequent power cuts and intermittent Internet access further restrict digital data entry and use. Although there is a proliferation of mobile phones, mobile application usage and human-to-human communication are limited due to ingrained habits and work cultures. Consequently, most public health systems in low-resource countries suffer from poor adoption of available information and communication technologies in PHCs and district offices.

2.3 No culture of data recording and use

Culture of data recording and data use is non-existent or weak at various levels, and more so at the health facilities [5][20]. Timely, accurate and complete data are generally unavailable in health information systems. In an audit of immunization data quality conducted in 1082 health facilities across 188 randomly selected districts spread over 41 countries, almost half the health units showed poor data quality [8]. Only 41% of the districts used computers to manage immunization data. Even though 89% of the districts had data reporting guidelines, only 49% of the health units had up to date ledgers for an important vaccine (Tetanus Toxoid). Another assessment in Botswana indicated low ownership of monitoring and evaluation at facilities, non-standard practices, limited dissemination of indicator definitions, lack of training programs to build monitoring skills, and limited functionality in software systems [16].

Software systems in the past have simply digitized the status quo, leading to two disparate systems for data recording – paper and digital. This has increased cognitive complexity and data entry effort, leading to low adoption and poor data quality. The flow of data is largely one-way, with aggregated data flowing upwards in the hierarchy to fulfill periodic reporting needs, rather than supporting decisions downstream. Even where policies and guidelines exist, the processes around data collection and use, are not enforced. This eventually leads to incomplete and inaccurate data in country-level health information systems, thereby rendering them perennially unreliable. Even where data is available, the capacity to derive actionable insights from data is not strong amongst the district managers, leading to poor use of available data.

2.4 Limited management capacity

District health managers are responsible for delivering health outcomes in a highly resource-constrained environment. Health managers are rarely trained in management. Studies such as in Africa [12] and Asia [6] have identified limited management capacity among local health managers as a major obstacle for health service delivery. District managers are generally overburdened because of their engagement in several ongoing programs, and relative underutilization and motivation of supportive staff [3]. Bureaucratic procedures and lack of responsive team downstream stifle their ability to manage operations remotely or invest in human development. Consequently, they tend to be reactive, focusing on mitigating high-risk situations (e.g. death or disease spread), while

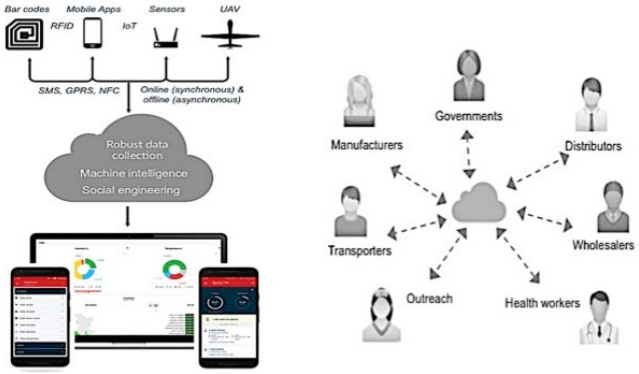
supporting services (e.g. supply chains) and human capacity development, receive less attention. This results in poor planning, improper coordination, and little or no capacity improvements in the district. With less oversight and recognition, people downstream tend to become less accountable, thereby leading to less motivation and degraded service quality. Even where good data exists, the district manager may not have sufficient technology and analytics capacity, thereby rendering such data useless.

The above challenges hinder data production and information use, both of which are considered critical to creating a data use culture [5].

3 Logistimo SCM Platform

Logistimo Supply Chain Management (SCM) is a software platform offered as a service for managing supply chains, and is built ground-up to work effectively in low-resource environments. People across the value chain are equipped with easy-to-use tools, actionable information and efficient ways to organize and collaborate. It offers rich functionality to manage inventory, forecast demand, optimize inventory availability, fulfill orders, monitor cold-chain and manage transportation logistics. These functions along with interactive dashboards are easily accessible in both web and mobile applications. More importantly, a host of capabilities exist that enable easy data collection, effective dissemination of information, and insights based on descriptive and predictive analytics. The system is highly resilient, and can be adapted according to a given user's capacity and available digital infrastructure. It can work fully offline, on mobile networks (2G or higher), and over SMS, ensuring reliable data transmission on unreliable networks. The web and mobile interfaces are responsive to a variety of devices including computers, mobile phones, tablets and large-screen digital monitors (such as televisions).

Figure 1(a) illustrates a system that ensures reliable collection of large amounts of data from humans and devices (such as cold-chain temperature loggers), and delivers actionable analytics in ways that can be consumed easily. The system leverages machine intelligence for forecasting and optimization, and social engineering to orchestrate action, thereby enabling collaborative problem solving using timely and reliable data. It provides two mobile applications; (1) Iota, a store management application typically used by health workers at PHCs and district warehouses, and (2) Pulse, a monitoring application, typically used by district managers or higher. Figure 1(b) shows all value chain partners connected in a single network with real-time visibility and insights.



(a) (b)

Figure 1. (a) Logistimo platform with resilient architecture and web/mobile applications, (b) The human value chain connected through a single network.

The system embodies a modular design, where different service components such as inventory, orders, and asset monitoring can be enabled independently or together through configuration. The system is based on a high-availability, micro-services architecture, with carefully delineated services, depending on the need for scalability (say, handling big data) and independent evolution (say, common services evolving on a different timeline). The above enable the system to be cost-effectively deployed depending on functional needs, infrastructure capacity and expected service availability level.

Logistimo is currently used in over 30,000 health facilities in rural areas spread over 600 districts across 6 countries. Health workers at a PHC such as pharmacists, nurses, midwives, lab technicians or cold-chain handlers use a mobile phone application to enter data, and manage inventory, orders and cold-chain assets. District managers or above use mobile or web applications to monitor supply chain performance and collaborate with health workers.

