02 SPRING 2014

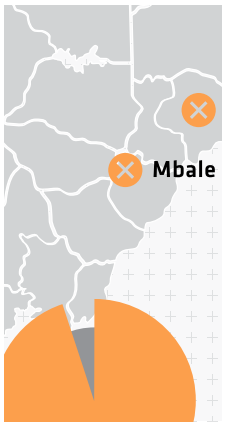
DEM+ND

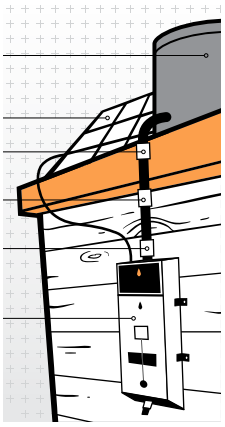
ASME GLOBAL DEVELOPMENT REVIEW

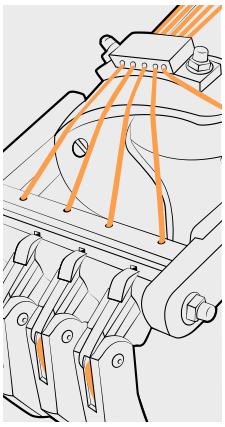
THE POWER OF FEEDBACK Successful design relies on listening to—and acting on—the insights of product users. But integrating feedback is not always simple. Engineers working on a medical device in Uganda devised a new way to co-create and make a traditional initiation rite safer. Page 2

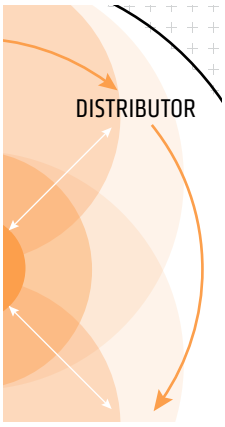
DEM+ND

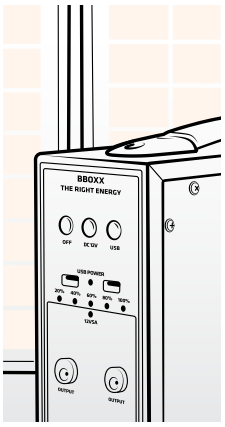
ASME GLOBAL DEVELOPMENT REVIEW











ABOUT DEMAND: DEMAND was launched by ASME in collaboration with *Mechanical Engineering* magazine and reporting from Engineering for Change to help meet the needs of individuals and organizations working at the intersection of technology and global development. All the case studies in this publication undergo significant review both by an independent editorial review board and by ASME editors. Our goal is to deliver high-quality, accessible and timely information.

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FROM THE EDITORS

WHAT LEADS TO THE SUCCESS of a technology intended for resource-constrained environments? Is there a secret recipe that some organizations have figured out? Practitioners working in the field tell us that if you don't have unlimited funding—and who does?—then robust feedback loops are key to the adoption and diffusion of products intended to lift people out of poverty.

In this issue of DEMAND we present a collection of case studies demonstrating the impact of feedback on the design, implementation and operation of products and services. The authors featured in this issue faced diverse challenges that highlight the need for accurate feedback loops. In the case of the non-profit product development company D-Rev, for example, feedback served as the prime assessment tool for the new model of their prosthetic knee. Sarvajal, a company focused on market-based models for providing clean drinking water, needed feedback as it struggled with kinks related to franchising clean water delivery in rural India. A continent away in East Africa, social enterprise BBOXX needed to ensure that their solar home system kits were performing as expected and minimizing usage barriers for remote off-grid communities. And researchers from the University of Michigan needed a methodology to systematically integrate user feedback to improve traditional circumcision outcomes for communities in Uganda.

These case studies cover a range of subjects, but the unifying thread is the unique viewpoint—an engineering perspective—for solving quality of life challenges of disadvantaged communities. We challenged the authors to demonstrate the application of engineering means and methods while capturing key "a-ha" moments in the field. We've done the same for ourselves with our feature article on the nuances of supply-chain economics in the delivery of extremely affordable products. The complexity of engineering for global development was evident in each interview, however what is pronounced is the pioneering approaches and user-focused thinking of these social innovators. Our hope is that their stories will inspire the greater engineering community to challenge the status quo and co-create solutions with social benefit.

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ASME GLOBAL DEVELOPMENT REVIEW + ISSUE 02

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DEMAND is supported by the ASME Foundation and produced in collaboration with *Mechanical Engineering* magazine.

ASME (founded as the American Society of Mechanical Engineers) promotes the art, science & practice of multidisciplinary engineering and allied sciences around the globe.

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CASE STUDY

DESIGN ETHNOGRAPHY AS AN ENGINEERING TOOL

01

Currently the design, development, and implementation of medical devices insufficiently address health care needs in low-resource settings. Most existing medical devices are simple adaptations of devices designed for high-resource settings. However, the spectrum of needs in low-resource settings is often beyond the scope of such simple adaptations, resulting in products with limited impact.

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UGANDA

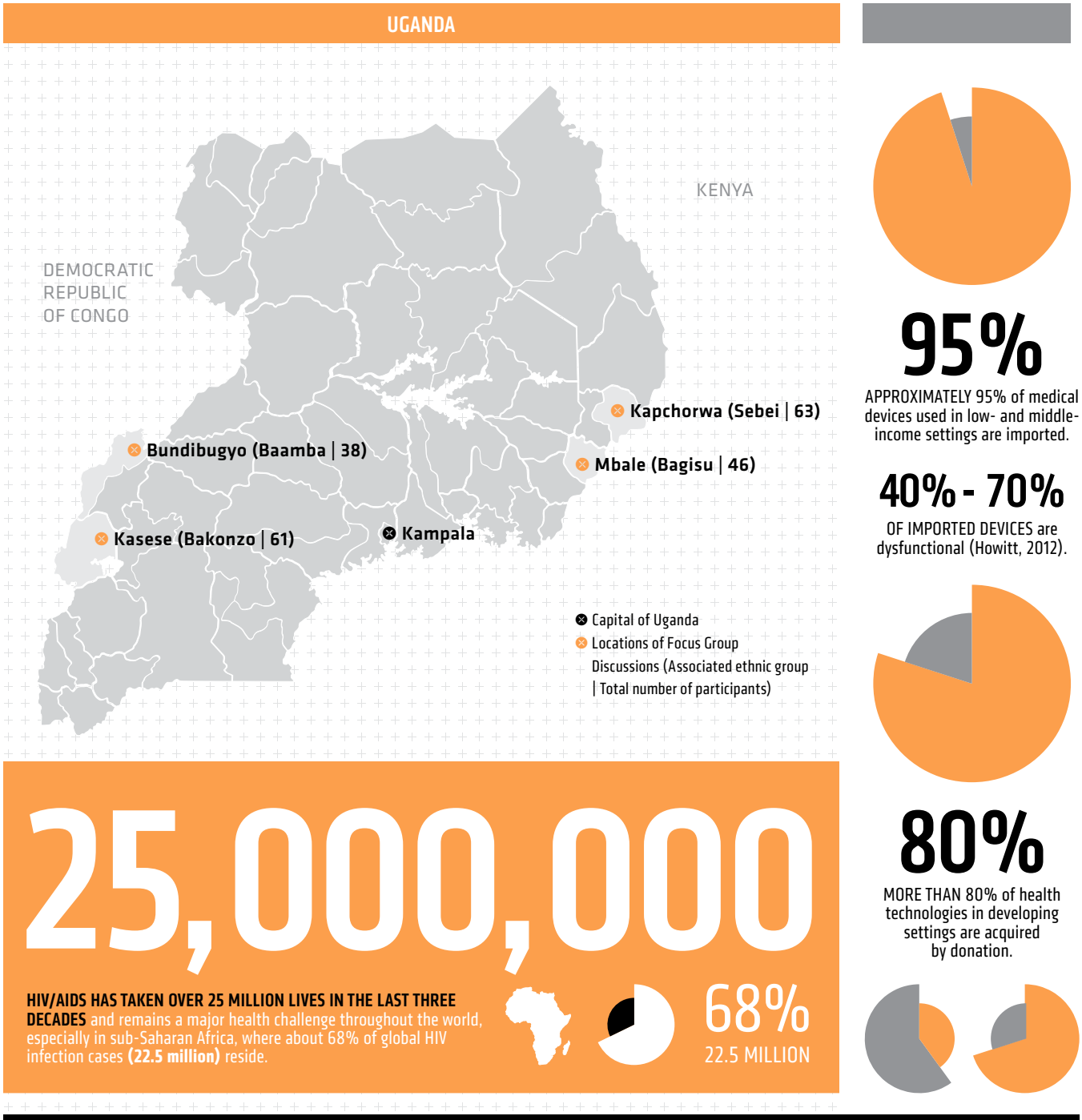
To develop medical devices that address the complex challenges of global health, we have studied how conventional engineering design processes can be supplemented by methods derived from social science fields such as anthropology. Design ethnography, which encompasses processes for gaining a complete understanding of stakeholders' actions, behaviors, words, and thoughts, provides a framework for acquiring tacit information from stakeholders that would not be obtained through commonly used methodologies in engineering design and market research. ¶ Although this technique is applicable to a broad range of global health technologies, we chose to highlight its application to traditional adult male circumcision given the unique design context and constraints. This study, among others performed to date, indicates the need for engineers to understand the broader context in which a medical device will be used, as well as the need for global health design decision-making processes based on rigorous studies that generate quantitative outcomes rather than anecdotal evidence.

