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STRATEGIC PREPAREDNESS OF THE COVID-19 VACCINE COLD SUPPLY CHAIN: A PERSPECTIVE OF SUB-SAHARA AFRICA

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ABSTRACT

Almost thirteen months since the first case of Coronavirus also known generically as COVID-19 virus (SARS-Cov-2 virus) was reported outside china, an estimated 76.1 million people have contracted the virus worldwide. Of these, close to 1.7 million have died while millions of others have reportedly recovered and or classified as being actively infected with the virus. The pandemic has swept through every country on earth with significant social, economic and health consequences. No proven curative remedy has been found as yet, however, it is highly expected that by mid- 2021, viable vaccines could be ready for mass anti-covid-19 immunization globally. Imperatively, the success of the delivery of the worldwide immunization campaigns will largely depend on how fast the vaccine cold supply chain works. More specifically, the cold chain configuration of the vaccine supply chain as in other immunization campaigns is expected to play a central role in safely delivering the vaccines on time to virtually everyone on the globe. The key question, however, is how prepared for the mass covid-19 immunization campaigns are regions across the globe and especially Sub-Sahara Africa where the cold supply chain enablers are still far from maturity? Through a systematic review of extant literature, this paper finds that despite Sub-Sahara Africa being a recipient of mass vaccinations against infectious diseases for over five decades, the cold supply chain is still poorly developed and vulnerable to haphazard breaks which can pose serious risks to the precious medical cargo and impede the immunization programs and in the worst case scenario lead to loses in cargo due to heat excursions and human life. Therefore, the cold supply chain preparedness of Sub Sahara Africa countries is critical at this point in time. Further, the paper examined the preparedness of the high value cold chain indicators, that is, transport infrastructure systems and the energy link. It emerged that both *the transport systems and the energy link were still underdeveloped to reliably provide last mile solutions to the immunization process in most contexts. This could increase the risk of temperature excursions also impair the immunization process. Also, most of the energy that is being used to power the refrigeration process is not green and this could have implications for the carbon emissions. The study, therefore, recommends that vaccine distribution agencies could explore partnerships with private and public transport and logistics sector players and strategize on how last mile distribution of the vaccines can be achieved seamlessly even in the remotest of the regions. Refrigerated trucks will also need to be introduced into the context in large numbers. Also it is recommended that energy efficient refrigerators using renewable energy such as solar replace the current domestic and absorption type refrigerators. Still other green energy powered refrigerators need to be developed and deployed so as to provide efficient vaccine refrigeration while keeping the carbon signature significantly low.*

Keywords: *Cold Supply Chain, Covid-19, Energy, Preparedness, Transport, Sub-Sahara Africa, Vaccine*

1.0 INTRODUCTION

1.1 Background

Beginning February 2020, countries all over the world were ushered into a new domain of public health challenge brought about byacute respiratory illness causing novel Coronavirus also known generically as COVID-19 or by its more precise scientific name, SARS-Cov-2 virus.The Covid-19 pandemic has occurred at a scale seldom experienced at the scale at which it is currently by any country on earth in the last 100 years.As at 20thDecember 2020, an estimated 76.1 million people globally had tested positive for COVID-19. Of these 1.68 million have died while 43 million have reportedly recovered and 31.42 were classified as being actively infected with the virus. However, the active cases could be more especially in the developing countries where the testing is still not being done *en masse*. More than 17.6 million people have tested positive in the US of which 315 thousand have lost their lives to the virus.In Africa alone, 2,464,175 cases have been reported including 57,909 deaths (Johns

Hopkins University, 2020). These statistics are mostly for the last 13 months since the first active cases and mortalities were recorded in Wuhan City in China. The pandemic has been described as the as the second global pandemic in a century since the Spanish Flu of 1918. In fact, no country or territory globally has failed to record an infection of the COVID-19 virus. This has led to global shut down of businesses and public activities in nearly all countries as the governments enforce strict social distancing restriction rules to curb the spread of the virus.