4 Designing for behavior change

Public health systems have employed a variety of capacity building programs with different levels of effectiveness [10]. Such programs help build knowledge and skills. However, changing ingrained cultures of data recording and use requires ongoing effort that can lead to an inner transformation amongst health workers and managers.

It has been generally recognized that to achieve effective change, interventions have to be brought across policies, information systems, practices and people [5]. Human centered-design, culture of accountability, and harmonized digital tools are recognized as necessary to enable a culture of data use [5][26]. While these are important, and necessary, systemic changes have to come from within, to achieve sustainable outcomes. Many health workers and managers are inherently capable, but feel incapacitated by the seemingly overwhelming constraints in the system.

The objective was to enable a digital service bottom-up that optimally leverages latent capacity to orchestrate data collection and use, in a way that aligns with top-down efforts. The belief is

that if people are able to use information, even minimally, and achieve better performance, their self-efficacy increases. This, in turn, can lead to sustained behaviors of data recording and use.

4.1 Principles of service design

The core principle of service design was to *empower* health workers *and* managers in a way that improves their *self-efficacy*. Self-efficacy is defined as a person's belief in their capability to successfully perform a task, and improves one's ability to collect relevant information, make sound decisions and take appropriate action, particularly when one is under pressure. It is understood that self-efficacy can lead to behaviors that eventually improve performance. There are three key determinants of self-efficacy that are worth considering [13]:

1. **Enactive self-mastery***:* Enactive self-mastery is achieved when people experience success at performing simpler tasks or at least portions of a task, and progressively advance to more difficult tasks.
2. **Role modeling***:* Role modeling inspires one to learn from the success of others who excel.
3. **Verbal persuasion**: Verbal persuasion is a form of constructive feedback and appreciation, which improves one's sense of what they can achieve.

The aim was to optimally leverage existing capacities of health workers and managers, and create the conditions that enable determinants of self-efficacy.

Another key principle was to motivate action by raising *awareness*, especially on supply chain risks, service quality and performance. Given the critical importance of information in this context, the following supportive principles were considered for information dissemination and use:

1. **Equity**: All data, information and services should be equitably accessible at all levels in the administrative hierarchy, from National down to district and health facilities. For instance, a dashboard or report provisioned at the National/State level should also be available at the district and PHC, based on their respective data.
2. **Ubiquity**: Data collection and use should be ubiquitously possible, wherever a person is and through a medium that they are comfortable with. The most ubiquitous means of information access in low-resource environments is the mobile phone, which provides computing and communication capabilities, anytime and anywhere.
3. **Redundancy**: Information must be redundantly disseminated to multiple persons on different types of devices such as computers, mobile phones, tablets, and television screens. Redundant communication ensures that awareness exists across a group of people, at least one of whom can act.
4. **Relevancy**: Information overload leads to cognitive burden and poses a serious challenge to adoption. Consequently, highly contextual and relevant information has to be delivered on a *need-to-know basis* to workers and managers at any level.
5. **Timeliness**: The information has to be timely so that awareness of risks or other events exists as they occur. Knowing them before time, predictively, would be even more helpful, given the lead time to mitigate risks.
6. **Traceability**: All information should be traceable, where raw data (such as transactions, orders) is completely accessible through one's preferred device, be it computers or mobile phones. This enables one to validate, refer and use such data in support or defense of decisions taken.
7. **Integrity**: The integrity of the underlying data in terms of correctness, freshness, completeness, consistency and coverage are essential to ensure validity of decisions made using them.
8. **Confidentiality**: Preserving confidentiality of personal and sensitive data is critically important to protect privacy at individual, community and organizational levels.

A third principle was to enable stronger *social engagement* amongst people across supply chain echelons to motivate sustained use and performance improvement. In particular, social incentives and conversations were considered. Social incentives could be in the form of "social pressure" to act, such as public display of performance, and individual recognition. Conversations could be carried out in the context of various information objects within the system amongst people across echelons.

4.2 Service mechanisms

We describe four mechanisms in the service that embody the above principles and enable the conditions to achieve behavior changes in data recording and use. These include:

1. **Adaptive data collection**, which allows adaptation of service complexity and data granularity according to a resource's capacity, thereby optimizing data entry effort.
2. **Flexible organization**, which enables one to effectively leverage a peer network of health workers or managers to maximize supervisory bandwidth.
3. **Proactive and collaborative operation**, which enables health workers and managers to move from a reactive mode to a pro-active mode of operation through event-driven notifications, escalation on a "need-to-know" basis, social pressure to act, and targeted feedback. This enables a good context for engagement and fosters collaboration between the manager and the health workers.
4. **Frictionless recognition**, which enables a frictionless way for a manager to identify and recognize good performance, thereby improving worker motivation.

We contextualize the discussion to districts and below, where the biggest challenges exist, and require the strongest interventions to transform the supply chain. However, the mechanisms described apply equally well upstream in the hierarchy.

4.2.1 Adaptive data collection

A health worker's capacity and behavior around data recording and use tends to vary within and across districts. When new technology is introduced, not all are able to adopt it in the same

way. Consequently, a holistic design of the system of data entry is required – one that minimizes effort, maximizes data quality and evolves with increasing worker capability. There are three key aspects to service design that enables an adaptive data collection system:

1. **Holistic data system design**: The data system design has to rationalize the data elements being collected, including the granularity of data, to meet analytic goals. One has to holistically design the system of data entry comprising both the paper form and the digital interface, making them complementary to each other in a way that reduces data entry effort. For instance, in the immunization supply chain in India [15], the issue register at a PHC was redesigned in a manner that one records issues per sub-center on paper, tallies them and records the aggregate issue quantity in the digital system using a mobile phone application.
2. **Progressive advancement**: Starting simple and progressively advancing the complexity of services and granularity of data is important to ensure adoption. For instance, a health worker can start with simple inventory management and enter counts for issues, receipts, physical stock and discards of commodities. As one's capacity to accurately record data improves, one is in a position to provide more granular data, such as batches and expiry. Subsequently, one becomes capable of handling relatively complex processes of expiry management, order management and cold-chain monitoring. The system allows selective provisioning of supply chain services and data attributes within an administrative domain or a facility, thereby allowing one to adapt system complexity according to resource capacity.
3. **Full mobile enablement**: Full mobile enablement implies that a user can access all the services, data, information, and analytics simply through an easy-to-use mobile phone application, anytime and anywhere, independent of network availability. This is critically important for the reasons mentioned earlier including lack of computer skills, lack of electricity and good network at the PHC. Data can be entered even when offline and is synchronized with the server when network becomes available. A robust data transmission middleware that leverages redundant channels of mobile Internet and SMS, ensures reliable synchronization of data with no additional effort.