Male circumcision is a culturally significant procedure in many parts of the world. For instance, traditional adult male circumcision (TMC) is an important cultural practice in parts of sub-Saharan Africa, and a rite of passage for boys between the ages of 10 and 18.

Recently, several randomized clinical trials have shown that clinical adult male circumcision is an effective medical intervention for the prevention of sexually transmitted HIV, reducing the rate of transmission by 60 percent among heterosexual men [2, 3, 4]. This is an important result for sub-Saharan Africa, where more than two-thirds of the 22.5 million people in the world living with HIV reside [1].

Traditional adult male circumcision is not without risks. Cutters and their assistants, typically with limited or no formal clinical training, perform TMC in non-clinical settings. While evidence supports TMC's effectiveness against HIV transmission when adequate foreskin is removed, rates of life-threatening risks and health complications for this practice are as high as 48 percent [5]. Infection, delayed wound healing, glans amputation and injury, bleeding, loss of penile sensitivity, excessive removal of foreskin, and even death are the major complications reported [6].

There are medical devices that accommodate clinical adult male circumcision (AMC), but none of them are suitable for TMC due



The African context: HIV/AIDS rates, medical devices and region of investigation

to their cultural inappropriateness, high cost, and complexity.

Based on a conversation with Family Health International 360's (FHI 360) Dr. David Sokal, with whom we partnered on this project, we raised the following questions: Was there a need for a culturally appropriate device to improve the likelihood of a safe outcome during traditional adult male circumcision? If a solution was identified, would it be accepted? What is the process associated with designing such a device, given that we have no firsthand experience with the procedure or context?

Since funding wasn't initially available to tackle these questions through field-based studies, the project was offered to a team of undergraduate students within a section of the University of Michigan's Department of Mechanical Engineering Capstone Design and Manufacturing course during the Winter 2009 semester. The students assigned to the unusual project—the course had never seen the likes of such a topic before—began work in a similar way to other academic design projects. They consulted the literature and interviewed clinical experts. We were surprised at the lack of data on traditional circumcision practice, which made the design of such a device extremely challenging. By

the end of the course, the students had generated a preliminary list of user requirements and associated engineering specifications, a concept solution and physical prototype, and preliminary validation results that enabled us to apply for external funding.

After applying for funding and receiving a Gates Grand Challenges Explorations Grant, we formed a multidisciplinary team that included engineers, clinicians, sociologists, and public health and business experts to further pursue the design. The funding enabled additional engineering analyses on the original prototype developed by the student design team, including fit and grip studies performed on cadavers at the University of Michigan's Anatomical Lab. Qualitative and quantitative measures were used in cadaver studies to assess the time required to apply and remove the device, the ease of application, the degree of glans protection, and the length of foreskin cut.

Most importantly, to gain much needed insight, we conducted fieldwork in Uganda, because of the country's multiple ethnic groups known to practice TMC, and because FHI 360 had a field office there with established relationships with the ethnic groups. In Uganda, as in many other sub-Saharan African countries, TMC has been practiced for centuries, particularly as an initiation ritual and rite of passage into manhood. Uganda's HIV prevalence rate is 6.5 percent, and approximately 10 percent (3.5 million) of the population belongs to ethnic groups that practice TMC [7].

DESIGN ETHNOGRAPHY AS A GUIDING COMPASS

The prototype for the first functional TMC device satisfied the initial requirements established during the design course [8]. We had, however, many reservations regarding the validity of the device, given that there were no publicly available data detailing TMC practices in sub-Saharan Africa at the time. We also had no sense for local perceptions of such a device. Would anyone consider using it? Could it possibly be adopted into the practices of any of the ethnic groups?

> Design ethnography provides a framework for acquiring tacit information from stakeholders, which would not be obtained through commonly used methodologies in engineering design and market research.

It was obvious that stakeholder input was required to establish the need for such an intervention and to generate the data necessary for informing key design decisions. With the input of social scientists skilled in qualitative research, we used principles of design ethnography that focus on the broad patterns of daily life that pertain to the conception, development, and implementation of new products in a given society. Design ethnography, which encompasses processes for gaining a complete understanding of stakeholders' actions, behaviors, words, and thoughts, provides a framework for acquiring tacit information from stakeholders that would not be obtained through commonly used methodologies in engineering design and market research [9].

We traveled to Uganda in 2010 to learn about the cultural implications of TMC and generate data needed to refine and justify our design decisions [11]. Together with FHI 360, we identified major stakeholders and planned for semi-structured focus group discussions (FGD) and interviews. We also planned for direct observation of TMC and contextual inquiry about the practice.

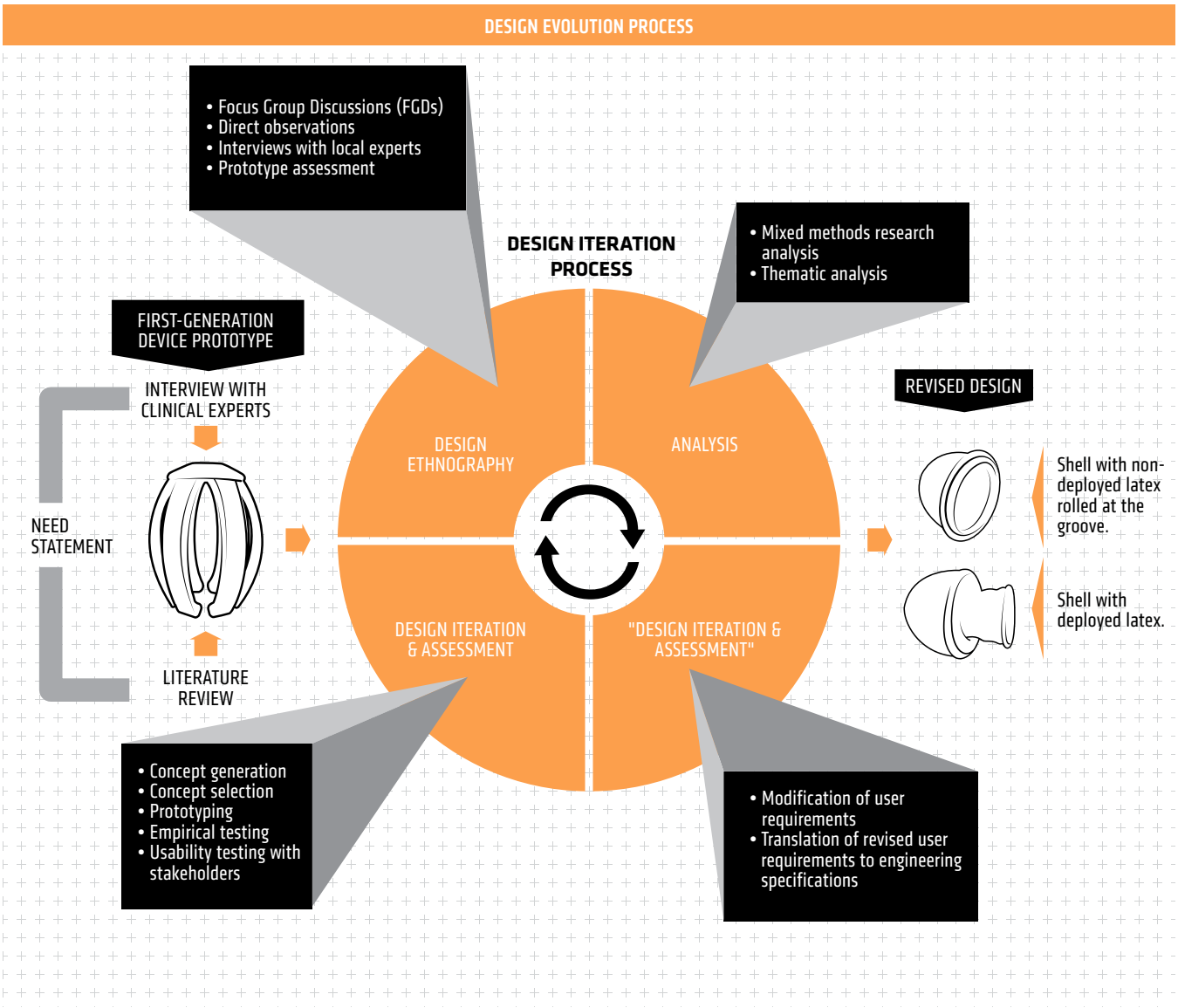
Stakeholders that we engaged with at this stage of the project included clan and cultural leaders, traditional cutters, assistant cutters, public health officials, and staff of international and national organizations promoting and implementing clinical male circumcision.

