GLOBAL CHALLENGES
EBOLA OUTBREAK

INNOVATIONS FOR
SUCCESSFUL SOCIETIES

OFFERING A LIFELINE: DELIVERING CRITICAL SUPPLIES TO EBOLA-AFFECTED COMMUNITIES IN LIBERIA, 2014 – 2015

SYNOPSIS

When an outbreak of Ebola virus disease began to spill over national borders in West Africa in 2014, halting the epidemic depended as much on logistics as on addressing the medical challenge the virus posed. As the rate of infection in Liberia rose in June and July, J. Dorbor Jallah of the government's Incident Management System knew that without chlorine, protective gear, and other critical items, it would be impossible for doctors and nurses to work safely. But Jallah faced obstacles at every level of the supply chain. Uncertain estimates of need, competing product standards, and limited vendor partnerships initially hampered procurement. Cargo volume strained capacity at ports of entry, and warehouse space was inadequate—or nonexistent. The country's limited road network hampered the transport of materials to rural areas during the rainy season. At clinics, safe disposal of contaminated items presented additional difficulties. And to make matters worse, responding organizations all had different policies and approaches. After initial disarray, the Liberian government, international organizations, nonprofit groups, and private companies began cooperating to simulate some of the features of a centralized and integrated supply chain. The volume, speed, and responsiveness of delivery increased across Liberia—just as the epidemic began to wane. The experience triggered a search for innovations that could address similar constraints more effectively during any future infectious-disease outbreak whether in Liberia or elsewhere.

INTRODUCTION

"We often said at that time that the Ebola response was not primarily a medical response but more about logistics and supplies," recalled William Vannier, supply chain director at Médecins Sans Frontières (MSF, or Doctors Without Borders), which played a significant role in bringing the crisis under control. "Doctors were not the main need in Liberia during the peak because we couldn't do anything medical—except basic care like rehydration and pain relief."

After its initial detection in neighboring Guinea in December 2013, Ebola virus disease spread rapidly and unpredictably, spilling across borders and moving from remote rural areas to towns and cities. Most of the people who contracted the virus fell ill, and the disease was usually fatal, with no vaccine, no known cure, and few treatment options available at the time.

Containing spread of the disease was essential, yet procuring, positioning, and moving critical supplies to field facilities on the frontlines of the outbreak presented an enormous logistical challenge. Ebola struck mainly in Liberia, Sierra Leone, and Guinea—post-conflict countries still recovering from civil wars or coups. Of the three, Liberia had the lowest gross national income per capita—$700 per person, adjusted for differences in purchasing power.[1] After years of wartime neglect, the country's health-care system had only limited ability to detect and cope with a disease previously unknown in the region.

What began as a small public health emergency ballooned into a full-scale humanitarian crisis with horrifying swiftness. Ebola first appeared in Liberia during March 2014 as a cluster of remote outbreaks in Lofa and Nimba Counties near the Guinean border. By June, the disease had surged from the forested backcountry toward Monrovia, the capital, and many health-care workers fell ill or abandoned their posts because they lacked what they needed to treat their patients and maintain their own safety. Across the country, health centers and clinics began to close.

By late July, 156 people had died and new infections began to rise exponentially.[2] The largest public health facility in the country, John F. Kennedy Memorial Medical Center in Monrovia, shut its doors soon afterward, when health-care workers contracted the disease and the center could no longer accommodate new patients.[3] Redemption Hospital, Monrovia's other main medical facility, closed a short time later, when 12 doctors and nurses fell ill and died of the disease. Speaking of the early months, Vannier said, "It was too much; it overwhelmed us."

Timely and targeted delivery of supplies could turn the tide against a modern plague that some top officials described as a threat to Liberia's existence.[4] Vital matériel included clothing to protect responders, such as specialized plastic body coveralls and face shields; chlorine and sprayers; diagnostic test kits; and therapies for keeping patients comfortable.

But the government and its partners faced obstacles at every level, from deciding what to order to last-mile delivery. J. Dorbor Jallah, the government's principal logistics officer, realized that the crisis demanded an approach that integrated supply chain functions and provided a foundation for effective

coordination and management among the many different organizations participating in the response. Adapting existing systems would not be easy: The problems on the ground were daunting.

THE CHALLENGE

"When [Ebola] first started, there was really a state of confusion," said Jallah. Few understood what the disease was or how it spread, but the consternation did not end when epidemiologists put a name to the virus.

Because of the fluid nature of the epidemic in Liberia, it was hard to forecast needs, which varied greatly day to day and by place. "What was very complicated with this outbreak was that it was a series of small outbreaks," Vannier explained. "You can have nobody coming in for two weeks, three weeks—and then you have 50 people coming in. So in terms of forecasting . . . it's extraordinarily complex." Moreover, poor data quality impeded the ability to offer reliable projections.

If forecasting was difficult, so was procurement. Few health centers in Liberia knew how to get the critical supplies they needed in sufficient quantities from manufacturers with which they had had limited or no prior relationships. Winning consensus on a single set of standards and ordering supplies made to certain specifications could take months. Although MSF had created specialized kits designed for to address small outbreaks of Ebola—including one that contained everything needed to run a 15-bed clinic for a month—the aid group quickly exhausted its inventory.

The number of health-worker deaths rose.[5] Without access to protective clothing, some Liberian health workers were wrapping their hands in plastic bags in an attempt to minimize the risk of exposure.[6]

By July 2014, problems had already started to arise in importation, the third supply-chain component. To efficiently move Ebola outbreak–related freight required changes in customs rules and expansion of port capacities. Liberia's largest airport facility was too small to hold the contents of even one cargo aircraft, which typically carried 60 to 80 tons. Both the international airport and the seaport relied on people with specialized skills who were not easily replaced if they became ill. And as infection spread, shippers and commercial airlines grew nervous about the risks to their crews and whether other governments would allow them entry if they thought the crews might transport the disease across borders.

Liberia's warehousing and inventory capabilities were inadequate at every level of health delivery. Facilities simply didn't exist. Moreover, the influx of supplies was difficult to track and organize because of high volume and wide variations in quality, condition, and purpose. A United Nations International Children's Emergency Fund (UNICEF) employee reported that when shipments of supplies arrived, it was like Christmas because no one knew what the boxes would contain.

Deliveries from other countries sometimes arrived with labeling that confounded those who had the job of sorting and classifying the supplies. "How

can we issue medicines when they're labeled in a foreign language?" asked John Harris, director of the Ministry of Health and Social Welfare's supply chain unit, which struggled to keep up with the tide of incoming matériel. "We speak only English in Liberia. Therefore, medicine descriptions written in foreign languages pose a challenge for us."

Many obstacles beset transportation, a fifth supply-chain component. Liberia's main ports were near the coast, but many of the more than 650 health facilities were in remote inland areas. From May through September, on average almost 20 millimeters (four-fifths of an inch) of rain fell per day. The precipitation could make dirt roads impassable for most kinds of trucks and other vehicles. Less than 7% of the roads outside the capital region, Montserrado County, were paved, and many areas had no roads at all.[7]

The final step in the supply chain—management at the end-user level—also presented tough challenges. Managers at each treatment unit, clinic, or hospital had limited space for medical supplies and other inventory. Tracking stock levels and placing new orders were difficult with poor Internet connectivity and only limited electrical power to support computers.. Used supplies accumulated quickly and posed an infection hazard. The country had few incinerators to destroy medical waste in the prescribed manner, and many Liberians feared that burying used supplies could contaminate groundwater or agricultural land.

To improve the ability to quickly get essential supplies to those who needed them, Jallah and his colleagues had to persuade other organizations to divide the labor, share resources, and cooperate seamlessly. But many responders operated their own partial or parallel supply lines and had different organizational cultures. Even government ministries and independent aid agencies had competing agendas. Early on, Jallah said, many officials saw the epidemic as an isolated health issue and not their responsibility.

FRAMING A RESPONSE

The textbook method for efficient product delivery in a volatile market called for a centralized, vertically integrated system[8] directed by one decision-making body, with real-time information sharing from one end of the supply chain to the other.[9] During the 1980s and 1990s, private companies had created ways to link key logistical functions so that they could more easily manage the flow of materials from beginning to end. Information sharing, pre-established contracts, and other practices helped improve responses to volatility or disruption.