Over one third of the people in the planet have had their movements significantly restricted. The corresponding economic impact has been huge estimated to be a shrinkage of between 2- 3% of the 89 trillion dollarsglobal economy. No proven curative remedy has been found as yet, however, nearly 120 institutions worldwide have embarked on vaccine development with a number beginning to show early signs of promise while a few highly effective Covid-19 vaccines like Pfizer-BioNTech and Moderna have been authorized for emergency use by the US Food and Drug Administration (FDA)-the Pfizer-BioNTech has also been given emergency approvals in the UK and Canada (de Jesus, 2020). Indeed, this means that by the first half of 2021 viable vaccines could be ready for mass covid-19 immunization globally, this notwithstanding the growth in cases of infections and the possible new strains of the coronavirus. Imperatively, the success of the delivery of the worldwide immunization campaigns will largely depend on how fast the vaccine supply chain works. More specifically, the cold chain configuration of the vaccine supply chain as in other immunization campaigns is expected to play a central role in safely delivering the vaccines on time to virtually everyone on the globe. The key question however is, how prepared is the vaccine cold chains across the globe and especially Sub-Sahara Africa for the mass anti-covid-19 immunization campaigns? How well-configured is its cold supply chain to deliver the vaccine to its remotest and marginal corners in the shortest time possible and in a cost effective and environmentally friendly manner?

1.2Vaccines

The discovery of vaccines at the end of the 18th century by British Scientist Edward Jenner was a small but important milestone in immunization. However, it was not until the middle of the 20th century where the full import of vaccination on public health was realized with the discovery of several vaccines. Essentially, vaccines provide active acquired immunity to a particular disease by training the body's immune systems to recognize and fight against the disease causing organisms. Subsequently, vaccines as the key component of immunization have proven to be the most successfully proven cost-effective public health intervention in history (Ashok et al., 2017). Millions of lives have been saved annually as a result of immunization campaigns globally. However, delivery of vaccines still remains a challenge globally owing to their fragile nature, especially sensitivity to heat, and other attendant requirements ofhandling, shipping and storage. Cold supply chains are, therefore, critical to the delivery of the vaccines in the immunization campaigns such as, that anticipated in the near future (late 2020 and beyond) for tacking the COVID-19 Virus globally. This paper focuses on the structural factors that affect the preparedness of the cold supply chain necessary for the delivery of the new vaccines in the challenging Sub Sahara Africa context. As such, the focus will be on the models of cold supply chains, the transport links, energy links and the legal framework for vaccine delivery in these contexts.

1.3Sub-Sahara Africa

Africa is undisputedly the world's hottest continent. The rainfall is on average minimal across many countries in the continent and temperatures can exceed 35°C and fail to drop below 25°C at night in the continent's expansive arid regions that include most of the northern half of the continent (Henry, 2018). The continental region lying below these desert plains is known as Sub-Sahara Africa and it is covered with expanses of rainforest regions and savanna in the Central and Southern parts. Therefore, climate control for medicine in transit is critical for safe delivery. In the past, numerous events have occurred involving vaccines being shipped into least developed countries, mostly in Sub-Sahara Africa, that have very limited or completely lack cold chain infrastructure where the vaccines were inactivated due to excess exposure to heat (Coghlan et al., 2007). This exposes the population to greater disease risk due to the inactivated vaccines while they thought they were being immunized. As a result, more emphasis is currently being placed on the entire cold chain distribution process to avoid such potential failures and make the immunization campaigns successful.

The African continent ripe with pharmaceutical potential, but the challenges for developing a viable market strategy are formidable, with distribution being consistently one of the largest challenges for pharmaceutical companies (Rosen, 2014). Yadav (2010) noted that a unique pharmaceutical industry supply chain landscape has developed in Sub-Saharan Africa. Inefficient or expensive distribution increases the final price to patient, reducing volume sales and hurting family finances in the largely out-of-pocket private market for medicines (Cameron et al., 2011). Ironically, this does not translate to pharmaceutical manufacturers making more money off their medicines, but instead the complexity of the supply chain adds incrementally to the cost of medicines such that typically the price of a medicine triples between the manufacturer and the patient (Yadav, 2010). The complex supply chain could even have more pronounced implications on vaccine distribution such as delayed delivery, increased per capita delivery costs, supply chain losses and even more dire being the breaks in the cold supply chain that lead to temperature excursions and eventual failure to deliver the much needed vaccines. All these could be mitigated with an improved cold supply chain.The question, however, is how do we create an efficient and resilient cold supply chain in the developing countries especially in Sub Sahara Africa?