We conducted 10 interviews with various experts during this initial visit, and held 12 FGDs with about 100 participants with the four ethnic groups that practice TMC in Uganda—the Sebei, Bagisu, Baamba, and Bakonzo. While the circumcision rate in Baamba and Bakonzo men is unknown, it is estimated that 80 percent of Sebei and Bagisu men are circumcised.

Each FGD consisted of 6 to 12 participants and was run by trained American and Ugandan study team members, who remained the same across the focus groups, with the assistance of translators, who varied. Predetermined themes, such as TMC's cultural importance, logistics of the practice, cutters' training procedures, and tools used during TMC were selected prior to holding the FGDs.

The FGDs were recorded, and we transcribed all the files verbatim and cross-checked the transcription results with research assistants to ensure accuracy. Transcripts were reviewed, and reoccurring themes based on the five topics were identified to develop a codebook. After an in-depth review of the transcriptions and cross-analyses of the four ethnic groups and different participants, additional codes were derived for further characterization. Hence our codebook, which was initially based on predetermined codes, evolved through an iterative process with the emergence of new information, which was either unique to a given ethnic group or common across all groups.

The focus group participants agreed that TMC is a major milestone in the process of becoming a man among the different ethnic groups. It is a traditional part of the cultural belief system to such an extent that those who are not circumcised traditionally are strongly stigmatized within their communities. Participants in all of the FGDs and medical doctors identified the most common TMC adverse events: excessive bleeding, prolonged wound healing, infection,



glans injury and amputation, and unfinished cuts requiring additional cuts.

In order to design a device that could accommodate all the ethnic groups practicing TMC, we needed to understand their cutting styles. While there is no single style practiced among the four groups, the majority of cutters in the Sebei and Bagisu groups share a similar method. A candidate for circumcision is called to the center of the area designated for the ceremony. The boy holds his hands up as the cutter removes his clothing to expose the penile shaft. The cutter pushes the glans inside and pulls the foreskin forward as hard as possible three to four times. While pulling the foreskin, he places his thumbnail where he can feel the glans. He uses his nail to mark where the glans ends and to protect it against the cut. While the foreskin is pulled, the cutter uses a traditional knife to cut through it. After the first cut, the assistant cutter holds the glans as the cutter removes the remaining foreskin through a radial cut using the same knife.

Cutters do not dress the wound with any medical supplies, but use herbs, clay and other products.

There have been some important recent changes and modifications to the TMC practices. Most significantly, while custom, ritual and cutting methods vary by ethnic group, the Uganda Ministry of Health mandated the use of one traditional knife or razor blade per candidate during circumcision. The change was implemented in early 2000 across all ethnic groups. Eastern groups still use a traditional

knife while the Baamba and Bakonzo groups use razor blades.

At the end of each FGD, we showed the participants the original TMC design to stimulate discussion among the stakeholders. Three out of four ethnic groups expressed without hesitation that they would be willing to use the device as soon as it is provided to them. They did, however, provide numerous suggestions to improve the design's form and function.

ORIGINAL REQUIREMENTS	ORIGINAL ENGINEERING SPECIFICATIONS	REVISED USER REQUIREMENTS	REVISED ENGINEERING SPECIFICATIONS
1. Fast cut	120 sec	1. Fast cut	Cutting time < 10 sec
2. No. of procedural steps	10	2. Safe cut	Full (100%) glans protection
3. No. of parts	3	3. Strong grip	No displacement while cutting
4. Adjustable diameter	15-41 mm	4. Low cost	Final cost < $1.00
5. Glans coverage	50%	5. Three sizes	Small (2.5 cm), Medium (3.0 cm), Large (3.5 cm)

Original and revised lists of user requirements and engineering specifications

DESIGN INFORMED BY ETHNOGRAPHIC RESEARCH

Based on the data gathered during our first visit to Uganda, we revised the original list of user requirements and engineering specifications as well as their associated ranks. Three particular user requirements and associated engineering specifications are worth highlighting:

> Fast Cut: Traditional cutters and ethnic leaders unanimously expressed their desire for a quick procedure. They emphasized that cutting should not last more than 10 seconds. Reducing the cutting time requirement from the original time suggested by clinical experts consulted (three minutes) to less than 10 seconds had significant implications during the design iteration.

> Safe Cut: We knew that our device must protect the head of the glans against the circumcision cut. However, our "safe cut" specification was informed by the guidelines developed by the World Health Organization for clinical male circumcision, which specify only partial coverage of the glans since the foreskin cutting technique suggested by WHO is not consistent with the "guillotine cut" used in cultural procedures. However, after meetings with stakeholders, we realized that the device must cover the penile glans fully in order to provide complete protection against any cutting style variations.

> Device Size: The original concept assumed that a one-size-fits-all solution would be desirable. This made intuitive sense and was supported by clinical experts and available literature. However, when we presented the original concept to the stakeholders in Uganda, they unanimously expressed that they'd prefer three sizes for the device. They mentioned that this is how they were accustomed to purchasing items such as t-shirts, and that it didn't make sense to them that one device could fit the perceived range of penile sizes. This is a good illustration of the fact that a low-cost, effective device will not always be embraced by its target community. There are cultural norms that will impact the adoption and implementation of such devices.

A low-cost, effective device will not always be embraced by its target community. There are cultural norms that will impact the adoption and implementation of such devices.

Based on feedback from Ugandan ethnic groups, public health officials, and medical practitioners, as well as our cadaver testing results, we generated over 20 additional device concepts. We then fabricated prototypes of the top five concepts and performed additional experimental tests on cadavers to evaluate each prototype against the revised engineering specifications.

We selected a second-generation prototype composed of two parts: a strong solid shell that provides complete protection of the glans against the cut, and a latex sleeve that covers the shell and anchors the device to the glans (see illustration).[11] The non-deployed latex sleeve, resembling a condom in its material, shape, and usability, rolls up so that it sits on top of a groove at the end of the shell. After the shell is placed over the glans, the foreskin is retracted and the latex sleeve is deployed by rolling it over the glans until it covers the coronal sulcus. Latex was chosen as the sleeve material due to its ability to firmly grip and anchor the device to the penis while the foreskin is pulled over the shell. Also, latex provides an auto-disable-like feature for the device; as it is removed from the device by the cut, the reuse of the device would be difficult.