Among the many organizations active in Liberia when the Ebola outbreak started, MSF was the only one with structures and practices that resembled a centralized, end-to-end logistics system. MSF controlled all levels of its supply chain—from procurement to patient treatment—and its managers delivered supplies as requested by the projects it operated.[10]

The MSF humanitarian aid group had gained extensive experience in working against Ebola during outbreaks in Central and East Africa, yet it found its operations tested. As the disease began to spread unpredictably and on an

unprecedented scale, MSF tightened its own centralized supply chain. The organization's five operational centers, each based in a different European country, usually operated autonomously. This time, senior managers decided to pool their resources at MSF's Belgium center, which had been the first to help in Liberia.

The Liberian government itself also had to decide what to do. It had some supply chain management capacity based at the National Drug Service and the General Services Agency. But the support the government could mobilize fell short of the level needed to respond to the crisis, especially as the rainy season intensified, the outbreak expanded, and the number of volunteer organizations and governments offering help increased. Moreover, many of its partners, like Samaritan's Purse or Last Mile Health, which typically ordered and transported what they themselves needed, had little experience with this particular disease and lacked relationships with the companies that could supply critical equipment.

Jallah recognized the difficulty of mounting a viable response without effective outside partnerships, as did his supervisor, Deputy Minister of Health Tolbert Nyenswah. To simulate an integrated approach within a highly decentralized system required rapid and effective coordination among diverse organizations.[11] Building closer working relations and clarifying the division of labor among Liberian government ministries, non-governmental organizations (NGOs), multilateral institutions, and private companies was essential. In late July 2014, Jallah and Nyenswah consulted with visiting international experts, including UN staff and Dr. Kevin De Cock, who was then the US Centers for Disease Control and Prevention (CDC) country director based in Nairobi, Kenya and the CDC team lead for Ebola.

In early August, three significant steps moved everyone closer to a solution. First, Liberia's president, Ellen Johnson Sirleaf, replaced her government's existing emergency response structure with an Incident Management System (IMS) adapted from a CDC model. The new approach brought the health ministry, other parts of government, NGOs, and international organizations into a collaboration organized around key functions. On August 10, Sirleaf appointed Nyenswah to lead the IMS, with Jallah as his second in command, in charge of logistics.[12]

The IMS, which had a logistics task force, could help substitute for a central decision-making body. It began to meet daily and included representatives of all key participants, not just the government. Those steps improved coordination by enabling organizations to share resources and information; it was easier to negotiate access to supplies and transport when partners were in the same meetings or only a few desks away. The system also made the government more quickly aware of holdups: "If you tried to do something and there was some government bureaucratic bottleneck, you just passed it by me and . . . [in] 20 or 30 minutes, we resolved [it]," Jallah said.

The second big change was the World Health Organization's (WHO's) long-awaited decision to declare the outbreak an international public health

emergency. That step opened the door for some of the UN's humanitarian agencies to assist in the crisis, especially by providing logistics help. WHO made the declaration on August 8, just two days before Nyenswah and Jallah moved into their IMS roles.

The UN's logistics cluster, created in the early 1990s to improve coordination among UN and nongovernmental agencies in disasters and in war, put its knowledge at the IMS's disposal.[13] The World Food Programme (WFP), which co-chaired the cluster, had extensive experience in moving humanitarian supplies during earthquakes, war, and other large-scale crises. WFP had a fleet of aircraft. It also had the ability to import vehicles for transporting supplies, and it could set up temporary bridges and warehouse tents, which it had stockpiled at strategically located UN humanitarian-response depots. By tapping those resources, WFP could provide what it called *common services* and could make them available to other organizations at no cost. Although not formally activated until September, the cluster began to put people on the ground in mid August.

The third change was the arrival of an Office of US Foreign Disaster Assistance response team, which could put help on the ground quickly, assist WFP's work, and find the people and equipment to solve problems WFP could not address. The US Agency for International Development (USAID) and its Office of US Foreign Disaster Assistance activated the team response and sent people to help just as the declaration of public emergency went into effect.

On August 17, WFP logistics cluster coordinator Frank Aynes met with Jallah, Nyenswah, WHO representatives, the US disaster assistance response team, and officials from Liberia's health ministry. Together they assessed needs and discussed possible solutions, even as gloves, chlorine, water tanks, plastic sheeting, and many other items began to arrive.

The idea behind the emerging IMS–WFP partnership was simple, however: "One plan, one coordination unit, one strategy, . . . so the partners aligned whatever they were doing behind what we were doing as a government," Nyenswah said.

The decisions were not always easy. Although the UN activated its cluster at the behest of the government, its priority was to get things working, which sometimes meant replacing dysfunctional systems rather than integrating and improving them. When conditions worsened steadily during August, some international aid groups argued for taking logistics outside the Liberian government completely.

Once the formal arrangements were in place, however, Jallah could ask partners to merge their parallel supply lines into one, at least for selected functions. To win support, he stressed economies of scale. "Assuming five of you have to send trucks up-country to the same destination with cargo, and let's assume each of you have the truck 20% full, wouldn't it make sense to consolidate all that cargo into one truck so that that way, we send one truck instead of five?" he asked, as he tried to build collaboration. In early September, smaller organizations ceded transport and central storage of their supplies to the cluster's facilities and vehicles.

As those preparations got under way, logistics co-chairs Jallah and Aynes met with the many organizations operating clinics, treatment units, isolation centers, and other parts of the response to identify critical bottlenecks and assess ways to streamline further.[14]

GETTING DOWN TO WORK

Managing supply was "like designing an airplane while in flight," said those who led the logistical parts of the response. Getting the right materials to the right places required constant adaptation because the disease and the

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Box 1. First Shipments

The first shipments of supplies began to arrive in Liberia well before the IMS logistics collaboration was up and running. The UN agencies and nongovernmental organizations relied on donations and appeals to pay for their operations—often a slow process. But time was of the essence, and private contributions helped fill the gaps when existing stocks were depleted or there were holes.

As early as April—days after tests confirmed Liberia's first cases and the outbreak seemed under control—the supply of protective gowns, masks, and gloves began to flow. MSF had its own resources, but other health-care workers needed gloves, masks, and gowns. The US government supplied some of the required gear through the Centers for Disease Control and Prevention. Among others to step up was MAP International, a faith-based medical charity that had an office in Liberia and a stock of 33,000 protective suits in a warehouse in Brunswick, Georgia. Earlier, MAP had run a program on emerging pandemic threats for the US government, but the funding had dried up and the suits were still in inventory. MAP began to ship out its stocks in phases by using Airlink, a service formed a few years earlier to serve humanitarian efforts in the United States and other countries. In the opening weeks of the response, a number of private foundations joined forces to support Airlink's air bridge.

Within days of activating its disaster assistance response team in August, USAID released $12 million to help UNICEF, WHO, and other partners on the ground, such as Global Communities and the Red Cross, send infection hygiene kits, gloves, masks, chlorine, and technical experts. USAID drew on discretionary funds its Office of US Foreign Disaster Assistance controlled, as well as support from its Bureau for Global Health.

By August 18, the United States had shipped a mobile laboratory from the CDC in Atlanta and more than 100,000 sets of protective gear, followed the next week by 16 tons of medical supplies, plastic sheeting, water tanks, and other matériel. The supplies were insufficient, but they represented a start. Those initial steps also highlighted some of the problems that the IMS logistics partnership would have to solve in order to meet the needs on the ground.

(See USAID Ebola Factsheets at www.usaid.gov/ebola/facts for additional detail and airlinkflight.org/airlink-airbridge-for-ebola-response)

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humanitarian crisis it created shifted quickly and unpredictably over space and time.

Forecasting

Deciding how much to order presented a special challenge for all organizations involved in the response. For items with short shelf lives or special storage requirements, such as very cold temperatures, it was especially important to estimate needs with a high degree of accuracy.

Before the crisis, Liberia's health ministry had maintained a so-called pull inventory system; that is, county facilities ordered medications from the National Drug Service when stocks ran low. As the crisis worsened and Ebola infections accelerated, responders needed a way to order and allocate supplies according to *predicted* consumption, a push system, but that approach could work only if the models the epidemiologists developed were robust and if they correctly predicted caseloads.