A model of adaptive data collection allows one to standardize data recording practices, without imposing a one-size-fits-all approach. It allows progressive advancement with a highly usable and resilient mobile application, thereby enabling the conditions for enactive self-mastery.

4.2.2 Flexible organization

The lack of resource availability has forced certain district health managers to adopt creative, localized solutions. For instance, shortage of staff has resulted in a redistribution of responsibilities, wherein the pharmacist of one facility is made responsible for monitoring and reporting medicine stocks of nearby facilities. At the district level, shortage of district health managers has resulted in one manager overseeing two districts until a replacement is found. New models of engagement are evolving, such as the Public-Private Partnership (PPP) for managing rural health centers [24]. This has been successfully followed by the Department of Health in Karnataka, India, with a Non-Governmental Organization (NGO) called Karuna Trust, which manages 21 PHCs in Karnataka [19]. In this case, the private organization is given complete autonomy in staffing and managing the PHCs, with the PHC staff accountable to both the partner organization and district management.

The above model resembles a *heterarchy* [18], which combines an administrative hierarchy and peer-to-peer supervisory relationships between health facilities or with private partners. Heterarchical networks can be both flexible and dynamic, wherein supervisory authority is not institutionally fixed but rather changes along with changing resource situations.

Modeling the heterarchy:

A heterarchy model allows a district manager to leverage competent health workers in the peer network for increasing supervisory bandwidth. In this context, the following are enabled by the system:

1. A flexible way of modeling a heterarchy.
2. An easy way for users to navigate it.
3. An easy way to evolve the model as the constraints change.

Two abstractions of *entity* and *domain* and their interdependencies help one represent such a model.

1. **Entity**: An entity represents the last-level organizational unit, which is a physical unit that is uniquely identifiable by an address or a geocode. An entity holds inventory. Typically, sub-centers, PHCs, and warehouses are modeled as entities. One or more users can be associated with an entity, each with different roles and privileges.
2. **Domain**: A domain represents an *administrative boundary* such as a district, region, state, country, or partner enterprise, and includes a set of entities. Each domain draws a logical boundary around entities, and restricts visibility of data to users in that domain or its ancestors. It also allows customization of workflows and rules to accommodate local needs. Domains can be nested within each other modeling the entire administrative hierarchy from National down to district. Domains are also referred to as *super-domains*, given they can recursively nest any number of domains, but more so due to their ability to achieve equity of services and information across domains. For instance, a new feature or report provisioned at the National domain becomes instantly available in all descendant domains including state, region, and district, all the way down to a health facility. This empowers managers across the hierarchy equitably, providing them an opportunity to improve local governance.

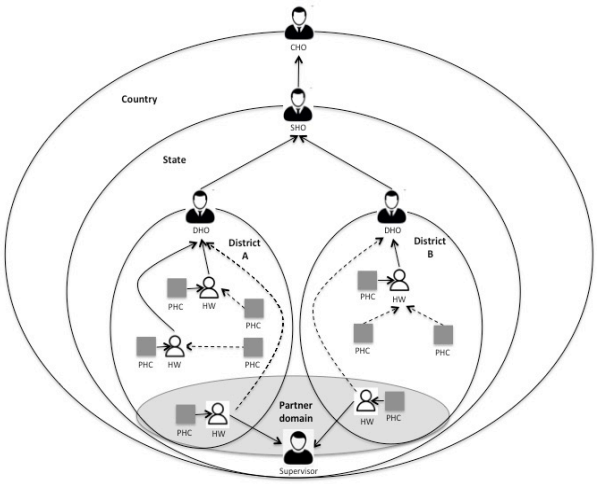


Figure 2. An organization model with domains, entities (PHCs) and relationships

Three types of relationships involving domains and entities enable one to effectively model a heterarchy:

1. **Hierarchical relationships between domains**: Domains can be hierarchically nested within each other through parent-child relationships, with visibility rules on data. In Figure 2, the District domains A and B are nested within the State domain, which in turn is nested within the Country domain. Master data (such as entities, users) and transactions created in a child domain automatically become visible in a parent domain. Managers in a parent domain, such as District Health Officer (DHO), State Health Officer (SHO) or Country Health Officer (CHO), can monitor performance of all descendant domains through interactive dashboards and reports, thereby allowing hierarchical monitoring and management.
2. **Many-to-many relationships between users and entities**: A user (say, a health worker) in one entity can be associated with multiple other entities, providing him/her controlled access to these entities. This allows a health worker to perform data entry and/or monitor operations across all associated entities. Figure 2 shows PHC entities lacking relevant staff in a dotted line reporting relationship with a resource in another PHC. This enables one to effectively create a peer-to-peer supervisory network in a district. In addition, multiple users can be associated with one entity, each with different roles and privileges, thereby enabling redundancy of resources within a PHC for data entry and monitoring.
3. **One-to-many containment relationship between an entity and domains**: One can make an entity a member of one or more peer domains that are not part of its primary domain ancestry. This ensures that the entity and its data are visible in the partner domain in addition to its source domain or its ancestors, thereby allowing a dual-management model. Figure 2 shows a partner domain encapsulating two entities, one each in district A and B, respectively. This offers a powerful construct to model public-private partnerships through a simple reconfiguration of entity-domain relationships, without requiring complex customization or data migration.