To increase functionality, a medical-grade elastic band, which can be applied over the foreskin and against the device's groove, helps hold the foreskin in place and provides a visual cue to guide the cutter. The applied compression to the foreskin also minimizes blood loss.

Three shell sizes were designed to accommodate adult glans diameters ranging from the 5th to the 95th percentile. Careful testing on fresh cadavers showed that this revised design provided 100 percent glans coverage during a cut, could be applied and removed in approximately five seconds, and provided excellent grip on the glans.

We returned to Uganda in 2011 with the revised design and met with the same ethnic groups with whom we had originally visited. We held 15 additional FGDs with the same stakeholder groups (the individuals differed) and interviewed over 30 leaders in circumcision policies and practices. These interactions were used to gauge community interest in the revised design among TMC practitioners and establish the extent to which Ministry of Health officials and clinical surgeons supported the design and associated procedure. To evaluate the preferences among stakeholders, we asked FGD participants to compare the original and revised prototype designs using a Likert scale.

We found that 80 percent of cutters and their assistants and 97 percent of clan leaders chose the revised device over our original design for its simplicity, ease of use, and perceived increased protection. When asked if they would use and/or support the revised device if public health officials supported its usage and the TMC cutters were properly trained, 74 percent of cutters and assistant cutters and 88 percent of clan leaders strongly agreed that they would do so.

We are currently conducting a study in Uganda to collect anthropometric data on penile sizes and evaluate the ability of the device to grip the penile glans.

UNDERSTANDING STAKEHOLDER VIEWPOINTS

The design ethnography techniques we used in our design process provided many critical insights. The techniques were key to establishing and confirming the need, which had a significant cultural load associated with it. They also helped us understand the stakeholders' viewpoints and concerns, and provided data used to generate justifiable user requirements and associated engineering specifications.

Indeed, there were no publicly accessible data available about TMC practices in Uganda and sub-Saharan Africa—at least not specifically detailed data necessary to base design decisions on. Therefore we, as engineers, needed to take the initiative to collect the data. This involved the use of both qualitative and quantitative techniques inspired by tools used by ethnographers.

The data garnered through this work would have been impossible to obtain in a conventional laboratory setting. For example, we learned that while the ethnic group participants had general knowledge about the effectiveness of AMC against HIV transmission, they preferred TMC due to cultural reasons. We found out about the potential role of churches and mosques with respect to the promotion of safe TMC and their religious leaders' interest in supporting the development of an intervention, as well as the recent formation of a "cutters union" among the Bagisu to preserve TMC's cultural significance. These data were directly used to inform the establishment of stakeholder-driven user requirements.

Design ethnography is an enabling methodology that can be can be used in product design when limited information is available.

Our experience demonstrates the value of an iterative, process-focused, design ethnography approach that actively engages stakeholders to confirm needs, drive the establishment of user requirements and engineering specifications based on rigorous studies that generate quantitative outcomes rather than anecdotal evidence, and provide continuous feedback on early stage design iterations. Design ethnography is an enabling methodology that can be can be used in product design when limited information is available. The methodology is especially useful when designing for low-resource settings, where financial, social, and cultural constraints impose challenges on designers developing affordable, accessible, available, and culturally appropriate devices.

ACKNOWLEDGEMENT

We would like to acknowledge the intellectual contributions of all individuals and organizations that assisted in this project. We also acknowledge the financial contributions of the Bill & Melinda Gates Foundation and the National Collegiate Inventors and Innovators Alliance.

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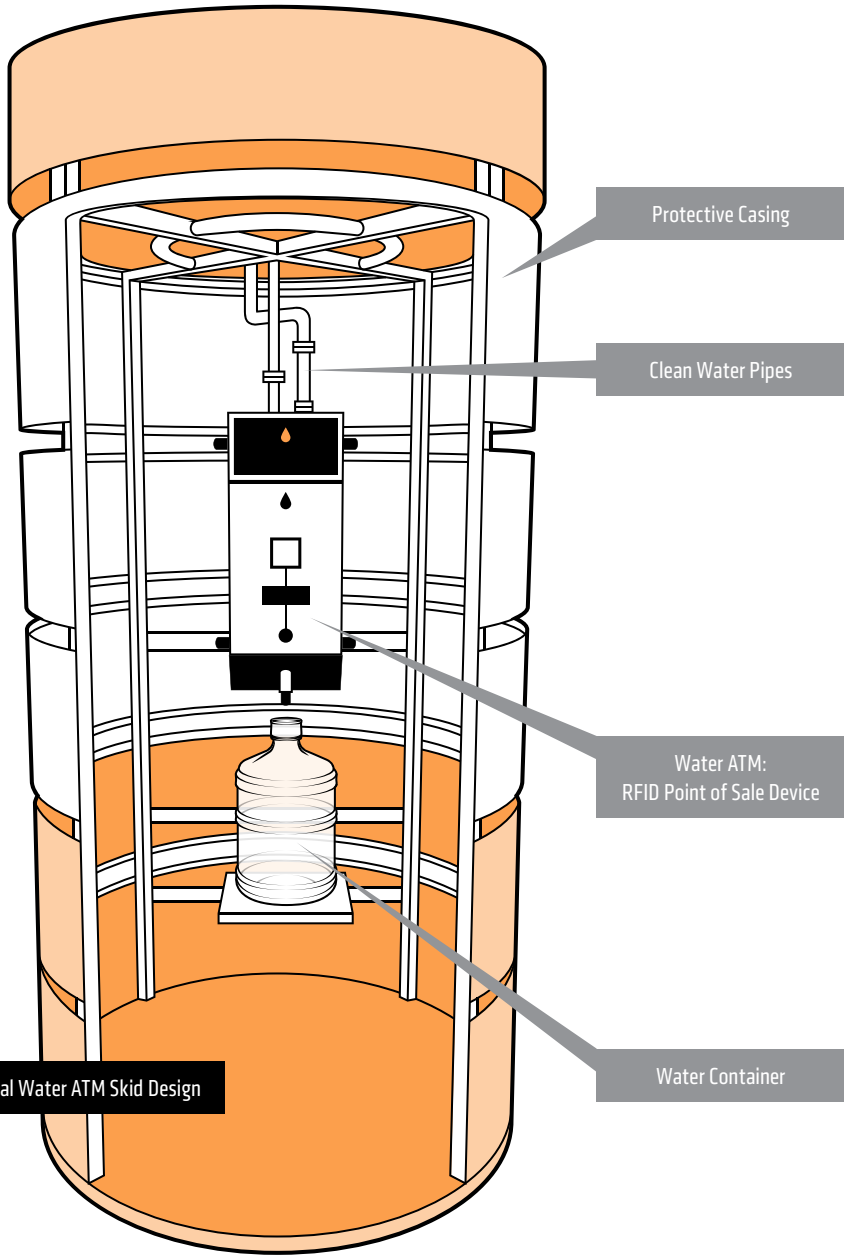
GETTING WATER TO ALL

Very little of the water distributed through conventional mains is used for drinking. By focusing on delivering only what is needed, it's possible to provide high quality water to some of India's poorest people.



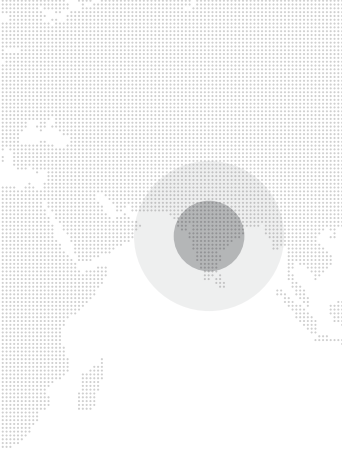
Sarvajal Water ATM Skid Design

02

PRIYANKA CHOPRA served as the CTO of Sarvajal, overseeing product development of the water ATM, the cloud-based management system, and additional responsibility over finance. Prior to joining Sarvajal, Chopra was a senior consultant with IBM's Internal Strategy Group.