Quantifying supply needs required accurate data, such as numbers of new Ebola cases, numbers of people exposed to each infected person, and locations of new outbreaks. Disease modelers used that information to calculate the case reproductive number, an indicator of the number of people they expected one diseased person to infect. Next, they combined that information with data on population density to project anticipated prevalence—how many people were expected to fall ill within the area served by each Ebola center. Last, they matched the estimates with information on the amount and type of equipment needed for every infected person. MSF knew the supply needs per patient from previous experiences in fighting Ebola.

Poor data quality and delay in providing information, combined with the fast-changing nature of the situation, complicated efforts to model the epidemic and create reliable forecasts of supply needs, however. Because the consequences of under-ordering were greater than ordering too much, MSF used its worst-case epidemiological forecast. Its model anticipated a peak of 1,000 patient beds in December 2014 across all three Ebola-affected countries, with operations expected to diminish by 100 beds per month.

MSF's supply estimates were among the strongest available, and most responders used MSF information on the amounts and kinds of supplies needed per bed when developing their own forecasts. MSF, which controlled its own supply chain, could also generate daily figures on supply consumption and stock levels. The organization's system collected consumption data daily and transmitted it weekly to headquarters in Europe, thereby helping staff members there refine forecasts and more accurately tailor supply orders to levels of use.

Many smaller humanitarian organizations lacked the data needed to inform projections. They simply procured as many items as their budgets and market forces allowed.

Jallah worked with colleagues at the IMS, the health ministry, and the Clinton Health Access Initiative to estimate projected needs for government-run treatment centers. John Snow, Inc., a Boston-based public health management

consulting and research company that ran a supply-chain management program on behalf of USAID, was already working with the health ministry on supply chain integration, and it pitched in too. Harris, who directed the health ministry's supply office, said the projections initially rested largely on guesswork, but they improved as the team received more information and support from others. Jallah asked responders to share updated information at daily IMS meetings.

But forecasting remained difficult. The epidemiological models used by MSF, the CDC, and WHO offered widely varying projections of the numbers of people likely to fall ill. In its late August Ebola Response Roadmap, WHO announced there could be 20,000 cases in the three countries most affected.[15] A month later, on September 23, the CDC shocked everyone when it projected that cases could reach 550,000 in Liberia and Sierra Leone alone by the end of January 2015—and even 1.4 million if cases were underreported at the level the CDC suspected.[16] Given the high need and the manufacturing time lags, it seemed impossible to order too much.

One of the grim indicators of the impact the forecasts had was the Liberian government's decision to order 80,000 more polyethylene body bags in mid October. [17]

Procurement

Shared guidelines for equipment were crucial. Besides reducing the risk of transmission by enabling health workers to learn safety procedures more quickly, standard specs lowered supply prices by enabling larger bulk ordering, permitted more-efficient delivery and distribution, and helped manufacturers decide what to produce. But MSF and WHO, which ordinarily took the lead in responding to health emergencies, had competing guidelines for the kinds of gloves, gowns, face masks, and other gear required.

Achieving agreement was difficult, partly because the organizations assigned varying weights to the factors they considered in developing their standards. Safety, price, ease of use, and breathability all mattered. MSF's personal protective gear complied with standards the organization had developed based on its previous experiences in combating Ebola. The organization used suits and gloves that covered more exposed skin than other models did. WHO tried to strike a balance between function and price.[18] It contended that MSF's preferred equipment was too difficult for local workers to put on and take off, and too hot for Liberia's steamy climate. And its preferred coverall cost about US$6.50 (5 Euro), whereas MSF's cost about US$9.00 (7 Euro).

During the opening months of the response, the differences went unresolved, and health workers had to adapt procedures to whatever equipment they had. But as partners sought to build confidence among volunteers and negotiate new supply contracts with producers, deciding exactly what to order came under renewed scrutiny. Said one private sector supplier: "We found that to instill confidence, it was essential to have the same type of equipment for every person—even the same-color goggles. If people saw differences, they

would start to question. Uniformity was important for muscle memory but also for signaling safety and for preserving equality."

In early October, WHO, MSF, the CDC, and others convened to develop guidance. They decided to allow aid groups some flexibility in combining items to protect workers. Later the same month, they updated their recommendations about product specifications and offered advice about the safest way to "don and doff" equipment. For instance, the CDC, which had previously followed WHO guidelines that allowed for some exposed skin, altered its recommendation to "no exposed skin," which was in line with MSF's practices. However, the organizations never completely harmonized their advices.

Figuring out how to secure supplies was as much a problem as determining what items to order. Under normal circumstances, most health groups understood how to get the materials they needed and had systems for purchasing and transporting them. The Ministry of Health and Social Welfare was responsible for procurement for government facilities, and it typically purchased only from a list of essentials, a basic kit. It had to clear purchases with the finance ministry, a cumbersome process. Once products arrived, the

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Box 2. Chlorine

The workhorse of the epidemic response was a household product well-known in some parts of the world but scarce in Liberia, Guinea, and Sierra Leone: chlorine bleach. In some ways, the Ebola virus was wimpy. A 0.5% solution of chlorine in water could break down the virus's structure, eliminating its ability to infect. Sprayed on a surface, the solution was powerful stuff. In weaker form—a 0.05% solution—it could substitute for soap in cleansing skin.

As the rate of infection rose, so did the need for chlorine, but supplying the chemical was not always simple. Said one US disaster assistance response team leader, "It was really hard to find the type needed and the quantity required." There were three forms of concentrate: powdered calcium hypochlorite (HTH), granular sodium dichloroisocyanurate, and liquid sodium hypochlorite. Solid forms could cause explosions without special handling, but the liquid form was bulky.

Moreover, in solution, each type degraded at a different rate and had a different shelf life, and high temperatures caused concentrations to drop more rapidly below the levels essential for infection control. Depending on type, temperature, and a few other variables, the solutions were good for between an hour and a few days.

The US government funded UNICEF to bring in some initial shipments of chlorine, and a mining firm shared its supply. Bottled chlorine bleach either donated by Olin Corporation, a United States–based chemical company, or purchased on the market arrived on supply flights. Later the United States sent high-powered HTH by cargo ship.

See Carol Han, "USAID Takes to the High Seas to Bring Reinforcements to Guinea's Ebola Fight," March 10, 2015, at https://blog.usaid.gov/2015/03/usaid-takes-to-the-high-seas-to-bring-reinforcements-to-guineas-ebola-fight-2/ and Qais Iqbal et al., "Shelf-Life of Chlorine Solutions Recommended in Ebola Virus Disease Response," PLOS, May 31, 2016, accessed at http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0156136.

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ministry's National Drug Service then delivered those supplies where needed.

The requirements of the Ebola outbreak challenged these existing systems. Although organizations like MSF and the United States–based NGO International Medical Corps and WHO already had existing contracts with some vendors, Liberia's health ministry and most other responders did not. Moreover, because previous Ebola outbreaks in Central Africa had been relatively small, even MSF had just one supplier of personal protective equipment.

One solution was for several organizations to piggyback on existing supplier relationships. Smaller organizations could consolidate and procure materials through UN organizations, including WHO. Eventually, MSF also enabled humanitarian organizations it had worked with before, such as the French Red Cross, to procure items through MSF channels.

Even so, it was hard to source the products needed. MSF had to persuade its suppliers to scale up production and find other manufacturing firms that could do the same. "The exponential growth of the epidemic . . . meant we needed [large quantities] of different things. But on top of that . . . [we had] only one [personal protective equipment] supplier," recalled Nicolas Dupont, a supply officer. MSF forecast a need for 120,000 personal protection suits per month, but its original supplier—United States–based DuPont—could provide a maximum of only 30,000. Later, DuPont outsourced additional production to a manufacturer in Mexico that produced protective equipment to DuPont's specifications, thereby alleviating the bottleneck.

In September, MSF's three European supply centers combined their resources and approached personal-protective-equipment vendors with a firm purchase order for the following six months valued at about US$13 million. Pooling resources guaranteed larger payments to vendors—an incentive to modify assembly lines and expand production—and reduced the number of buyers vying for a manufacturer's attention. The offer guaranteed demand until June 2015, which was when MSF expected the outbreak would end.