2.0 Cold Supply Chain Delivery Factors

2.1 Vaccine Cold Supply Chain

The term cold chain or cool chain denotes the series of actions and equipment applied to maintain a product within a specified low-temperature range from harvest/production to consumption (Hibbs et al., 2018). A cold chain ensures the shelf life of the product is extended and ensures the products remain safe for consumption. The term 'cold chain logistics' refers to the storage, handling and transportation of product under temperature-controlled conditions. These conditions can be frozen, chilled or ambient, but any product that requires a controlled, monitored environment where a constant temperature is maintained is included. The two main product categories under the 'cold chain' umbrella are food and Healthcare & Life Sciences products (Ashok et al., 2017). Cold chain logistics is becoming ever more important in the globalized supply chain world we live in today. The global healthcare cold chain logistics sector annual growth has been forecasted at 8-9%, pushing the market value close to $17 billion by 2020. A third of this value is in the temperature-controlled packaging and service solutions arena. Further, the losses that are incurred in the case of unmitigated breaks in the cold supply chain are massive. For instance, in 2017, over USD $ 13 billion was spent in the global cold-chain logistics for biopharmaceutical goods alone. Approximately 20% to 40% of the products in the estimate were damaged before they could reach the end-user (Henry, 2018). With the global spending in the industry being in constant rise, the total amount of pharmaceutical losses worldwide is immense and this could increase the healthcare costs due to provisioning (Goldberg &Karhi, 2019). The losses could even be compounded to include human lives where vaccines are concerned. In the past, firms such asGlaxoSmithKline (GSK) has lost an entire vaccine shipment, worth millions, when Fahrenheit temperatures were misread as Celsius.

Cold supply chains are commonly used in the food and drugs industries and also for the delivery of some chemical shipments. In the pharmaceutical industry, the usual temperature for a cold supply chain ranges from 2 to 8 °C (36 to 46 °F), however, more often the specific temperature (and time at temperature) tolerances depend on the actual product being shipped, for example vaccines. In fact, the World Health Organization (2016) prescribes a vaccine cold chain temperature range of between of 2–8 °C (36–46 °F) to ensure the stability of the vaccine. The emerging Covid-19 vaccines have, however, extremely low temperature requirements (-70 degrees for Pfizer and -20 degrees for Moderna) which already presents a challenge in handling even to developed countries like the US, Canada and UK where it is currently being distributed. This is further compounded by the requirements that the vaccines are given in doses comprising two shots days apart; with the Pfizer shots spaced 21 days apart (US CDC, 2020) while Moderna's shots are administered 28 days apart (US FDA, 2020). The cold chain, however, comprises more than temperature control. As a supply chain configured uniquely to fresh produce consignments, the cold chains additionally need to maintain product specific environment parameters which include air quality levels (oxygen, carbon dioxide, humidity and others), making it the most complicated cold chain to operate (Kohli, 2015). In comparison to dry cargo, the risks in the cold supply chain are exponential when the consignment is being transported or ware-housed due to temperature control requirements.

Temperature excursions (where cargo temperatures deviate from the shipper's optimal levels) can cause massive financial losses due to spoilt, damaged or degraded cargo (Lee & Haidari, 2017). Therefore, as a type of supply chain, the behavior of the cold chain in many aspects resembles that of the nominal supply chain, however, it requires more input than the ordinary supply chain owing to the sensitive and fragile cargo it contains. Subsequently, deeper collaboration among cold supply chain actors has been urged to mitigate such temperature excursions, particularly, among airline carriers where excursions can occur up to 70% of the time (Lawler, 2016). Understanding the vulnerability of the cold supply chain to temperature excursions is, therefore, vital in the supply of vaccines to remote clinics in hot or humid environments which are served by inadequately developed transport networks. In vaccine delivery, an unbroken cold chain is important; having an uninterrupted series of storage and transportation events that ensure its given temperature range is maintained is essential in vaccines. Disruption of a cold chain due to war may produce consequences similar to the smallpox outbreaks in the Philippines during the Spanish–American War (Office of Medical History, 2017). In Africa, patients' lives have been put at risk on numerous occasions risk due to the inactivated vaccines they received as a result of broken cold chains exposing the vaccines to heat.