ANAND SHAH is the founder of Sarvajal, a cleantech venture focused on providing clean water to villages and urban settlements. Shah was also the founding CEO of the Piramal.

INDIA



In developed regions like the United States and Europe, vast amounts of clean water get to millions of households every single minute of every day. Making this happen is a mundane yet critical engineering task. Water needs to be brought from a sometimes-distant source, a relatively constant positive pressure has to be maintained either via gravity or an intricate network of pumps, and a network of pipes must be extended to pretty much every single street in modern society as a municipal service. Designed during times of abundance, this system has remained virtually unchanged for the better part of the last 75 years.

India, like most developing countries, does not have reliable water systems, and as a result is vulnerable to water-borne diseases. Half a million Indians die from diarrhea each year, and many of those deaths would be prevented by access to clean drinking water. Household water treatment could reduce India's diarrhea-related mortality figure by 39 percent, yet two-thirds of Indian households do not treat their drinking water.

In India the prevailing policy is to follow the lead of developed countries and build a piped grid that provides each household with 24-hour drinkable water on tap. But this expectation of infrastructure is unrealistic for emerging markets and is unsustainable globally. Piped water remains elusive even in cities, as poorly maintained pipes and pilferage leads to large losses in supply, and shortages lead to restricting supply to a few hours a day, leading to a booming demand for groundwater supplied in tankers that lowers the groundwater table. Indeed, the cost of laying such a water grid is so expensive that many western countries are unwilling or unable to proactively repair their own aging infrastructure.

But not every drop of water coming out of a pipe needs to be drinkable. Of the 135 liters of water per person per day recommended by the Bureau of Indian Standards, only 10 liters is needed for drinking and cooking—one-third of the amount allocated to flushing toilets. Why should we spend all of our effort cleaning 135 liters of water in an attempt to ensure that 7 percent of it is actually potable?

Sarvajal has approached the problem of providing potable water from a novel direction. Instead of looking at water through the utility model and try to solve the intricate infrastructure problems inherent in that model, we decided to sell water as a service. This approach has decided advantages, but comes with its own set of technical and human-centered design challenges.

WATER AS A SERVICE

Organizations working in the water sector—such as Water Health International, the Naandi Foundation, and Safe Water Network—find it financially untenable to pay for the capital expenditures of water filtration equipment and buildings in which to house the equipment. Instead, they receive money from the government at the time of installation. There is little incentive for them to improve machinery or the process of getting potable water to the last mile. The result is a model that depends on the whim of government to find scale, with a cost structure that is increasingly obsolete because of the lack of flexibility inherent in such a model.

Although water from the municipal drinking supplies in India is generally untrustworthy, wealthy households are able to obtain clean water. They split their water supplies by installing point-of-use filtration systems to extract drinking water from the piped supply that they use for everything else.

Could a similar split model work for poor Indians as well? That was the question that led us to start Sarvajal, a for-profit business that gets its name from the Sanskrit word meaning "water for all."

WHY THINK BEYOND THE WATER GRID?

- In a centralized grid, failure and contamination impacts everything downstream.
- Most water that people take out of pipes does not need to be of drinking water quality.
- If water pressure is not consistently maintained, the negative pressure in empty pipes sucks in contaminants from the environment.
- Any failure creates distrust across customers of the entire system even if it is working.
- In countries developing quickly, roads and pipes are dug up almost daily as part of the growth story, and hardly ever put back correctly.

We based the Sarvajal business model on several underlying hypotheses and intentions: We wouldn't sell water but instead sell a service to clean local water. Instead of a network of pipes, our "grid" would take the form of above-ground kiosks within villages where water could be available in 20-liter reusable containers. We also decided to keep the price of water below every alternative option, including point-of-use filters. We initially set a price of 25 paise or $0.005 USD per liter (now 30 paise) of reverse-osmosis treated water in rural Rajasthan, cheaper than the per-liter total cost of ownership of the cheapest bacteriological home filter on the market.

As we developed our business model, the challenges at first seemed to be about operations, supply chain, and collections. But as we refined our focus to one basic question—Could we imagine a solution to ensure people at the last mile get water that is safe to drink in a way that works for them?—we

realized that this was actually a technical and human-centered design challenge that presented an incredible opportunity for us to innovate.

For instance, people in India are not accustomed to paying for water. Even if they are willing to pay, cash collection is an incredibly expensive task in villages that are far apart. And, even if you could get the cash, a distant company selling a locally available natural resource is simply untenable.

Our solution was that local water should be treated and consumed locally. Villagers would buy the Sarvajal service from a local franchise, not directly from Sarvajal. And, to best support a franchisee model, the technology needed to be a turnkey solution.

We had early success. Of the communities in the Shekhawati region of Rajasthan where we first began our operations, roughly 20 percent of households started buying from Sarvajal within weeks. Franchisees started making money.

But we ran into problems. Water had to be available as we promised—daily and dependably—and we quickly learned that it is an unimaginably difficult task to keep hundreds of complex machines running in dispersed villages with unskilled operators, unreliable electricity, intermittent mobile phone service, with franchisees who are likely to blame you for any and every failure. Although our business was fundamentally hardware, the challenges of distributed infrastructure for water in India began to seem a lot like the challenges of distributed infrastructure in information technology.

To live up to our promise of water for all, we had to think through major technical and engineering challenges. Those challenges ranged from industrial design to thermal management to sensors barraged by power outages, operator error, and people trying to game the system, while at the same time keeping a tight rein on our costs. Frugal innovation was the only way we could fulfill our fundamental promise of affordable clean drinking water to our customers.

OUT OF THE BOX SOLUTIONS

When we started Sarvajal six years ago, we knew very little about water filtration machines. The machine for our pilot effort in Rajasthan came to us in a truck full of crated parts: motors, pumps, switches, membranes, tanks, and so on. The truck was followed by a welder, a plumber, a filtration expert, all of whom built the filtration machine onsite. It was a custom-built machine that took several days to assemble inside the room where we installed it.

Frugal innovation was the only way we could fulfill our fundamental promise of affordable clean drinking water to our customers.

We realized that this process was highly inefficient. Experts told us that machines had to be custom built based on the water source and output requirements. When we asked another supplier to send us a pre-built machine to a particular specification, and it came to us in a wooden crate that took up a lot of space and the crate alone was 20% of the cost of the machinery.

There was no way this was going to work.

Our initial team was full of tinkerers who were obsessed with Internet technologies. We dreamt of solutions that came more clearly from our experience with web technologies, not with clean water policy per se, giving us a fundamentally different perspective on approaching the problem than others with strictly policy backgrounds.