The need to scale up production only continued to intensify. Demand quickly outstripped availability in October, after Liberian Thomas Duncan died in a Texas hospital, two nurses were infected, and US and European hospitals began to place orders. Said one supplier, "All of our customers started ordering assuming they would get patients, and all of our reserves went to current customers; and even if had wanted to give supplies [to the West Africa responders], we couldn't." Hospitals in places like Oklahoma quickly purchased and stored supplies, so there was no matériel for Liberia. The supplier said: "It was very unsettling. The places with money and firm infrastructure ordered. That's what they should be doing, but at the same time, we had people on the ground where the epidemic was raging who really needed the equipment." Private suppliers' warehouses became completely depleted.

As the weeks progressed, some of the major global companies that produced medical supplies and drugs also took additional steps to assess anticipated needs. Some had preexisting relationships with major medical nonprofit organizations and had monitored the situation through the war rooms

of organizations like the International Federation of Red Cross and Red Crescent Societies and the International Medical Corps almost from the beginning. However, the speed with which a humanitarian problem became a disaster caught everyone by surprise. Working through the Partnership for Quality Medical Donations, several of the larger companies and NGOs talked about how to expand manufacturing as well as how to target donations. Like many, they too were shocked that what initially looked like a relatively limited humanitarian issue had morphed into a disaster. They also worried that capacity problems on the ground would limit effective use of the supplies they provided.

Moving supplies through ports

Obtaining the right kinds of supplies in the amounts needed was just the beginning of creating an effective supply chain, and it led to another daunting task: bringing an unprecedented volume of cargo through Liberia's strained ports of entry. At first, larger organizations chartered regular flights to resupply their projects, and smaller organizations banded together to fill cargo holds and share the costs of sending provisions. Governments and private companies, such as United Parcel Service, sometimes helped pay the bill. But once on the ground, it was not always easy to pick up the cargo. Customs and port fees were significant impediments to bringing in vital matériel quickly and cheaply.

Jallah needed high-level help to persuade another part of the government to alter its rules. A team from the Incident Management System met with the president to ask for her help. Sirleaf quickly issued an executive order stipulating that no organization involved in the response would have to pay customs duties when bringing in critical supplies. Said one partner, "I was surprised how fast the government resolved this problem in Liberia." In Sierra Leone, the challenges were greater and took longer to address, he noted. Nonetheless, sometimes lower-level officials adhered rigidly to the old rules they knew, and IMS partners had to spend time dislodging shipments that had gotten stuck in the system.

New problems forced constant adaptation. For example, unscrupulous third-party customs brokers took advantage of the crisis by charging usurious fees for their services in clearing shipments. To curtail such practices, the government designated an authorized customs broker to handle Ebola-related imports, which resolved the problem until the WFP logistics cluster took over the function.

Then an additional wrinkle arose. The governments of Liberia, Sierra Leone, and Guinea had approved-drug lists, and unless contributed items were on those lists, customs officials would stop them at ports of entry, causing waste of scarce resources. Private donors urged governments to revise their drug registries to ensure that those providing services could import what they needed, but even small departures from the specs in the lists could cause problems. Organizations that had people on the ground who could preclear shipments fared a bit better than others, although their work was not trouble free.

But there was worse to come. At the same time the logistics team was sorting out customs problems, an even more difficult challenge began to

materialize. As the number of new infections had started to increase, other governments grew nervous that moving freight and people into and out of the affected countries would cause the disease to leap borders. They began to deny flights from the region permission to land, and in the middle of August, commercial carriers, including British Airways, canceled service. Soon Brussels Airlines and Royal Air Maroc, Morocco's national carrier, were the only two airlines that still ran commercial operations in the region. Freight companies also grew hesitant to unload at Liberian seaports. And Senegal, a key logistics node, announced it would close access too, with potentially disastrous consequences for the response.

As the IMS and the logistics cluster became fully operational, the WFP engaged the UN's own Humanitarian Air Service, which normally moved supplies into areas affected by war or natural disaster. With US government funding, the service activated Ebola-relief cargo flights, and planes began to depart from Europe twice a week. Responders could use the service to move matériel to Liberia on a first-come, first-served basis. Each organization could reserve space for items it had ordered. The downside was that the flights left only when full, whereas needs were usually time sensitive. From September 2014 to February 2015, the US Air Force also pitched in to transport people and cargo to the affected region, in order to help fill gaps.[19]

Monrovia's Freeport, Liberia's main seaport, was located just north of the West Point slums, where Ebola had started to spread. "When Ebola struck, it became clear to everybody that we were sitting on a place considered the single point of failure," Nyekeh Forkpa, manager at Liberia's main seaport, asserted, adding that more than 90% of Liberia's trade and commerce flowed through its seaports—and more than 70% through the main Freeport in Monrovia. "If the country needed to survive—not only succeed in beating Ebola—but *survive*," he said, "the seaport needed to be kept pristine and open for commerce and the supply of Ebola emergency response materials."

Maintaining the safety of the port and the health of its skilled workforce was of paramount concern throughout the crisis. Even before August, port authorities consulted with disease control specialists, including the CDC, to decide how to maintain staff safety and keep operations running. To minimize the risk of infection, Forkpa and other managers put 30 to 40% of nonessential personnel on paid leave, retaining only those with the most experience and requisite skills to keep the ports operating and secure. Forkpa also opened an Ebola isolation center within the port and reassigned the port physician, ordering that he learn to deal with Ebola cases so that he could respond if a staff member or port user had a suspected infection.

The port authority required all staff members to perform basic infection-control measures at three separate points: once at the port's main gates, then when entering the secure area run by APM Terminals, the private company that managed the terminal, and a third time prior to boarding docked cargo ships. The new routines required handwashing and foot wiping using chlorinated water, wearing long pants and shirts with sleeves to minimize exposed skin, and

taking infrared temperature checks. The port also created a medical status form for each employee and recorded key infection indicators, including body temperature and contact history. Health staff had instructions to report to management immediately any changes in that information. If a change suggested possible virus exposure, managers placed the affected worker on paid leave for three weeks. Forkpa also restricted crews to their vessels, denying them passes to enter Monrovia.

The seaport had to demonstrate to shippers that it was taking effective measures to prevent infection. But the new procedures, which slowed operations, coincided with a massive influx of supplies and a much greater workload, creating the risk of bottlenecks. To compensate, Forkpa gave docking priority to shipments carrying Ebola-specific supplies.

Roberts International Airport, 56 kilometers (35 miles) outside the capital, presented different challenges. Like the seaport, it initiated infection-prevention measures designed to ensure the safety of skilled workers and customers by initiating in late July both entry and exit screening. Unlike the seaport, however, the airport had limited storage space, and its infrastructure and equipment were ill-suited to a large-scale cargo operation. Moreover, it had only one runway capable of handling the types of aircraft that could deliver supplies.[20] "Prior to Ebola, we had, on average, four cargo flights that would come in per month," said Robert Morris, manager of the international airport. "During Ebola, we had an average of 100 per month. . . . Those 100 were coming [in] full, so you're talking about an average of 60 to 80 tons per aircraft." The average cargo aircraft held enough supplies to fill nine 40-foot flatbed trucks.

In October, the US Air Force helped construct additional temporary warehouse capacity and improve coordination, a vital need at an airport that could handle only one flight at a time.[21] By early November, a new system for the scheduling of incoming cargo planes was in place. Airport staff set up a spreadsheet with times blocked out. When a flight applied for landing permission, staff checked the spreadsheet for available times, taking into account how much cargo was on board and estimating the amount of offloading time. Each carrier received a request number for a specific time slot, valid for plus or minus two hours. Delayed planes had to request new numbers. Morris said only one plane was unable to land on schedule during the peak of the crisis.

Flight scheduling was only half the battle. Airport staff also had to unload the planes and clear the cargo from the tarmac. "We weren't a major cargo operation, so the equipment we had was geared more toward our commercial passenger operation," Morris said. "So, all of a sudden, you have a cargo operation . . . it's a different sort of beast." The airport could handle four cargo planes at a time, and each took an average of one or two hours to offload.