Moreover, unreliable electricity power systems and poor road conditions in many developing countries often result in cold chain breakdowns (Duijzer, Jaarsveld & Dekker, 2018; Lauton, Rothkopf&Pibernik, 2019). The WHO and UNICEF (the United Nations International Children's Emergency Fund) assessments in 65 low and lower-middle income developing countries revealed that few countries met minimum standards for effective vaccine storage, distribution, handling, and stock management (Lydon, Raubenheimer, Arnot-Krüger&Zaffran, 2015). In a context such as Sub Sahara Africa where the cold supply chain enablers are still far from maturity, this can pose serious risks to the precious cargo and needs early mitigation measures especially now that the entire world is in the grip of the Covid-19 pandemic and requires urgent vaccine interventions to curb its spread and remove the strain from the limited medical facilities as curative remedies are being sought. Therefore, the cold supply chain preparedness of Sub Sahara Africa countries is critical.

2.2Transport Link in the Vaccine Cold Supply Chain in Sub Sahara Africa

Transportation plays a very critical role in the medical supply chain, medical personnel, patients and pharmaceutical supplies all depend on the available transport system. In terms of the medical supply chain, transport systems largely determine the ability of critical medical cargo to reach the patient in good time and at a reasonable cost and state. In other words, transport systems are highly valuable in enabling access even for the remotest points over a geographical area. In 1976, Professor David Morley of the Institute for Child Health, London, proposed that WHO establish a team within EPI to address three critical issues constraining WHO's ambition to establish routine immunization services globally among them appropriate equipment to store and transport vaccines (Lloyd &Cheyne, 2017). Transport solutions have the highest value and are the most critical link in the Cold chain logistics (Lawler, 2016).

The transportation problem of vaccines has led to the development of the cold transport solutions which basically means having conveyances available to move goods while maintaining stable temperature and humidity conditions as well as protecting their integrity (TRANSAID, 2013). A surge in demand for temperature sensitive pharmaceutical goods together with global warming has led to an increase in demand for cold transportation solutions. The resulting pressures have produced a swath of technological developments designed to maintain unbroken cold chains. According toLawler (2016), approximately four million refrigerated road vehicles comprising trailers, semi-trailers, trucks and vans are in operation globally and the value of this Global Refrigerated Trailer Market is projected to reach 72 billion USD by the end of 2021. Managing the transportation of temperature-controlled products (refrigerated and frozen) totaled over $13 billion in 2017 and is expected to continue to grow at a 5%-6% rate. By 2021 pharma cold-chain logistics – the transport of temperature-sensitive products along a supply chain through thermal and refrigerated packaging methods and the logistical planning to protect the integrity of these shipments – is predicted to be a $16.6 billion industry (Sedlak, 2018).

Goldberg and Karhi (2019) point out that transportation of some kinds of vaccines requires refrigeration and freezing. The transportation of these refrigerated healthcare products can be diverse as they move along the cold chain from the manufacturer to the distribution center and beyond. However, Matthias, Robertson, Garrison, Newland and Nelson (2007) established that 35.3% of shipments and 21.9% of refrigerators were below the WHO recommended freezing temperature range for vaccines. Murhekar et al. (2013) found that up to two-thirds of vaccines were damaged by freeze exposure in transit between state stores and administration sites across ten states in India and that exposure to subzero temperatures was frequent during vaccine storage at peripheral facilities and vaccine transportation. This then places demand on a high integrity cold chain. Lawler (2016), however, points out that despite it being a demanding task, it’s important for stakeholders to identify the potential sources of harm to a payload being transported through a variety of modes, several temperature zones and multiple transit points. When evaluating possible sources of temperature excursions, it’s important to consider route, logistics provider and the packaging solution in place. Each of these of these can play a role in the prevention of temperature excursions. Lawler (2016), further, observes that risk management should not be centered only upon the choice of which route, which logistics provider and which type of packaging solution to use.