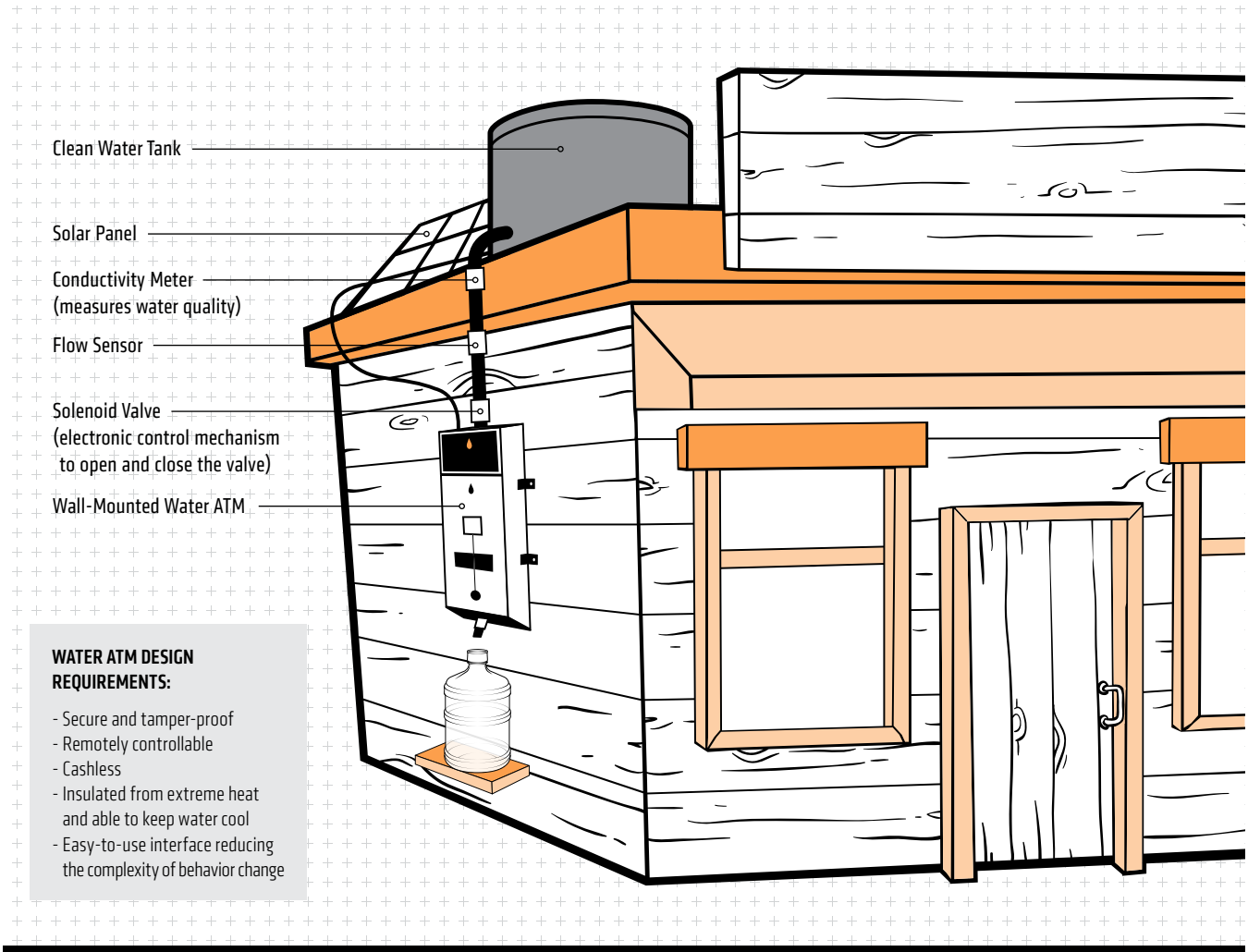
We had to figure out how to reduce the all-in costs of the machinery, including time, installation, transport, and so on, and we wanted to standardize and modularize the machinery to make it easy to deploy. We were confident that the math around customizing machines could be translated into a basket of products built around a standard design, especially because water quality was reasonably predictable if mapped by locality. Our goal: install and remove within an hour and ship the machine without any crates.

Largely out of ignorance, we started trying to build machines in various configurations. We needed to reduce space, maximize the number of machines we could fit in a standard 24-foot open-top truck, create quick-release connections, pre-calibrate and prep membranes, among other issues.

We came up with a standardized 500-liter-per-hour vertical membrane machine built inside a frame that would also protect it during transport (thus requiring no expensive packaging material) and that could be installed within minutes of arrival. Moreover, the standardization of the machine helped us reduce the costs of machinery by 75 percent without significant re-engineering of the components. It wasn't perfect, but within a year and a half, after much trial and error, we had a machine that was cheaper and more efficient than those of our competitors—and nearly every one of them eventually began using our machine template and/or our supplier for their own water-cleaning systems.

Once we started deploying our machines, we realized that we were still quite far from our goal of reaching those who had the least access to clean water. Our goal was to get water to the last mile, but even our small and standardized plants required around 800 customers to make it financially feasible for a franchisee. And that fact kept us from reaching the small hamlets where water was an even more acute problem.

Our search for a solution to this problem found inspiration in a piece of technology very common in the developed world: the automated teller machine. For a "water ATM" to work, it would need a number



Wall-Mounted Water ATM System

of critical features: it would have to be secure and tamper-proof; it would have to be remotely controllable; it would need to be cashless; it would need to be insulated from extreme heat and be able to keep water cool; and it would have to have an easy-to-use interface that would reduce the complexity of behavior change.

We began to develop a low-cost, solar-powered, self-contained water-vending machine that would keep clean water secure and could be refilled by the nearest franchisee, thus reducing the capital, operating, and maintenance cost of each unit. It also helped our franchisees increase capacity utilization of their units by broadening their customer base; one franchise could distribute water at many widely distributed points. Our water ATMs are now operated by RFID-based smart cards that can be "topped up" in the same way that users buy talk time for prepaid cell phones: at any local store or through a roving representative.

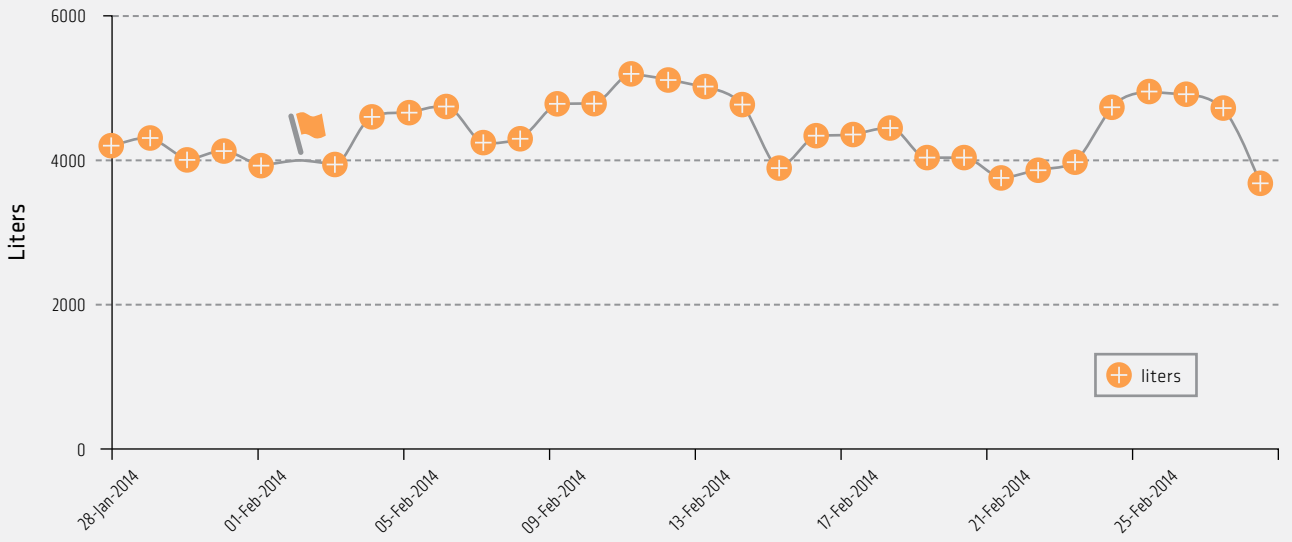
This device is central to our future—it has inspired a vision of a saturated marketplace with water ATMs on every corner that allow villagers and city-dwellers alike to get safe water when they want it.