Although the airport staff had the proper equipment, workers did not have enough of it, and the only way to unload all cargo was to operate shifts both day and night. Employees who had supported passenger flights, which had almost ceased, were diverted to assist. They had already been cross-trained in both commercial and cargo operations. The US military, which had set up its own

cargo operation in an adjacent space after it arrived to assist, lent the airport forklifts and other equipment when necessary. It also helped organize local contractors to maintain the runway, which needed constant repair as use intensified.

Warehousing

After workers unloaded freight at the ports of entry, the next big challenge emerged: storing and organizing cargoes.

Kassia Echavarri-Queen, MSF country director and head of mission, said MSF had a well-established warehouse and inventory system at all three levels of its supply chain structure: at its European supply centers, at its country offices in Monrovia, and at each project site. In Monrovia, MSF at first rented a warehouse and later built eight temporary storage tents next to its main offices and near its large Ebola treatment center in Monrovia. At all three levels, basic inventory data like supply counts and consumption levels were closely tracked and synchronized across facilities.

Storage needs created big problems for the Liberian government. The influx of bulky Ebola supplies quickly overwhelmed the small storage facility at the National Drug Service. The health ministry converted a conference room at its offices into temporary supply space and later began to store matériel in another room that was otherwise unusable due to fire damage. In September, officials commandeered National Election Commission facilities, including a large central warehouse and smaller spaces in Liberia's counties. However, none of them proved sufficient, because equipment and medicine began to arrive in much higher volumes.

The WFP began to address some of those problems when it stepped in to co-lead the logistics cluster. The first priority was to set up storage tents in areas with the highest case rates, where the biggest Ebola treatment centers were located: one in Monrovia and the other in Foya County.

At the largest center in Monrovia, Jallah worked with WFP logistics cluster coordinator Aynes to set up two central hub warehouses. For their main logistics hub they chose a 35,000-seat stadium located in a suburb east of the capital. Next, they began to establish warehouse facilities in the counties so that supplies could quickly reach target areas when new infections appeared. The WFP team built five county forward logistics bases with storage capacity. It selected sites with a specific objective in mind. "The idea was that the coastal ones would mutually reinforce the inland ones . . . and move cargo in," explained Jallah. Near county health facilities, the WFP also gradually set up temporary tents. By July 2015, across all Ebola-affected countries, the WFP had built more than 30,000 square meters (about 323,000 square feet, or 5.5 football fields) of facilities to house personal protective equipment and essential supplies.[22]

The IMS and the logistics cluster relied on John Snow, Inc., and NGO responders to complete so-called last-mile delivery—that is, to move supplies from county health facilities to the more than 600 clinics and health centers

scattered across Liberia. Each of those facilities managed its own stock and inventory.

Many government and nongovernment responders maintained parallel supply lines until the WFP's system became fully operational, which took more than two months. Some of the main elements of the system were not in place until November, and the storage tents adjacent to country health facilities became available beginning only in February 2015, after the peak of the outbreak.

Once the logistics cluster was up and running, most partners' supplies could flow through the system the WFP had set up. The cluster controlled transport and warehousing from the time items entered their main bases in Monrovia until they left their five county forward logistics bases and flowed into county health unit tents. To use the service, a partner organization with supplies to ship sent the WFP a service request form. Within 48 hours, the WFP would schedule the items for delivery and track the cargo as it moved through the system to its main warehouse and country hubs. The partner then picked up the items or had someone else do so. A WFP manager at the warehouse signed off.

At first, the system was slow in releasing supplies, and organizations running treatment centers pressed for faster service. The WFP eventually streamlined its operations, permitting county hub managers to authorize supply releases—a decision formerly made by central offices in Monrovia.

Inventory

Ensuring frontline responders had protective clothing and other supplies also required an inventory system to help track the locations of specific items in the web of warehouses and to warn of low supply levels. MSF operated its own system and synchronized information across all of its units. For other partners, however, inventory presented fresh delivery challenges.

Before August, the health ministry's inventory system had assigned each item a number, which clerks recorded on paper cards. In August, before the new warehouses came online, clerks began to improve the tracking system, and with the help of volunteers, transcribed the information into a Microsoft Excel database each night. Over time, an Excel-based electronic system replaced the paper cards at central points, and it became much easier to show the supplies each facility received within a given period. The logistics cluster had piloted the system—called the Relief Item Tracking Application—only a year earlier.[23] Because most of the end-user facilities lacked computers, however, the system could not indicate when someone used an item; and without consumption data, it remained difficult to replenish stocks quickly and efficiently.

Additional problems arose in developing the inventory system for supplies that moved through the WFP transport and warehouse system. Normally, the WFP worked in conflict zones or areas hit by natural disasters, and most of the supplies it usually moved, such as food, could be exchanged with substitutes without doing much harm. But in a medical operation, precision was essential. "In a food aid operation, if you don't have bulgur wheat, you can get rice or

corn," said Sando Dogba, supply chain expert at John Snow, Inc. "But . . . there are no substitutes for gloves."

Moreover, personal protective equipment kits comprised a group of specific items—including gloves, face shields, coveralls, boots, and aprons—that most often came in different packages, which could become separated as they moved through WFP systems. Those kits were less effective or even useless— and could be hazardous—unless they contained all the necessary items in the correct proportions.

When there were gaps in available stock, WFP staff lacked the expertise to make safe, appropriate substitutions involving medical goods. "WFP doesn't have skills . . . in distributing medical supplies," said Shahid Muhammad, logistics coordinator at WHO's offices in Liberia. "They are skilled about food and nonfood items, . . . [but] making their system and internal software capture these Ebola supplies . . . was a big challenge for them." To solve the problem, WHO stationed medical supply experts at each main warehouse to help make appropriate substitutions for supplies when necessary.

An additional problem arose from the WFP's inventory system, which identified cargo by carton dimensions rather than the quantities of the supplies each carton contained. Dimensions were important for loading and transport, but for partners, such information was insufficient and sometimes misleading. Because the system assigned each carton size a specific inventory number, the register might contain 20 different line items that were, in reality, all similar or identical quantities of coveralls, in 20 slightly different carton sizes. The clutter confounded efforts to track overall supply levels and forecast future needs because the system might show an item as depleted when in fact it was available in a different carton size.

It was early 2015 before a partial solution emerged. The Clinton Health Access Initiative, which had worked with the health ministry on inventory systems before the crisis, suggested reorganizing the inventory system. No matter how much carton sizes fluctuated, they could always be labeled as units of 100, which would give all responders a better idea of overall stock levels and consumption levels. After some initial hiccups, the WFP agreed to use the same system the health ministry had put in place. Every item received a specific number. Other partners agreed to use that approach as well.

Gradually, inventory management became easier for all partners because of information sharing through the Incident Management System and the associated logistics cluster. And responders acquired three new means by which to exchange information: at daily IMS meetings, on WFP's dedicated website, or by looking at aggregate WFP inventory data. Moreover, responders with the highest-quality consumption data, including MSF and the International Medical Corps, a nonprofit that managed an Ebola center in Liberia's Bong County, freely shared that information with other organizations.

Some suppliers also tried to make it easier for frontline health centers to operate by shipping complete kits instead of individual items. MSF had long used that approach, and some others did the same. Said Vannier: "Our premise

is that every day is an emergency, so we try to anticipate needs. We tried to produce identical shipments that could be offloaded directly onto trucks."

Transport

Getting supplies between locations, especially from central hubs to county warehouses and rural clinics or to homes where people had self-quarantined challenged creativity. Few parts of rural Liberia were accessible by paved road in the best of times, and the rainy season could render dirt roads impassable. *The Economist* magazine called Monrovia "the wettest capital in the world," reporting that the city often received as much rain in the month of July alone as London received in an average year.[24]

In outlying areas, the effects of heavy rainfall were devastating and slowed the response to the epidemic. Building teams found they could not work for hours each day, slowing progress at the peak of Ebola virus transmission from August through early October 2014.[25] Increasingly treacherous roads forced partners to find new ways to move supplies, occasionally with helicopter support. But some things, such as gravel for clinic construction, could not travel by air.