With a flexible mechanism to model a heterarchy and navigate it, a district manager can ensure an optimum level of supervision even in spite of resource constraints, which in turn, sustains good data quality, data use and capacity improvements.

4.2.3 Proactive and collaborative operations

Poor planning and insufficient management can lead to critical risks in the supply chain, such as extended stock out periods or product loss due to expiry. This results in one working reactively to solve problems. The following mechanisms enable pro-active, coordinated action that can help mitigate risks:

1. **Preemptive, redundant notifications**: Preemptive notifications are sent redundantly to all designated health workers in an entity, so that as a group they become aware of a problem or a potential problem. For instance, one could be made aware of a stock out, an item that is likely to stock out soon, or a certain quantity of stock that is likely to expire soon. Rules and predictive analytics help identify such events, which are delivered to users on redundant channels of phone notifications and SMS. Preemptive notifications nudge health workers towards action, thereby improving the likelihood of timely problem resolution.
2. **Escalation on a "need-to-know" basis**: District or higher-level managers have limited bandwidth, and cannot track all possible risks. Information overload can lower adoption. Consequently, managers are notified only on a *need-to-know* basis of events that have *not* been acted upon downstream for a specified period. Based on big data analytics, the system heuristically summarizes critical risks in the supply chain, such as stock outs persisting beyond a certain period, a large quantity of stock that may expire before usage, or prolonged delays in data entry. Summaries of such events are notified to managers on their phone through a monitoring mobile application, while giving them an ability to drill-down to the problematic locations. The manager can instantly call or message the corresponding health worker from within the application to coordinate actions, thereby initiating a conversation (see Figure 3a). This enables a manager to become aware of potential risks, and instantly engage the health worker to mitigate them. This fosters better collaboration between workers and managers, while also increasing worker accountability.
3. **Social pressure to act**: Being aware of a problem may not be sufficient to motivate action. The system provides digital bulletin boards, which are a collection of dashboards and event summaries that stream continuously on a television monitor. A bulletin board helps a manager become aware of critical events even if s/he is not yet a system user. If mounted in a public

place, it generates "social" pressure to act, given others around become aware as well. This mechanism has been helpful in motivating data use amongst managers [22].

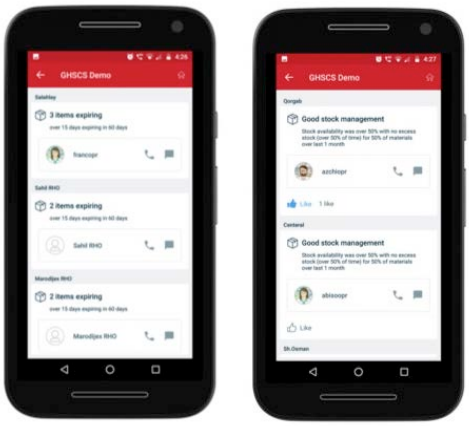
4. **Targeted feedback on an "as-needed" basis**: Behavior change towards better performance is effective where there is targeted feedback and handholding by a supervisor. The system provides a set of human performance indicators on data entry quality, application usage and response times on expected actions. Example metrics include data reporting rate, data recording delays, replenishment response times and order processing times. These indicators give supervisors a reasonable understanding of a health worker's behavior and capacity. This enables them to provide targeted feedback on an *as-needed* basis, thereby optimizing their effort in closing capacity gaps. This further enables continuous capacity improvements, leading to sustained performance improvements.

A combination of the above mechanisms enables health workers and managers to work proactively and collaborate effectively, simply through mobile phone applications. Managers are able to engage health workers in a focused manner, leading to timely mitigation of risks, a joint sense of accomplishment and increased accountability.

4.2.4 Frictionless performance recognition

The importance of improving district management performance cannot be understated. A study in six districts of Ghana showed a strong correlation between management capacity at the district and district performance [12]. It is well understood that a motivated workforce can overcome even the severest of constraints. Generally, individual performance of workers within a health facility is not directly visible to a district manager, nor are there consistent practices of recognizing good performance.

To address this, the system provides performance metrics on quality of data, inventory management, cold-chain maintenance, and supply performance. Consistently good performance in a facility over a sustained period, say, 3 months, are surfaced to the district manager through phone notifications. This is coupled with an option to "Like" or "Appreciate" the corresponding health facility for the same (see Figure 3b). If exercised, it results in a notification of appreciation to the corresponding health worker. This provides the district manager a frictionless way to identify and recognize good performance, thereby motivating health workers to sustain it. In some cases, good performers were showcased as role models to others, where a screenshot with "likes" was shared on the district's Whatsapp group [23]. This, in turn, led to increased worker motivation, encouraging a stronger behavior of data use to improve performance.



(a) **(b)**

Figure 3. Monitoring mobile application (Pulse) showing (a) critical events with options to call or message a worker, (b) good performance indicators with an option to "like"

Together, these mechanisms enabled the determinants of self-efficacy for both health workers and managers.

5 Case studies

The service mechanisms described in this paper aimed to enable conditions that promote sustained data recording and use behaviors. To illustrate the effectiveness of these mechanisms in practice, we present results from studies of three deployments of Logistimo SCM in public health supply chains.

5.1 Drugs inventory in Karnataka, India

Karuna Trust, a health NGO, directly manages 21 PHCs in Karnataka and 25 PHCs in North East States of India as part of a public-private partnership model with the respective State Governments. Karuna Trust has a relatively simple administrative hierarchy, with a head office in Bangalore, and two administrative domains for Karnataka and North East States. The PHC entities in these domains are also directly accountable to their respective District administration of the Government. In Karnataka, Karuna Trust has distributed responsibility of a few entities each to two supervisors. The pharmacists at the PHCs use the store management mobile application to manage stock. The supervisors use the mobile application to monitor stock across their assigned PHCs. The central office uses the bulletin board on a television monitor and web-based dashboards on their laptops.