DEPLOYING THE WATER ATMS

We deployed the first water ATM in early 2011 and currently have about 40 of them in the field. We are at a point where we can build thousands of them. The real issue we now face is where exactly to put them? We're currently working with the city of Delhi to bring clean drinking water to a resettlement colony on the outskirts of the city, and interest has already started

SARVAJAL MONTHLY WATER PRODUCTION REPORT EXAMPLE: REVERSE OSMOSIS FRANCHISEE - FEBRUARY 2014

Monthly Report: Total Water Produced: 1,16,548 Liters **Time Period:** 1m **Moving Avg:** Trailing 3 days **End Dates:** 2014-02-28



Franchisee Information, Dasrath Goyal, 99292XXXXX **Operator** ---- **Relationship Manager,** Gorendra Jhajharia, 77420XXXXX

Type	Last Session	Yesterday	7 Day Average	30 Day Average	All Time
Raw Water Total	1,305	7,881	7,393	7,421	87,41,662
Product Water Total	510	4,816	4,662	4,341	40,72,482
Reject Water Total	795	3,065	2,731	3,080	46,69,180
Product Water TDS Avg.	5	52	52	53	51
Raw Water TDS Avg.	64	588	536	572	394
Pre-Memb. Pressure Avg.	5	5.25	5.35	6.05	5.38
Post-Memb. Pressure Avg.	5	5.1	5.24	5.89	5.3
Differential Pressure Avg.	0	0.15	0.12	0.16	0.09
Product Water LPH	0	501	480	496	495
Reject Water LPH	0	897	730	771	776
Product Reject Ratio	0	0.56	0.66	0.64	0.64

Parameter	Daily Avg	Median	Max	Max Date	Min	Min Date
Product Water	4316.59	3865.5	5777	2/9/2014	1275	2/28/2014
Reject Water	2998.04	3695.5	7461	2/25/2014	92	2/10/2014
Product TDS	57.32	65	118	2/10/2014	4	2/6/2014
Pre-membrane Pressure	6.38	6.625	10.35	2/23/2014	2.88	2/25/2014
Differential Pressure	0.17	0.125	1	2/28/2014	0	2/6/2014
Product Reject Ratio	0.65	0.665	0.69	2/28/2014	0.56	2/25/2014

Machine Analysis

- Congratulations! Your water production ranks in the top 5%of franchisees.
- Your machine is due for membrane wash in the next few months. Please work with your relationship manager to schedule a 4-hour membrane wash.
- You are not operating at the recommended Product: Reject ratio. Doing so will reduce long-term maintenance issues.

Source: Company documents.

THE SARVAJAL MODEL

- **We don't sell water. We sell a service to clean local water.** To inspire confidence in Sarvajal, we designed our filtration plants to be transparent, literally allowing customers to see, hear, and taste the difference our clean water makes. Customers can ask for a water conductivity test and call a toll-free hotline that we set up to handle any complaints they might have.
- **We don't transport filtered water to other communities. Local water needs be treated and consumed locally.** Because India has a history of foreign companies destroying local water tables for products that are destined for sale elsewhere, we knew that we needed to be sensitive to the issue of "buying local." We also had to build machines that could handle small quantities at an economical enough price point to make sense for local communities.
- **Villagers don't buy from Sarvajal. They buy the Sarvajal service from a local franchise.** Franchisees are often someone whom villagers know within their community. Frequently these people are relatives, neighbors, or local leaders with deep relationships. The franchisee earns a living by promoting the benefits of clean water to his or her own community. And thus most of the jobs and the revenue generated by Sarvajal stay local. This ensures that a local champion continues to promote the advantages of clean water, and that Sarvajal mitigates the risk of being seen as an exploiter of local resources.
- **To best support a franchisee model, the technology needs to be a turnkey solution.** Standardization and modularization reduced the overall cost of the machinery and enabled us to install and remove machines within an hour, and to ship them without using any crates. This, in conjunction with our network of entrepreneurial franchisees, enabled us to move beyond the water grid and to deliver clean drinking water to widespread rural communities.

coming in from other communities in Delhi and beyond for similar solutions.

The machines have low-cost controls based on programmable logic controllers that send SMS text messages on an event basis. That enables us to use a cloud-based control and diagnosis system for our filtration units. We now know everything our machines do in real time, including detailed information about the quality of the water they produce. We also have a set of operational data on our standardized machines, helping us develop a learning mechanism to predict and reduce failures.

To our distress, we discovered that franchisees in Rajasthan were using cooling systems to chill water. Basically, these were jerry-rigged air conditioning compressors with a coil of copper pipe submersed in an underground tank with filtered water, thus using the water as a heat-exchange medium and therefore refrigerating the water. This was a violation of our franchise agreement because the copper pipe was usually dirty and underground tanks were easily contaminated by particles introduced by gravity.

Franchisees needed a cooling solution, preferably off-grid, that would ensure the water stayed safe. With support from a large automobile manufacturer, we repurposed a variable-drive 12 V car compressor with a high-capacity chiller, which is used to cool electric car batteries, to make an inline water chiller. The system can be connected directly to solar panels without storage or an inverter, simply increasing its cooling capacity with intensity of the sun: an optimal application for solar and an incredibly powerful off-grid cooling solution.

Our franchisee-based business model required some other sorts of engineering. We developed a prepay mechanism that gets the franchisee to pay for filtration capacity in advance. The franchisee pays for a minimum water balance on his machine either as a cash handover to a Sarvajal representative or via direct bank deposit. Since we have daily, monthly, seasonal, and annual water production data for each of our franchises, we are able to suggest an approximate amount of water balance recharge for the month. As the water balance nears completion, we sent alerts to the franchisee recommending recharge, to ensure that there is no downtime in water production.

All of this had to be managed by a cloud-based system that could handle the nuances of unreliable electricity, Internet, and mobile service. Most of these solutions were invented in a conference room with a bunch of Post-it notes, but this only captures a narrow part of the technical challenges we faced to turn the model we had conceived into something we could deliver.

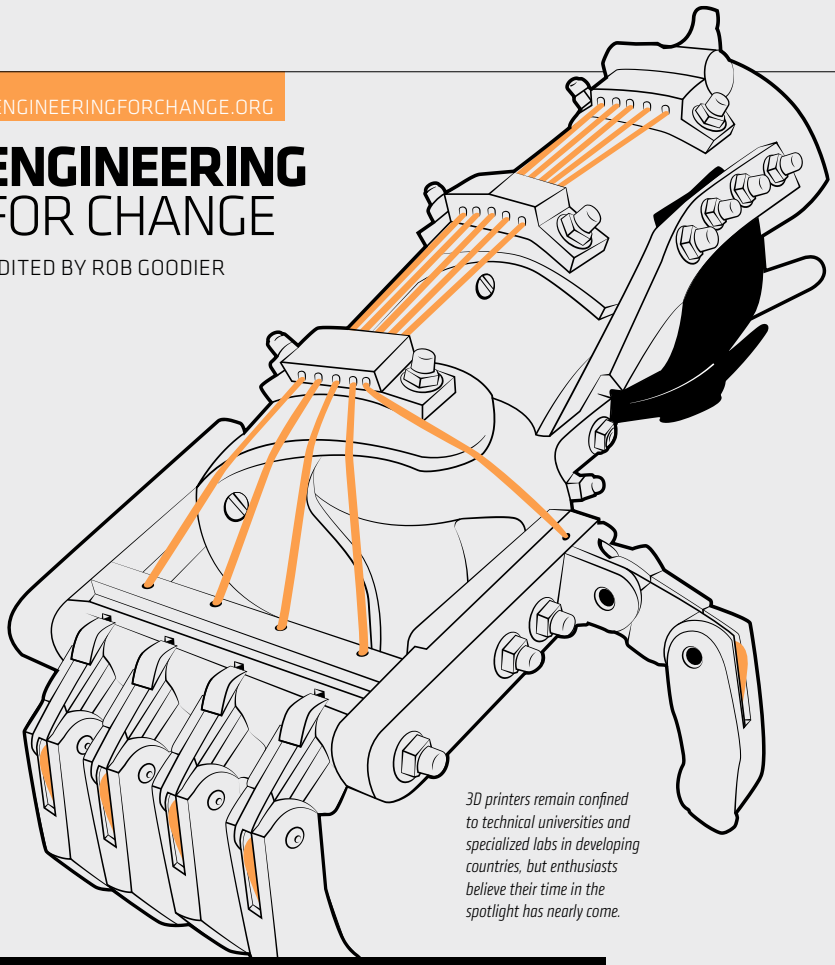
We currently serve more than 150 villages across seven states in India, bringing clean drinking water to over 100,000 customers daily. Our goal is to increase the size of our impact tenfold over the next three years.

Sarvajal's next task is to develop a point-of-dispensing disinfection solution that ensures any biological contamination in the supply chain of water to the ATM is neutralized. We've started by looking into UV LEDs that could function as a low-power method to disinfect water, and dosing solutions of iodine or chlorine that could ensure the longevity of filtered water (though people generally do not like the taste of chlorinated water when they have a choice otherwise).