The government teamed with the WFP to handle transport with occasional help from the US military. The WFP obtained 40 four-wheel-drive trucks from the Netherlands, each about 15 feet (4.5 meters), with capacity to carry 20 cubic meters (706 cubic feet) of cargo. To serve the remote hubs along the coast, WFP relied on other options, including a boat provided by the UN mission.

Moving supplies between county hubs and the nine county health units that the health ministry managed also required a team effort. The Liberian government played a central role, using 50 vehicles the UN mission had donated. Smaller NGOs supplied vehicles when they could. This was a group effort; even international organizations that in ordinary times had little to do with humanitarian work lent spare vehicles for the effort.

Getting matériel from the county health units to Ebola centers or smaller facilities required special ingenuity in the absence of roads and in the midst of heavy rains. Initially, most partners were on their own and had to figure out how to move the supplies they had ordered. By December, John Snow, Inc. (JSI), had assumed much of the responsibility, working with smaller organizations like aptly named US nonprofit Last Mile Health.

The key was to plan carefully in order to take advantage of local expertise and available vehicles while adapting to fast-changing conditions. Liberians, who had the most at stake, were eager to fight Ebola by any means possible. JSI logistical experts met with county health unit staff members to gather information about the best supply routes to take and places to stop in the event of a storm in isolated backcountry. The company embedded its own employees in each county to establish a strong working relationship with community leaders and local institutions and to continue building knowledge of the context.

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Box 3. Rapid Response for Rural Areas

In October 2014, the CDC and the health ministry created investigation and response-ready health teams that used helicopters to deploy people and supplies to remote regions across the country at the first sign of a new Ebola breakout. Each team consisted of several experts and had the equipment and supplies necessary to isolate and treat patients, collect blood samples to confirm the presence of Ebola, conduct basic epidemiological initiatives like contact tracing, train local community members on safe burial practices, and monitor contacts of the initial case for the 21-day Ebola incubation period.

A CDC evaluation later reported that the six Liberian outbreaks that occurred after the rapid-response system began "lasted less than half as long, had lower death rates, had shorter chains of transmission, and had nearly three times as many Ebola patients enter isolation and receive treatment." By November, CDC and IMS officials had upgraded the teams' basic supplies with everything needed for the first 14 days of activity.

See "Ebola containment strategy succeeding in Liberia," CDC press release, February 20, 2015, accessed at http://www.cdc.gov/media/releases/2015/p0220-ebola-containment-strategy.html.

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The next step was to borrow or rent vehicles that could handle the terrain, including motorcycles and four-wheel-drive pickup trucks provided by the health ministry. Of the 80 vehicles deployed in distribution, nearly half (45%) were already in the counties when JSI took over. After renting the remaining vehicles from local suppliers, JSI provided fuel, trained drivers, and paid for lodging for last-mile delivery staff.

In the absence of supply consumption data, best practices suggested sending enough supplies to meet facilities' needs for at least one month. But JSI supply chain expert Dogba said that in the remotest counties, he worked with his colleagues to send enough for two or three months in case damaged bridges, bad weather, or other circumstances disrupted the usual monthly deliveries.

Adaptability was the name of the game, Dogba explained. "If the bridge breaks, we had to use [people on foot]. . . . If the motorbike is [able to access it], we use the motorbike. . . . We used canoes, . . .we used the river to get to the facilities. We [used] whatever the people who live there use to travel." Reaching remote districts remained difficult, however. Throughout August, September, and October, weekly situation reports indicated trouble with delivery.

End-user management

When supplies arrived at health facilities on the front lines of the Ebola battle, clinic managers had to manage space, use inventory systems to organize supplies, collect information on stock and consumption to relay to supply managers upstream, and find safe ways to dispose of used equipment and

medical waste. Managers also had to make sure they had somewhere to store excess supplies that sometimes arrived unexpectedly.

Some clinics assigned off-duty doctors the task of monitoring incoming supplies because accurate supply numbers were critical. Although the practice could overwhelm key personnel, who had many competing demands on their time, often there was no option.

Center managers also had the difficult task of overseeing the safe disposal of used supplies. Ideally, clinics could disinfect reusable supplies with chlorinated water and incinerate expended items. But Liberia had few incinerators, and demand was high—particularly in the dense capital region. During July and August, responders co-opted an incinerator in Monrovia that was ordinarily used for Hindu cremations by the country's small Indian community.

The supply of incinerators slowly increased. MSF bought some in the United Kingdom and sent them to Liberia in September, easing the constraint. The UN purchased and donated 13 for use in Montserrado County,[26] although it was still hard to find places to install them. And even when incinerators ran around the clock, supplies were used at such high rates in the dense capital region that they could still quickly accumulate, posing an infection hazard.

Nor was it feasible to deploy incinerators to rural locations with low population densities. In those instances, center managers had to identify other ways to dispose of items. Burying expended materials deep in the ground was one option. Josh Balser, acting country director of nonprofit Global Communities, said burial was common in remote regions of Sierra Leone, and the same was true for parts of Liberia far from incineration facilities.

However, burying used materials was sometimes unsafe. For example, Monrovia was nestled in the swampy Mensurado River delta, where water quickly collected in disposal sites and could leach contaminants into wells. Monsoon rains easily washed open shallow sites, raising the risk of new infections and infuriating the public. Absent an alternative, some clinics burned used supplies in the open.

OVERCOMING OBSTACLES

"This really is unlike any emergency we've dealt with before," said Frances Kennedy, communications officer with the WFP, in the middle of the crisis. "We are dealing with this invisible enemy. WFP is having to do a lot of thinking, reflecting, and adjusting rather than just rolling out a well-oiled emergency response machine."

In August, as efforts to learn and adapt were beginning to get under way, another challenge—hunger—began to emerge. Food costs consumed more than 75% of many Liberians' family budget. As the government began to quarantine affected communities, farmers in some parts of the country no longer could reach their fields, and villagers could not travel to markets. Food became less available, causing prices to rise just as incomes were diminishing. In some markets in Monrovia, the price of cassava, a staple, rose 150% in the first weeks

of August. On average, for the period that ended in mid-October—with higher spikes in a few areas—food prices rose about 24% in the three countries most affected by Ebola.

The logistics teams had to find ways to deliver food as well as medical supplies—and to meet the needs not only of patients at treatment centers but also of residents of communities under quarantine. Food distribution during crises was the WFP's specialty, and the organization had delivered food in Liberia before the Ebola outbreak. But getting rice, beans, cooking oil, and other staples to people during an infectious-disease outbreak required new ways of working.

Samuel Terefe, the logistics cluster coordinator who succeeded Aynes at WFP-Liberia, worked with the government's General Services Agency and partners—including the Liberian Red Cross—to deliver family ration packs of rice, split peas, and cooking oil. To ensure safety, they decided to allow only small numbers of people to assemble at a time and to require that people leave at least four feet of space between one another. The people delivering the ration packs and other supplies wore protective suits.

The first quarantines limited the movement of people out of Ebola-affected communities to other locations for the 21-day incubation period of the disease. In consultation with the local paramount chief, village chief, and elders—and on the advice of the health officers—the county-level Ebola task force could close markets and set up checkpoints on any access roads and river crossings to keep people from leaving or entering. Because of the impact on livelihoods, county officials sometimes modified the rules to allow limited access to farms and fishing areas. Health workers visited to provide care. County officials promised food, but typically, it took a week to 10 days to get rations and hygiene kits to affected households or communities—at least outside the capital.

Finding a workable system intensified later. On August 20, with clinics and hospitals closed or at capacity and with dying or dead patients lying on their doorsteps, the government imposed a quarantine on the 50,000 residents of West Point, a crowded Monrovia township that had become an Ebola hot spot. Residents resisted and violence flared as people worried they risked infection and would be unable to feed their families.

The clashes at West Point forced a change in policy. On September 8, the government ended most community quarantines and instead encouraged voluntary home isolation. The Monrovia Incident Management System asked people potentially exposed to the virus to remain in their houses for 21 days, and in return, response teams would provide their families with food and water and supplies like chlorinated water. At least that was the idea.