A study conducted inbetween July 2012 to September 2013 [22] indicated that data entry rates were low for the first 5 months of the period, and progressively improved as soon as the bulletin board was introduced on a television monitor in the administrative office in December 2012 (see Figure 4). The social pressure caused by a more public display of supply chain events led to sustained follow-ups on part of the supervisors, resulting in improved data entry rates. Soon after, over a period of 10 months, 9 commodities in the study reached an availability of 99% with a 53.5% reduction in variability (see Figure 5). Over a four-month period, stock replenishment response times decreased from 14 days to 5 days per commodity on the average

– a 64% increase in responsiveness. Whenever the Government rolls out Logistimo across the state, super domains will ease the integration of these PHCs into their corresponding district domains, through a quick reconfiguration rather than expensive systems integration or data migration.

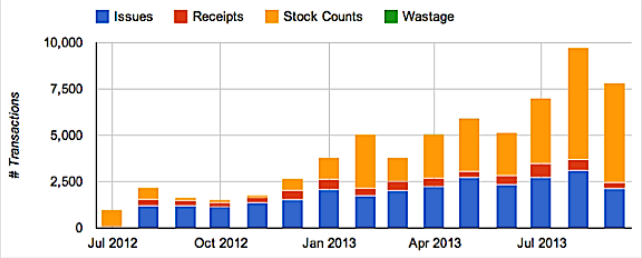


Figure 4. Number of transactions increased starting December 2012 onwards after introduction of the bulletin board (courtesy [22])

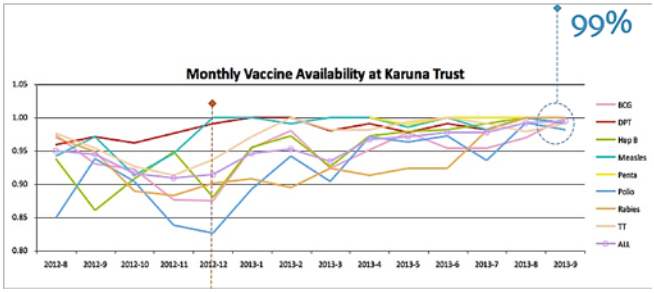


Figure 5. Vaccine availability increased to 99% with variability progressively reducing, after introduction of the bulletin board in December 2012 (courtesy [22])

This study highlights the importance of optimally utilizing available supervisory bandwidth and tactics such as social pressure to motivate data use. It also shows that supervisors are able to effectively engage health workers to improve their capacity and achieve good supply chain performance within a reasonable timeframe.

5.2 Immunization supply chain in Zambia

Zambia had a challenge of vaccine availability and the Ministry of Health along with World Health Organization (WHO) implemented Logistimo SCM platform in 2016 across 116 National, Provincial and District health facilities, and 37 health centers in Lusaka district. Zambia's deployment was unique in the sense that their Ministry of Health directly took ownership of deployment, and had no external supervisory bandwidth infusion. There was one National logistics manager who oversaw all provinces. There was also initial resistance on part of users to enter data digitally due to perceived increase in workload and inertia to change.

A 2017 study indicated that initial adoption rates hovered around 60%-90% with high variability, where health facility users were intermittently entering data [25]. Introduction of dashboards, bulletin board, SMS-based broadcasts by the supervisor, topic-based videos on application usage, and a methodology of targeted capacity building over Whatsapp saw a rise in user engagement. This increased user adoption and receptiveness. This led to higher data reporting rates, eventually leading to over 92% availability of vaccines, and 87% reduction in replenishment response times. In addition, early data between January-July 2015 showed that a province A with sufficient supervisory bandwidth achieved an increasing data entry rate, going from 75 transactions per store to150 transactions per store (on average), whereas province B with little supervisory bandwidth remained at a flat rate of about 75-80 transactions per store (see Figure 6). This underscores the need to have a minimal level of supervisory bandwidth in a province. However, it also indicates that even without such bandwidth, motivated users are able to adopt the system and sustain data entry behavior and use, resulting in improved supply chain visibility.

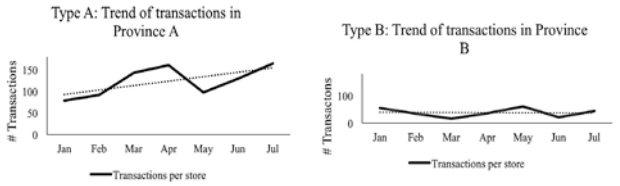


Figure 6. Transaction data entry in Province A with higher supervisory bandwidth showed an increasing trend compared to Province B with relatively lower bandwidth (courtesy [25])

5.3 Immunization supply chain in India

Electronic Vaccine Intelligence Network (eVIN), based on the Logistimo SCM platform, is an online service for managing the immunization supply chain in India [15]. At this time, the United Nations Development Programme (UNDP) has deployed eVIN in India across 22 states of India, covering over 500 districts and around 23,000 PHCs. The administrative hierarchy in the public health system in India is at least 5 levels deep, including National, State, Region, Division, District and/or Block. The supply chain can go up to 7 levels deep, including warehouses in the administrative domains, PHCs and sub-centers. At the end of 2019, there were 21,813 cold-chain handlers managing vaccine inventory at the PHCs using the store management mobile application; 487 District Immunization Officers largely using a monitoring mobile application; 590 designated district logistics managers using both the web and mobile applications; and 26 State Immunization Officers largely using the web application.