To understand the functionality of the transport systems in the pharmaceutical cold supply chain in Sub Sahara Africa, it is important to understand the historical context of the medical supply chain in Africa. Rosen and Rickwood (2014) observe that historically, distribution in Sub-Saharan Africa suffers from an imbalance between consolidation and multiplicity. This results in a highly fragmented supply chain, a lack of incentive for modernization and entrepreneurship, high overheads for distributors and retailers (who typically blame the other for the high price to patient) and ultimately high drug prices for patients that limit sales in the price elastic sections of the market. The lack of transparency in the medical value chain has had exacerbated the complexity and inefficiency of the medical supply chain resulting in supply chain interruptions and price markups in an unpredictable value chain. These ultimately impact the transport logistics in the cold supply chain. In a study on public health challenges in the supply chain management of cold chain medicines in the Greater Accra Region in Ghana, Agyekum (2012) established that absence of quality management systems, poor contingency for power outages, weak validation of cold storage facilities and qualification of cold chain vans and carriers for transport of cold chain medicines along the supply chain which obviously impact negatively on product quality, efficacy and potency and finally putting public health and safety at risk.

Sub-Sahara Africa's landscape further complicates the task of transporting temperature sensitive medicines. Road and mains power access is challenging for over 70% of health facilities in Uganda, with limited road networks further complicating access to 'off-grid' solutions like gas (WHO, 2007). Frank Peeters of Rotary Clubs for Development notes that central Africa's stubborn road conditions demand the use of 4x4s vehicles and draw out the time needed to cover its vast distances. For this reason, airfreight is often a key alternative. However, as pointed out earlier, aviation cold chains have their own challenges notably the high temperature excursions. Though the continent has over 700 airports, majority of them are rarely used and lack the requisite cold warehousing for the vaccine cold chain. Besides, even in the even that remote environments are reached by air, still other accessing areas will require considerable road transport.

However, the little investment in the transport sector has resulted in most countries in SSA having a low road-network density and worse still excessive private sector control of the road transport. This may mean that at some stage in the transport distribution network, for-profit transportation must be involved through outsourcing. The for-profit transport model can be effective where there are deficiencies in the capacity of the public transport system or other non-profit transport systems. However, when the outsourcing is done correctly, the benefits in terms of efficiencies can outweigh the costs. For example, in 2012, the Ministry of Health of Gambia, outsourced the management of their transportation fleet to a third party, which fulfilled vehicle maintenance and driver-training roles for the Ministry of Health. As a result, the health programme increased their frequency of visits three-fold, could visit three times more villages and was able to improve vaccination coverage by almost 20 percentage points (Ceesay& The Republic of Gambia, 2013). Further, research in Nigeria outlines savings from 12-19% for outsourcing. However, structural or political barriers can exist such as the capability of 3PLs, client communication or conflicts (Transaid, 2010b).

Some of the transportation and distribution challenges include limited funds for vehicle purchase, maintenance, repairs, fuel and driver salaries (USAID, 2011a). Other challenges include In Ghana 13% of the stock value of the essential health commodities constitute for logistics costs. There are competing interests between low distribution costs and high service quality. If distribution frequency is high, transportation costs are high, but in a more reliable demand planning horizon with less stock-out situations (Yadav et al., 2011). Research shows that decentralized transportation systems in Guatemala results in a high performance (Bossert et al., 2007). Another more peculiar challenge is that of last mile delivery is that of last mile distribution. This challenge is influenced by a lack of human resource (HR) capacity, low salaries, a lack of capital to cover transportation costs and limited electricity and communication infrastructure (USAID, 2011a). The study by Ashok et al., (2017) further revealed that several countries in Africa had limited delivery and installation capabilities. Many countries face bottlenecks in their capacity to store, test and transport new equipment, leading to deployment delays. Limited technician availability further slows deployment, and poor quality installation can result in early breakdown and reduced equipment lifespan.