The shift in strategy created new logistical challenges, however. It required the identification of specific people exposed to the disease, drawing on contact-tracing data. It introduced many more delivery points, whose locations were constantly changing. Therefore, it was hard to improve over time because delivery staff could never get used to their routes or select the most-efficient

means to reach the people they served. It also caused new problems when people not identified as candidates for quarantine also demanded food.

The Montserrado County Incident Management System set up a process for linking quarantined households to food deliveries. A case investigator, a contact tracer, and a social worker together visited each household where there was suspected exposure. If the investigator determined that an ill family member possibly or probably had the disease, the contact tracer began a conversation to identify other people who had been exposed, and the team left a two-day emergency supply of food after all three team members signed off. Back at headquarters, the names were cross-referenced with existing lists and placed on a food distribution roster. When the food was ready, a community leader, a logistics task force representative (or county task force representative), and a contact tracer all had to be present—in order to verify distribution—before transfer to the household could take place.

The teams often improvised. Sometimes neighboring households also asked for food, hit hard by price increases or lack of income or the stigma of living near someone with the disease. The best solution was sometimes just to treat them as affected households and provide the support—sometimes covering the cost out of pocket—in order to ensure the quarantine would be effective and they could continue to visit to manage cases. The diet was also fairly relentless: rice, oil, split peas. Team members sometimes used their own time and money to visit markets and bring back fresh vegetables for the families to eat.

Quarantine at home also threatened to increase the risk of Ebola transmission among members of a household and increased the need for home delivery of hygiene supplies. MSF anticipated the problem and developed a disinfection kit containing basic items like chlorine, buckets, and gloves specially intended for home use. It chartered two cargo aircraft to fly these items weekly to the Ebola-affected region, including Liberia, from September to December, said Dupont, the MSF supply officer. During 2014, the organization provided 70,000 home protection and disinfection kits for Monrovia alone—enough to protect 600,000 people. USAID, UNICEF, and WHO delivered similar hygiene kits through logistics cluster common services.

ASSESSING RESULTS

During 2014, the peak of the outbreak in Liberia, the Logistics Cluster transported 28,900 cubic meters (1 million cubic feet, or enough to fill about 11 Olympic-size swimming pools) of cargo on behalf of the Ebola response in the three affected countries. It stored 38,900 cubic meters (1.4 million cubic feet) of cargo, established a main warehouse hub in each country and 11 forward logistics bases, imported 179 mobile storage units, and introduced a Relief Item Tracking tool to help trace items shipped to the region. But those numbers understated the total amount of matériel transported and stored, because not all cargo flowed through the cluster during that period; much of it came through private chartered planes and through the US military, for example.

Officials at the IMS, WFP, and several organizations present before and after coordination reforms all reported improved supply delivery during September, October, and November 2014. How much of the gain in efficiency and effectiveness flowed from improvements in supply chain management and how much from the slowing of the epidemic and better data were unclear, however. It took a long time to put all the elements of the supply chain in place. The main logistics base was not fully operational until December 2014, and county storage space was not fully rolled out until February of the following year—well past the peak of the Ebola epidemic.

Whether the driver was lower demand or the new systems, it gradually became easier to achieve the six logistics "rights": the right goods, in the right quantities, in the right condition, to the right place, at the right time, for the right cost.

WFP-Liberia logistics coordinator Terefe said the total time between a partner's request for supplies and delivery decreased, according to WFP's inventory software. Terefe attributed the improvement to staff members' becoming more comfortable with their roles over time and to changes in structure and processes. However, those improvements were unevenly distributed; the length of time required to move matériel from main warehouses to the county logistics bases remained roughly the same, suggesting that the gains in speed happened mainly in importing and unloading.

In terms of broader outcomes, the results were less happy. Most of the specialized Ebola treatment and isolation centers, including the Monrovia Medical Unit designated to provide care for health workers, opened their doors three months after the response started in earnest—in early August—and infection rates had fallen by that time. Some of the treatment units went unused as a result of (1) actions taken by Liberian citizens to protect themselves, which caused infection rates to drop, and (2) the delays in construction, which were linked partly to supply problems but also attributable to personnel systems, weather problems, and other factors.

Increased supply delivery and training gradually enabled many closed government health facilities to reopen their doors for essential services. In mid October, the John F. Kennedy Memorial Medical Center in Monrovia resumed operation, beginning with its maternity clinic, and others followed suit during succeeding weeks and months. Redemption Hospital was back in operation in early 2015, newly provisioned with equipment to protect its workers.

As of July 25, 2015, the UN said that Liberia had pre-positioned enough supplies and related equipment to provision 16 rapid-response facilities that could curtail new Ebola outbreaks before they grew unmanageable.

NEXT STEPS

"Preparation is the key," said Robert Morris, who helped oversee operations at Roberts International Airport. "In times of peace, prepare for war. The better

prepared you are, the more in shape you are, the less likely things will pull and break when you need them."

At the January 2015 World Economic Forum, the president of the World Bank and leaders of private companies challenged the international community to continue the search for solutions. The WFP, the World Bank, governments, pharmaceutical supply associations such as the Partnership for Quality Medical Donations, and corporate leaders such as Stanley Bergman, chief executive of Henry Schein, Inc., championed the cause.

The paramount question was what specific steps should be taken to improve supply chain efficiency and effectiveness in response to a similar crisis in the future.

EPILOGUE

Almost as soon as the international response began, the search for innovations that might speed up future responses to similar crises started. Attention focused on developing protocols and divisions of labor in advance, devising stronger financial guarantees for manufacturers, developing a virtual supply chain system to identify and pre-position critical supplies, loosening donor restrictions that impeded a rapid response or the flexible use of materials, harmonizing import rules, and strengthening systems within vulnerable countries.

1.   During the crisis, it was hard to think and to take time to identify best practices. For that reason, Jallah suggested that the Liberian government, perhaps in consultation with others, create a general emergency response framework that could facilitate supply operations for all partners involved when a crisis erupted. Specific directives on how to manage personnel, supplies, transportation, and finances in a crisis could save vast amounts of time. Jallah said he regretted that such a framework was not under development as of late 2015 and that talk about it had subsided.

The private pharmaceutical and medical supply companies concurred. Speaking for her members at the Partnership for Quality Medical Donations, Executive Director Elizabeth Ashbourne said: "We can propose and provide the best system in the world, but if a country doesn't have the capacity to know what it needs or how to use the products, that's a problem. We need to have a structure on the ground for the contributions to be useful."

2.   MSF and WHO identified the procurement of sufficient protective equipment as the biggest supply bottleneck during the response. Had case numbers not collapsed in the fall of 2014, said Dupont and his boss Stefaan Phlips, the stock that MSF had available would have met the organization's own needs but could not have covered all of the demand the CDC epidemiological model forecast.

At MSF, Dupont reflected on how to structure a financial guarantee for manufacturers so they could expand production of essential supplies regardless of the risk that changing disease patterns might pose. Pooling resources in a humanitarian bank could increase financial guarantees to manufacturers, which might be afraid of making financial commitments when projected demand might not materialize.

3.   Financial guarantees represented only part of the likely solution. Wolfgang Herbinger, former worldwide director of logistics at WFP headquarters in Rome, launched a public–private initiative for a Global Supply Chain for Pandemic Preparedness and Response, focused on countries with weak health systems or weak logistical capacities. Herbinger and his colleagues began to examine how to hasten response times from the international community whether by pre-positioning selected items or by establishing relationships that would lessen reaction time.

WFP worked closely with an American team led by Amy Kircher of the Food Protection and Defense Institute, a research group at the University of Minnesota, to develop a virtual supply chain system. To strengthen collaboration and enable information sharing between manufacturers, retailers, and government, Kirchner's team modified a software platform originally developed for managing problems in food distribution systems. When triggered by indicators of a potential outbreak, partners could enter information into the shared platform, including their stock of needed supplies. Such a step would speed response.

Simply identifying manufacturers in advance also could help. At WFP, Herbinger's team, working closely with WHO, worked to develop a supply chain information platform, map commercial production capacities and supply routes, and explore the terms required to create a strategic reserve, among other things. They identified more than 60 critical supplies needed to respond to potential pandemics and listed the companies that produced them. Then the team began to map a way to activate production and delivery efficiently.