An early study was conducted using data from 2014-2015 on 39 health facilities across two districts in Uttar Pradesh, India, as part of a pilot jointly executed with the Immunization Technical Support Unit (ITSU), India [11]. Each district had one dedicated logistics manager working alongside the district official. This study reviewed adoption, data quality and performance. It was found that data quality stabilized from month 3 onwards (see Figure 7), with data entry error rates reducing by 87% over a period of 16 months. Data errors included incorrect units and quantity mismatches between vaccine doses and diluents. Supply chain performance stabilized from month 3 onwards. This was attributed to an efficient data collection system design, a better experience on a mobile phone that optimizes data entry effort, and increased accountability achieved due to supervisory monitoring using web and mobile applications.

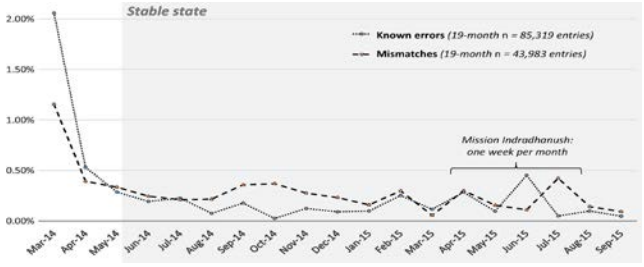


Figure 7. Data error rates stabilized from month 3 onwards (courtesy [11])

Another study in 2017 using data from 16,500 PHCs across 12 states indicated that eVIN has achieved high vaccine availability of >97% across these states (see Figure 8) with a >95% weekly reporting rate (see Figure 9) [15]. Vaccine availability was measured as the proportion of health facilities where all vaccines were available over 90% of the time. Another pre- and post-eVIN comparative study using data from 2018 has reported a 40% reduction in stock out instances, 37% reduction in the days of no stock, and 25% reduction in wastage across vaccines [17]. The accuracy of the digital data was 94% when compared to entries in paper-based stock registers. Record keeping practices had improved, in spite of the fact that it took additional time to complete data entry in both paper and digital systems. These outcomes have sustained until today, and provide a clear indication that the system has been able to achieve sustained behaviors of data entry and use at scale. The behaviors have also persisted over time in each of the health facilities. Some of the factors this was attributed to include the holistic data entry system design that optimized data entry effort, prompts and timely alerts of information received by workers and managers in ways they can consume, and targeted supervisory feedback on an ongoing basis.

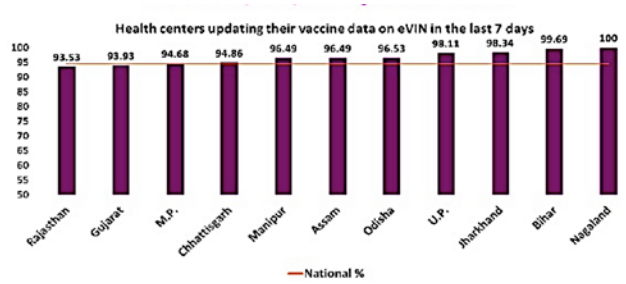


Figure 8. Percentage of health facilities that reported inventory data within a 7-day period (courtesy [15])

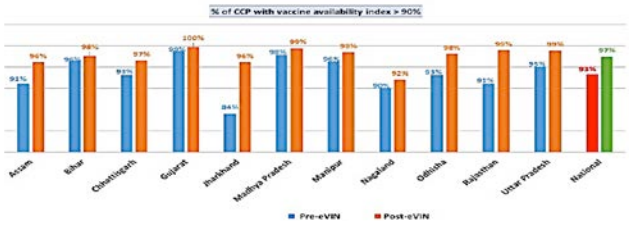


Figure 9. Percentage of cold-chain points (CCP) with vaccine availability >90% across 12 states in India (courtesy [15])

In 2018, adoption of the monitoring mobile application by district managers was studied in 370 districts using 11 months of data between January to November 2018 [23]. The study indicated a strong adoption of the mobile application by district managers, with up to 342 daily active users (see Figure 10), over 600,000 screen views, and 6,525 "likes" given by district managers to health workers. Awareness of critical events had led to pro-active actions taken by the manager. A qualitative study involving 22 district managers across 16 districts indicated that: (a) 7 near-expiry events were alleviated through timely redistribution of stock amongst PHCs, (b) 12 cumulative heating/freezing events of vaccines were prevented with a series of actions, including enhancing power backups, shifting vaccines to other refrigerators, replacing defective refrigerator models and reinforcing equipment maintenance practices, and (c) 5 delayed data entry instances were rectified by retraining the corresponding health workers. This is clearly indicative of the fact that surfacing risks on a need-to-know basis generates a healthy engagement between the district manager and health workers, motivating actions towards better performance. Another independent qualitative study done in [17] reconfirms the sustained use of information by district managers and the value they perceived in it. Similarly, surfacing consistently good performance resulted in district managers recognizing performance through "likes", leading to new management practices. Out of the 16 districts studied in [23], 34 facilities were "liked" on the average by district managers. In 3 districts, a new practice was initiated in their monthly review meetings to appreciate Medical Officers of PHCs that had "likes". In 4 districts, managers had shared screenshots of PHCs with "likes" on the district's Whatsapp group. Survey respondents confirmed an increase in worker motivation, with health workers looking up to those "liked", and seeking feedback on improving their own performance.

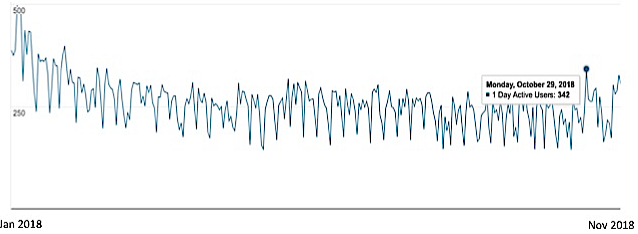


Figure 10. Adoption of monitoring mobile application showing up to 342 daily active district managers in steady state between January – November 2018 (courtesy [23])

The above studies indicate that with sufficient supervisory bandwidth, easy-to-use tools, and timely awareness, managers and health workers engage more strongly and adopt the system effectively.