2.3Energy Link in the Vaccine Cold Supply Chain in Sub Sahara Africa

The WHO (2006) outlined inadequate storage facilities and temperature control systems and a lack of quality assurance procedures as among the most critical challenges in the medicine supply of African countries. Temperature control for the cold chain requires refrigeration. Refrigeration an essential and an energy demanding element component in cold chains. Vaccines are extremely temperature sensitive products and as such are less tolerant to temperature excursions. Vaccines require temperature-controlled environments to be stored and distributed, however, there are many instances where the appropriate temperatures are not maintained, affecting the quality of the vaccines (Goldberg &Karhi, 2019). Temperature control is either maintained by passive systems, insulation material around the commodity, or active systems, packaging around the commodity plus refrigerants (WHO, 2014). The application of barcoding, radio frequency identification or mobile technologies, along with temperature monitoring sensors, is becoming more commonplace for the collection and monitoring of medicines and health products. There are an estimated 1.2 million refrigerated containers (reefers) globally (Markarian, 2015). However, with a global accelerated vaccination program such that anticipated in the wake of the COVID-19 pandemic, the available refrigerated containers could be expected to increase dramatically especially in areas of hot and humid climate such as Sub-Sahara Africa.

Network and electricity supply in Africa is unstable. Frequent power outages coupled with poor cold chain equipment and data monitoring restricts the transportation of vaccines to remote populations. Existing vaccine systems are unable to provide treatment to remove populations due to poor cold chain equipment – power outages and lack of reliable data, monitoring. Therefore, the role of reliable and efficient energy sources in the medical cold supply chain cannot be under- estimated when configuring a vaccine cold chain (Rosen & Rockwood, 2014). For instance, in 2008, the Ministry of Health in the Cabo Delgado province of northern Mozambique, measured the impact of redesigning their supply chain, in which they removed inventory levels, invested in technology to improve information flow, consolidated tasks into a small group of workers focused full-time on supply chain operations and provided reliable sources of energy to clinics. They found that their efforts dramatically increased vaccination coverage, from 69% to approximately 95% of children, reduced stock-outs to less than 1% of health centers and improvth centers, and improved the cold chain by ensuring that 93% of health facilities had reliable refrigeration (Kane, 2008).

Lloyd and Cheyne (2017), for instance, observe that in 1977, electricity was absent from approximately two-thirds of health facilities that stored vaccines, making it impossible to use standard electric-compression refrigerators. Only absorption-type refrigerators running on kerosene, gas, or electricity could be used. Even among facilities with access to an electrical grid, power supplies were intermittent and voltages fluctuated widely. The search for more reliable vaccine refrigeration equipment began with a preference for modifying low-cost refrigerators and freezers used to store food in the home. These 'Domestic' refrigerators and freezers were typically designed for industrialized markets where energy sources were reliable and the ambient temperature seldom exceeded +32 °C. To perform well enough to reliably store vaccines in areas of intermittent energy, polluted fuel supply and high and low ambient temperatures, modifications were made to the design of walls and cooling units. These performance-enhancing features were collected within draft standard performance specifications from 1979. In Sub-Sahara Africa, the challenging transport conditions coupled with the energy needs of the cold supply chain require the development of different models of refrigeration units that could use different forms of energy.

To power the millions of refrigerators will require energy resources and these could increase the levels of Carbon Dioxide in the atmosphere where fossil fuel generators are used in areas that have no access to electricity from non-fossil fuel sources. A move towards zero ODP (Ozone Depletion Potential) refrigerants and low Co2 producing vehicles is now seen as the inevitable next move. The road transport industry has seen speedy adoption of alternative lower-GWP (Global Warming Potential) gases. However, the container market has faced greater challenges including the availability of continuous alternative gases throughout the supply chain and a lack of technical tools. Despite improvements in emissions, cold transport consumes 20 per cent more fuel than other heavy vehicle types due to refrigeration equipment. This is significant as refrigerated/temperature controlled freight transport accounts for approximately seven per cent of new vehicle and 10 percent of all new trailer registrations in Europe. A European Commission study in 2011 concluded that efficiencies to on-board equipment such as refrigeration units could be up to 50 per cent helping to reduce fuel consumption.