4.   David Kochman at Henry Schein, Inc., one of the world's largest medical supplies distributors, said customs control issues required more attention not just in the main Ebola-affected region but also globally. At the time, his company, which was known for its corporate social responsibility efforts, worked in 21 countries. It had responded to a CDC request for gloves, masks, and gowns as well as other equipment in September–October 2014, quickly raised $1 million with its supplier-partners, and sent the needed items. The shipment went smoothly, but Kochman said such was not always the case. "A lot of the time we can get stuff there, but we can't get it off the ship. It's a kind of last-mile piece."

Suppliers noted continual customs issues and delays in Sierra Leone. In Liberia and Guinea, it had proved easier to move materials through ports and customs.

Harmonizing import rules and procedures for clearing medical shipments during outbreaks was one possibility, along with rules that—to reduce diversion—permitted shippers to put cargoes directly into the hands of responding NGOs or agencies. The World Bank began to spearhead an effort to address those issues, and the Bill & Melinda Gates Foundation, which had earlier supported supply chain innovation for vaccine delivery and other needs, such as delivery of HIV antiretrovirals, also became engaged in the conversations.[27]

5.   Speeding financial support for responding organizations and reducing restrictions on the uses of money were other high priorities. UN organizations and NGOs usually had to raise cash through emergency appeals. So did the governments of affected countries. But because some contributors failed to make good on their pledges or failed to do so quickly, mobilization of commitments was difficult and disease control efforts often got delayed.

The World Bank began to work on an emergency pandemic financing facility to help ease the financing problem. Herbinger of the WFP said the aim was "to have money available for governments, but also . . . for international organizations such as WFP, WHO, UNICEF, and MSF to quickly respond." Instead of having to call for donations, the proposed facility would use a combination of public and private funds to provide support for UN agencies, nongovernmental organizations, multilateral banks, and countries to help defray the costs of low-frequency, high-severity outbreaks.

Jallah and Nyenswah also underscored the need for a better balance between accountability and flexibility, because donor restrictions on where and how responders could use supplies often complicated the effort to respond to the most-urgent priorities. Often, by the time supplies arrived, the context had changed, yet restrictions meant the supplies could not be deployed elsewhere. To illustrate, Jallah said: "The bulk of the supplies we had were [from] the US government. And when the Congress approved those funds, they approved them for Liberia . . . They had a nationality stamp on them." The problem was that if new infections appeared just across the border in Guinea, within the same remote region as the villages for which a shipment was originally destined, the Liberian government or NGOs could not use the supplies to respond. As a result, the risk of rekindling the epidemic grew. "Even though we had Ebola supplies that could go into the forest region to save human lives, we couldn't move them because they were tagged 'Liberia,' and there was some imaginary thing that colonialists placed here that they call a border that we couldn't go across."

Jallah suggested that supplies be tagged to an affected *region* instead, so they could be reallocated depending on rapidly changing needs—especially for something as volatile as an infectious-disease epidemic.

6.   Promoting logistics capacity (resilience) in affected countries was a sixth focal point. Nyenswah lamented that donor restrictions limited funding to emergency measures that were usually temporary—thereby undermining the

capacity building that promoted resilience. "The [WFP] forward logistics bases were not permanent," he said. "So it means we don't have a permanent solution." In December 2015, WFP operations—but not facilities—were scheduled to transition to the Liberian General Services Agency.
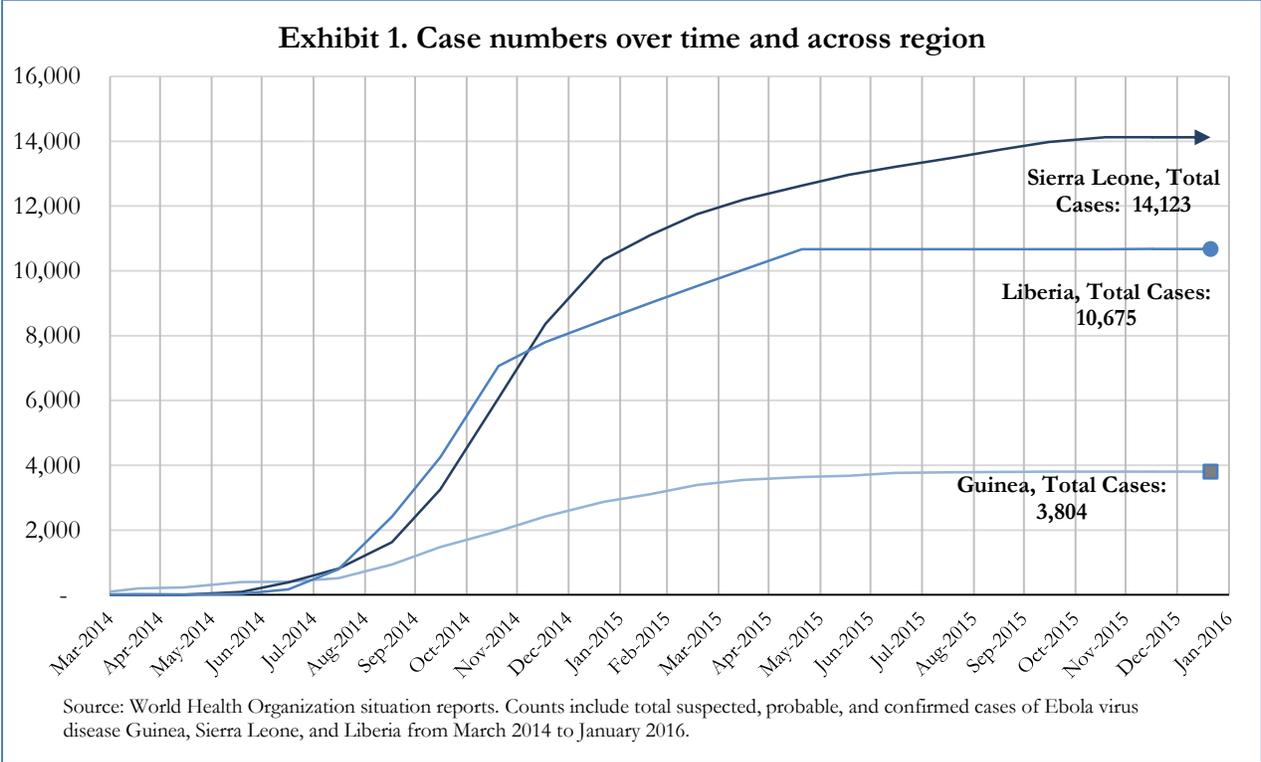
Although Liberia already had talented logisticians, some of whom had benefited from partnership with John Snow, Inc., in previous years, it was important to mainstream supply chain management into the curriculum of Liberia's public health programs. Without those skills, leaving behind infrastructure would yield little improvement.

Nahid Bhadelia, MD, an infectious-disease physician, scholar, and former CDC and WHO consultant, noted that after Liberia was declared free of Ebola in mid January 2016, "the systemic weaknesses in public health infrastructure that allowed the virus to spread like wildfire still exist. If we were able to stop this epidemic, it was not because we rebuilt the public health systems in West Africa but because massive resources were poured into immediate response and heightened surveillance."

"We missed out on absorbing as much as we could for resilience. And if we could do it again, I would plan that better," Jallah said. "We would match a young local person with each international person, so that afterward there would be some level of knowledge transfer and some experience so that if it were to happen again . . . [but] we missed out on that completely. We still need that even in our peacetime development work, and we just don't have it." As the outbreak subsided, leaders of the responding organizations began to think about how to improve responses to similar crises in the future.

7. Technological advances could also help. United Parcel Service had started to experiment with drones that have cold-storage capacity and could deliver blood and other temperature-sensitive supplies to remote areas in Rwanda. Although most aspects of the Ebola response, except vaccines, did not require maintenance of a cold chain, the use of drones held some promise for selected supply deliveries in very remote areas.

EXHIBITS

Exhibit 1. Case numbers over time and across region

Sierra Leone, Total Cases: 14,123

Liberia, Total Cases: 10,675

Guinea, Total Cases: 3,804

Source: World Health Organization situation reports. Counts include total suspected, probable, and confirmed cases of Ebola virus disease Guinea, Sierra Leone, and Liberia from March 2014 to January 2016.

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