More recent data for seven vaccines – BCG, bOPV, DPT, Hepatitis B, JE, Pentavalent and Td – indicates that high availability has been sustained over time, even as the system has scaled across 22 states. Figure 11 shows a monthly trend of the *percentage of time stock was available during a month* between January 2019 and May 2020. It can be seen that all vaccines have consistently had high availability with low variability over time. Even a new vaccine introduction, such as Td (Tetanus-

Diphtheria), introduced in February 2019, has been able to quickly stabilize, indicating the readiness of the system to manage product expansion.

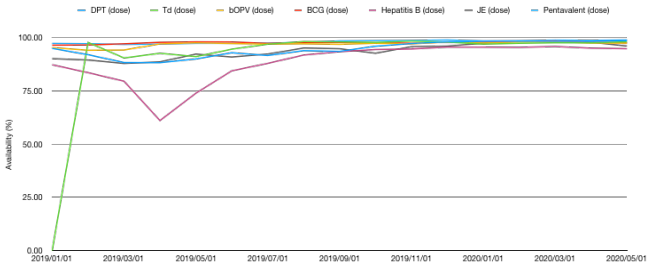


Figure 11. Availability (%) of 7 vaccines between January 2019 to May 2020 across 22 states in India

The high adoption and performance metrics over time, qualified by improvements in management practices, are indicative of sustained changes in data recording and use behaviors by both managers and health workers.

6 Conclusion

We have described the inclusive design of a service that empowers people bottom-up to achieve sustainable changes in data recording and use behaviors. The design is based on three core principles of *empowerment* by increasing individual self-efficacy, raising *awareness* through timely and relevant information with an aim to motivate action, and stronger *social engagement* to sustain good data use and performance. The underlying approach was to create service mechanisms that enable key determinants of self-efficacy, with a belief that it could lead to sustained behavior changes. In particular, the four mechanisms described have enabled the following: (a) higher data reporting rates by enabling adaptation of service and data complexity according to resource capacity (adaptive data collection), (b) optimizing supervisory bandwidth by leveraging existing resources in the peer network (flexible organization), (c) moving from a reactive to a pro-active mode of operation, with increased engagement between health workers and managers, thereby leading to timely mitigation of risks (pro-active and collaborative operation), and (d) reduced friction in performance recognition, thereby increasing worker motivation (frictionless recognition). The case study in Karuna Trust has demonstrated improvements in data recording behavior and supply chain performance as supervisors adopted the mobile application and dashboards, such as the bulletin board, and used data to intervene in a targeted manner. The Zambia study showed that a minimal supervisory bandwidth is required to sustain data recording and use behaviors. Those who were motivated continued to sustain data recording and use even without supervision, and achieved good performance. The eVIN case study in India indicated how data recording and use behaviors have sustained at scale and persisted over time. In contrast to other top-down approaches, this approach has enabled a way of empowering people bottom-up using a software service, in alignment with top-down structures and policies. The mechanisms presented here are generic in nature, and can be applied to any low-resource environment with similar challenges. We hope that system designers can adopt the principles outlined in this paper when creating information and technology systems for low-resource environments.

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REFERENCES

[1] Sandra Hakiem Afrizal, Putu Wuri Handayani, Achmad Nizar Hidayanto, Tris Eryando, Meiwita Budi harsana and Evi Martha. 2019. Barriers and challenges to Primary Health Care Information System (PHCIS) adoption from health management perspective: A qualitative study. *Informatics in Medicine Unlocked*, Volume 17, Article 100198. https://doi.org/10.1016/j.imu.2019.100198

[2] Kalid Alwan, Tadesse Awoke and Binyam Tilahun. 2015. Knowledge and utilization of computers among health professionals in a developing country: A cross-sectional study. *JMIR Human Factors*, 2(1), e4. https://doi.org/10.2196/humanfactors.4184

[3] Nitin Natthuji Ambadekar, Kavya Sharma, Sanjay Zodpey, and Shubhnagi Prakashrao Lanjewar. 2015. Revisiting the district level human resources for health architecture in Department of Public Health in Maharashtra. *Indian Journal of Community Medicine*, 2015 Apr-Jun, 40(2): 75-78. https://doi.org/10.4103/0970-0218.153864

[4] Stella C.E. Anyangwe and Chipayeni Mtonga. 2007. Inequities in the Global Health Workforce: The Greatest Impediment to Health in Sub-Saharan Africa. *International Journal of Environmental Research and Public Health*, 2007, 4(2), 93-100. https://doi.org/ 10.3390/ijerph2007040002

[5] Breese Arenth, Ashley Bennett, Cristina Bernadotte, Emily Carnahan, Mandy Dube, Jenny Thompson and Jason Walton. 2017. *Defining and building a data use culture.* Hallie Goertz, ed. Seattle: PATH. Retrieved from https://path.azureedge.net/media/documents/DHS_Data_Use_Culture_wp.pdf

[6] Augustine Asante, et. al.. 2011. *A review of health leadership and management capacity in Timor-Leste.* Technical Summary No. 4, The HRH Knowledge Hub of The University of New South Wales, April 2011. Retrieved from https://sphcm.med.unsw.edu.au/sites/default/files/sphcm/Centres_and_Units/LM_TL_Summary.pdf

[7] Ian Bates, Christopher John, Andreia Bruno, Pamela Fu and Shirin Aliabadi. 2016. An analysis of the global pharmacy workforce. *Human Resources for Health*, 14, Article number: 61 (2016). https://doi.org/10.1186/s12960-016-0158-z