Transportation Refrigeration units are on the whole unregulated and are large polluters. The emissions in question are connected to the premature deaths of 400,000 in the EU and 600,000 in India. Therefore, the projected expansion of the global cold chain is likely to have significant environmental and health impacts. A study by Dearman (2015) concluded that zero emission transport refrigeration vehicles could shrink these emissions by just over 90 per cent. The study found that poorly compliant auxiliary diesel engines that power refrigeration systems can emit up to 6x the NOx and 29x the particulate matter of a truck's Euro6 propulsion engine. These emissions could be cut by 73 per cent and 93 per cent respectively with the use of a zero-emission refrigeration system.

Refrigerators that are powered by solar (photovoltaic) energy are gradually replacing absorption refrigerators in the cold chain market. Several models of solar refrigerators were initially developed and deployed in the late 1980s, but problems with the battery and control module were common and difficult to fix. New-generation solar refrigerators, known as solar direct drive, adopted the concept of the Ice-Lined Refrigerator (ILR). Solar energy is used to freeze an ice liner that can keep the unit cold overnight or during cloudy days, so there is no need for a battery and control unit. The resulting refrigerator has demonstrated trouble-free operation without premature failure and now dominates sales. In fact, the concept of solar powered refrigerators has been recommended by GAVI (2016) for areas with less than eight hours of per day or power outages that last more than 48 hours.

A survey by Ashok, Brison and LeTallec (2017) found that the Clinton Health Access Initiative, Inc. (CHAI) experience working since 2010 with national immunization programs and partners to improve vaccines cold chains in 10 countries—Ethiopia, Nigeria, Kenya, Malawi, Tanzania, Uganda, Cameroon, Mozambique, Lesotho and India experienced three limiting factors in refrigeration. The first wasold and obsolete technologies where it was established that between 15% and 50% of equipment are older than the recommended 10 years, after which they are more susceptible to breakdown and poor temperature control. Second was the use of domestic fridges. It was noted thathousehold refrigerators are cheaper, widely available and easily purchased. However, they are not safe for vaccine storage, as they do not reliably maintain optimal temperature ranges (WHO, 2016). Despite this, some countries meet 45% of their CCE need with such fridges. Finally, there was the use of Absorption-type fridges. *These* Fridges fueled by kerosene or bottled liquid petroleum gas are widely used (60–80% of CCE in some countries), but are no longer approved by the World Health Organization (WHO) Product, Quality and Safety (PQS) system (WHO, 2016). They pose a risk to stable service delivery and storage, as fuel availability can easily be disrupted by gaps in funding, procuring and/or canister distribution (McCarney, Robertson, Arnaud, Lorenson& Lloyd, 2013).

Kenya, with a yearly birth cohort of nearly 1.5 million children, currently provides immunization services at nearly 6000 facilities equipped with cold chain storage capacity (Kenya National Bureau of Statistics & ICF Macro, 2014). In Uganda, the government discovered the benefits of using solar direct drive refrigerators at off-grid facilities over absorption equipment by calculating total cost of ownership, with the phasing out absorption equipment (>50% of all equipment in-country) potentially saving US$3.45 million in energy costs over five years (Ashok et al., 2017). In Nigeria however, temperature excursions are still a major problem in refrigerators in public healthcare facilities due to maintenance issues. For example, Burchett et al., (2014) found that the average time to repair a fridge at the lower government area (LGA) level ranged from two months to two years. Furthermore, excursions – extended deviations from the safe 2 – 8 °C range –are failing to be detected and resolved, even accounting for deviations in monitoring practice. In Eastern Nigeria, another study by Chukwuma, Okoye, Ngwoke and Esimone (2013) revealed that 42% of yellow fever vaccines available in the private sector had been compromised by freeze damage. This problem of poor maintenance of Cold Chain Equipment (CCE) is being significantly addressed in CHAI's operational countries. For example, in Tanzania and Ethiopia, CCE maintenance and repair is being integrated into the curriculum of major technical colleges. This produces graduates already trained to enter cold chain roles. Further, In Kenya and Tanzania, the country is looking to existing technical service providers (e.g., MoH and Ministry of Works), and adding cold chain to their competencies. This shares the financial burden across the government system, while still allowing access to maintenance (Ashok et al., 2017).