[8] Xavier Bosch-Capblanch, Oliver Ronveaux, Vicki Doyle, Valerie Remedios and Abdallah Bchir. 2009. Accuracy and quality of immunization information systems in forty-one low income countries. *Tropical Medicine and International Health*, Volume 14 No. 1, PP 2-10, January 2009. https://doi.org/10.1111/j.1365-3156.2008.02181.x

[9] Andrew Brown. Muhammad Atif, Erin Hasselberg, Pamela Steele, Chris Wright and Zaheer-Ud-Din Babar. 2014 Human resources, health supply chains and access to essential medicines. *Journal of Pharmaceutical Policy and Practice*, 7 (Suppl 1), 12. https://doi.org/10.1186/2052-3211-7-S1-I2

[10] Kara DeCorby-Watson, Gloria Mensa, Kim Bergeron, Samiya Abdi, Benjamin Rempel and Heather Manson. 2018. Effectiveness of capacity building interventions relevant to public health practice: a systematic

review, *BMC Public Health* **18**, 684 (2018). https://doi.org/10.1186/s12889-018-5591-6

[11] Sarah Skye Gilbert, Neeraj Thakare, Arun Ramanujapuram and Anup Akkihal. 2017. Assessing stability and performance of a digitally enabled supply chain: Retrospective of a pilot in Uttar Pradesh, India. *Vaccine*, Volume 35, Issue 17, 19 April 2017, Pages 2203-2208. https://doi.org/10.1016/j.vaccine.2016.11.101

[12] Anne C.S. Heerdegen, Moses Aikins, Samuel Amon, Samuel A. Agyemang and Kaspar Wyss. 2020. Managerial capacity among district health managers and its association with district performance: a comparative descriptive study of six districts in the Easter Region of Ghana. *Plos One*, January 22, 2020. https://doi.org/10.1371/journal.pone.0227974

[13] Peter A. Heslin. 1999. Boosting empowerment by developing self-efficacy. *Asia Pacific Journal of Human Resource* 37(1):52-64, April 1999. https://doi.org/10.1177/103841119903700105

[14] Anup Karan, Himanshu Negandhi, Rajesh Nair, Anjali Sharma, Ritika Tiwari and Sajay Zodpey. 2019. Size, composition and distribution of human resource for health in India: new estimates using National Sample Survey and Registry data. *BMJ Open,* April 2019, Volume 9, Issue 4. http://dx.doi.org/10.1136/bmjopen-2018-025979

[15] Rakesh Kumar. 2017. A shot in the arm: The India story, Electronic Vaccine Intelligence Network (eVIN), UNDP India, August 2017. Retrieved from https://www.slideshare.net/UNDPasiapacific/a-shot-in-the-arm-the-india-story-of-electronic-vaccine-intelligence-network-evin

[16] Jenny H. Ledikwe, Jessica Grignon, Refeletswe Lebelonyane, Steven Ludick, Ellah Matshediso, Baraedi W. Sento, Anjali Sharma, and Bazghina-werq Serno. 2014. Improving the quality of health information: a qualitative assessment of data management and reporting systems in Botswana. *Health Research Policy and Systems* **12**, 7 (2014). https://doi.org/10.1186/1478-4505-12-7

[17] Ministry of Health & Family Welfare, Government of India. 2018. *Techno-Economic Assessment of Electronic Vaccine Intelligence Network (eVIN).* December 2018. Retrieved from https://nhm.gov.in/New_Updates_2018/NHM_Components/Immunization/Guildelines_for_immunization/eVIN_Assessment_Report.pdf

[18] Satoshi Miura. 2014. *Heterarchy.* Social Science, Encyclopedia Britannica. December 2014. Retrieved from https://www.britannica.com/topic/heterarchy

[19] Reena Nayak. 2010. *Role of Karuna Trust – A public-private partnership venture in delivering healthcare services.* Master's Thesis. Rajeev Gandhi University of Health Sciences, Bangalore, India.

[20] Tara Nutley and Heidi W. Reynolds. 2013. Improving the user of health data for health system strengthening. *Global Health Action* 6:1. https://doi.org/10.3402/gha.v6i0.20001

[21] Arun Ramanujapuram and Anup Akkihal. 2011. Challenges in deploying transactional mobile-web services in rural areas. In *W3C/Web Foundation Workshop on Mobile and Web Technologies in Social and Economic Development,* Dar es salaam, Tanzania, June 4-5, 2011

[22] Arun Ramanujapuram and Anup Akkihal. 2014. Improving performance of rural supply chains using mobile phones. In *ACM Dev-5'14: Proceedings of the Fifth ACM Symposium on Computing for Development*, December 2014, Pages 11-20, San Jose, CA, USA. https://doi.org/10.1145/2674377.2674382

[23] Arun Ramanujapuram and Kaushal Shukla. 2018. Pulse: A supervisory mobile application for performance management at the last-mile of health supply chains. In *11th Global Health Supply Chain Summit*, Lusaka, Zambia, November 2018. http://ghscs.com/wp-content/uploads/2018/12/11.2Pulse-a-supervisory-mobile-application-for-performance-management-at-the-last-mile-of-health-supply-chains-8.pdf

[24] Michael R. Reich. 2002. *Public Private Partnerships for Public Health.* Harvard University Press.

[25] Siri Shetty and Prateek Shetty. 2017. Improving last-mile stock manager experiences and engagement in Zambia. In *10th Global Health Supply Chain Summit*, Accra, Ghana, November 2017. http://ghscs.com/wp-content/uploads/2017/12/T3.3-Logistimo.pdf

[26] Wayan Vota. 2019. RHIS: create a culture of data use in health information systems. *ICTWorks*, November 27, 2019. Retrieved from https://www.ictworks.org/create-culture-of-data-use-health-information-systems/#.XlqQeJMzZsN

[27] WHO. 2004. Equitable access to essential medicines: A framework for collective action. World Health Organization, Geneva, March 2004. Retrieved from https://apps.who.int/medicinedocs/pdf/s4962e/s4962e.pdf