3.0 CONCLUSIONS

Sub-Sahara Africa is expected to become an important battlefield in the eradication of the COVID-19 virus just like it has in the past regarding other infectious viral diseases. However, despite recording inordinately the lowest number of infections and mortality rates contrary to expectations, it remains a very critical frontier in the battle against the disease. Mass vaccination is expected to be rolled out soon globally and Sub-Sahara Africa is anticipated to become a major formidable terrain in the immunization campaign. The major difficulties expected to impede the mass immunization just like in previous campaigns are the poorly developed and owned transport facilities which are more often than not in private hands. However, partnerships between the public sector and private sector in the past in some contexts such as Mozambique have proven effective in increasing the efficiencies of the program. This means that there could be short falls in financing where contingencies in outsourcing are not well factored in the budget owing to cost over runs. Moreover, the fact that the current transport systems in Sub-Sahara Africa that can be exploited for vaccination campaigns are mostly road and air. However, while roads offer last mile solutions, their major limitation is that in several rural contexts they are not in serviceable conditions and could prove difficult to use in wet seasons. This leaves air transport as a viable option, though, temperature excursions notoriously run high when using air transport for vaccine cargo. This may render the vaccines unusable if not controlled.

Refrigeration is also a highly valued component of the vaccine cold chain. Its critical nature means that it should be safeguarded from damage and other malfunctions in order to be serviceable at all times and reduce the incidences of the cold chain breaks. However, the study established that the refrigeration used in most hospitals are either too old (over the recommended 10 years), use the home refrigerator model and are of the absorption type, the last type being no recommended due to its inefficiencies. Consequently, solar powered refrigerators have emerged which promise to address the need for more energy efficient and greener cold chain needs. The abundance of solar energy in Sub-Sahara Africa could mean that the solar powered CCEs could work well and be relied upon to deliver. However, large scale use of solar in refrigeration such as in warehouses may still pose a serious problem and could lead to cold chain breaks in countries with electricity supply challenges. Further, the other challenge the anticipated concerns maintenance. Though there is progress towards availing trained technicians in CHAI operational countries, maintenance spare parts, training and remuneration costs need to be strongly factored in budget models so as to avoid industrial unrest and costly downtime that could expose the vaccines to temperature excursions.

4.0 RECOMMENDATIONS

Transportation is an important high value link in the cold supply chain and the underdevelopment of the transport infrastructure networks and systems significantly impedes the distribution of vaccines in Sub Sahara Africa. This adds to the cost of delivery and also affects the quality of the immunization programs. Therefore, in the short time towards the forthcoming mass vaccination against COVID-19, it may not be practical to expect accelerated development of the transport infrastructure and systems to have more grassroots penetration. However, vaccine distribution agencies could explore partnerships with private and public transport and logistics sector players and strategize on how last mile distribution of the vaccines can be achieved seamlessly even in the remotest of the regions. Refrigerated trucks will also need to be introduced into the context in large numbers.

Refrigeration is also critical and valuable component of vaccine cold supply chains. However, much of Sub Sahara Africa healthcare facilities still use 'Domestic' refrigerators and freezers which typically designed for industrialized markets where energy sources. Standard electric-compression refrigerators are also used by intermittent electric power supply limits their utility. Absorption-type refrigerators are increasingly dis used. Further, the challenging transport conditions coupled with the energy needs of the cold supply chain require the development of different models of refrigeration units that could use different forms of energy. Therefore, given these considerations, energy efficient refrigerators using renewable energy such as solar would be the most ideal. Still other green energy powered refrigerators need to be developed and deployed so as to provide efficient vaccine refrigeration while keeping the carbon signature significantly low.

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