Technology is an enabler, but the real wisdom is in building an operation that sustains excellence in service delivery at the last mile. There are many lessons in our experience in India that we believe could inspire similar solutions around the globe. We've found that the key to finding an answer is reducing the problem to one that is solvable, setting constraints, and innovating until you make it work. Every step along the way is an opportunity to engineer solutions that make a difference, and there are few ways to have more impact than ensuring all people have access to clean water.

ENGINEERING FOR CHANGE

EDITED BY ROB GOODIER



3D printers remain confined to technical universities and specialized labs in developing countries, but enthusiasts believe their time in the spotlight has nearly come.

3D printers may be poised to take off in developing countries

FOOTPATHS, NOT ROADS, connect villages in the Nuba Mountains in South Kordofan, Sudan, and motor vehicles are scarce. But there is a 3D printing lab. The region is officially a war zone, caught in the conflict between Sudan and the new South Sudan. In late 2013, the California-based technology company Not Impossible established a prosthetic printing facility to assist the growing number of amputees.

Project Daniel, named for a teenaged boy who lost both of his arms to a bomb attack, has fitted its namesake with a printed RoboHand prosthetic. Since then, local trainees have printed and fitted two more prostheses after the lab's founders left the operation in their hands.

The lab seems like a non sequitur in that pastoral context. And critics may point out that it owes its existence to the world outside of Sudan as a technology transplant in a lesser developed region. But 3D printing may be catching on in the developing world.

The technology leapfrogs some problems more cheaply than traditional methods. There are few roads in the Nuba Mountains, but printing things reduces the need for delivery. Printing also reduces waste and saves money. In 2013, a research team at Michigan Tech found that printing things is both cheaper and consumes less energy than buying them. In time, printers in remote regions may manufacture parts to repair other devices, create new products and, of course, jobs.

"3D printing is something that has definitely taken off in South Africa. As for most of 'Africa' that will take some time. But it will certainly get there. Let's give them a year," Richard Van As, the South African who invented the Robohand and trained Sudanese technicians to print the prosthetic, told E4C.

To make something, 3D printers melt a filament, which is usually plastic, or sometimes a soft metal or even a food, like chocolate. Then they deposit it, stacking layer upon layer to gradually build an object.

Not Impossible brought Van As together with an international team to launch its lab. But fans of 3D printing and other rapid prototyping tools can pool their knowledge in less formal ways. Low-cost communications make it happen through wikis and other shared documents, text messages, VOIP calls and so on. Those work because of the famously generous spirit of open source communities. The worldwide 3D printing community seems to bend toward open source tools and donated time for support.

As far we can tell, most 3D printers in developing countries remain confined to technical universities and specialized workshops such as FabLabs. FabLabs, an extension of MIT's Center for Bits and Atoms, provide tools to prototype inventions and stimulate local entrepreneurship. Nearly 130 are up and running worldwide, many of those in Africa, India, Southeast Asia and Latin America.

Take Dhananjay Gadre and his 3D-printed lantern, for example. Gadre, a professor of electrical and computer engineering at Netaji Subhas Institute of Technology in New Delhi, India, designed and printed parts for a lantern that mimics a flame and even turns on when touched with an electronic "matchstick."

"There is a lot of talk about 3D printers and the time is very ripe for this gadget to explode on the scene and suddenly a lot of people could acquire one," Gadre says. In fact, he has been predicting their popularity for a while, he says.

> **"There is a lot of talk about 3D printers and the time is very ripe for this gadget to explode on the scene."**

Back in South Africa, Van As seems equally as optimistic about the printer's prospects.

"3D printing is certainly a great buzz and I think it will last for a good while to come. It seems that it may also become part of the education systems in the schools all over the world," Van As says. ⊗

Paper diagnostic tests: Coming soon to Kenyan dairy farms

TESTS FOR MILK ON KENYAN DAIRY FARMS MAY SOON BE ULTRA CHEAP, printed onto paper sheets and delivered to farmers and milk processing plants. Diagnostics for All (DFA), a US non-profit biotech firm, is designing tests for milk spoilage and estrus in cows (to detect when the cow is ovulating).

The tiny coin-sized microfluidic chips are made mostly from thin strips of paper printed with wax. They do not require electricity or the storage of liquid samples. And they are simple enough for farmers to read, either by sight with a mobile device app.

These tests, and others coming online behind them, could streamline the dairy industry in Kenya and other developing regions. They may also boost profits on family-owned farms.

"I think it will have great impact," Patrick Beattie, Director of Operations at DFA, told E4C. "What it's doing is enabling farmers and veterinary workers to better manage their herds, and in some cases to improve their quality and access better markets that they wouldn't be able to access otherwise. All of that goes to a bottom line of improved farmer incomes," Beattie says.

WICKING WITH PAPER AND WAX

The tests operate under capillary action, the same principle that allows plants to draw water from their roots up to their leaves, and the way a paper towel soaks up water when its edge is dipped in a glass. A drop of milk or a blood sample from a cow wicks through the paper along channels bounded by waxen barriers. It collects in wells that contain a chemical reactant. If the milk contains a threshold level of certain bacteria, a spot on the test will change color to indicate that the milk might be spoiling.

The estrus test works in the same way. The farmer pricks a cow's ear to draw a blood sample and applies it to the paper where a chemical reaction reveals the absence of the hormone progesterone. (When cows ovulate their progesterone levels drop.)

WHY SPOILAGE AND ESTRUS?

Small-plot dairy farmers in Kenya gather their milk and deliver it to central milk chilling plants. The plants pool the milk from dozens or hundreds of farms so that even a few gallons of spoiled batches could contaminate many others. Milk spoilage tests already exist, but DFA's paper strip, when the design is complete, is likely to be less expensive and more accurate.

Estrus testing is important, also, because of how domesticated cattle reproduce. Most cows are artificially inseminated. The practice is widespread and practical because bull semen freezes and ships well. The best bulls are in demand for breeding worldwide and it is easier to ship their semen than to ship the bull. It is also cheaper for farmers to buy semen rather than raise bulls for breeding.

DFA's estrus test can take guesswork out of the insemination process and tell the farmer when the cow is ready. A cheap and widely available test can save the farmers' time and money.

> "The tests are enabling farmers to better manage their herds, and in some cases to improve their quality and gain access to better markets."

PAPER MICROFLUIDICS FOR DEVELOPING COUNTRIES

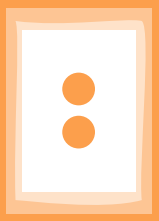
DFA has a grant from the Gates Foundation for $3 million over two years to develop the agricultural diagnostic tests. The organization is also developing tests for liver damage, which is common in HIV/AIDS patients, and for malaria, dengue fever and preeclampsia, a complication of pregnancy.

NEXT STEPS

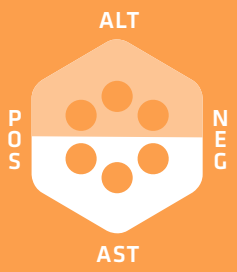
When the tests are ready for distribution, DFA plans to seek partners to manufacture and sell them. The idea is that selling them, rather than giving them away, could help the tests catch on. DFA's field research has shown that farmers can make more money by using the tests, so they have incentive to buy them. And they will be cheap to manufacture, so private companies could have incentive to make them. "There will be incentive all around," Beattie says.

THE BOTTOM LINE

DIFFERNT TYPES OF PAPER DIAGNOSTIC STRIPS:



THIS SQUARE TESTS FOR AFLATOXIN, A COMPOUND PRODUCED BY FUNGI THAT CONTAMINATE GRAINS AND MILK.



THESE ARE HUMAN LIVER-FUNCTION TESTS DESIGNED WITH THE SAME BASIC PAPER AND WAX STRUCTURE OF THE AGRICULTURAL TESTS THAT DFA IS DEVELOPING NOW.

5

Five questions with Ashok Gadgil

ASHOK GADGIL'S NAME IS ATTACHED TO HUGE, AND HUGELY INFLUENTIAL PROJECTS IN THE DEVELOPING WORLD. He deals in big numbers. Five million people in six countries drink water that his UV Waterworks disinfects. Twenty-thousand people cook with his fuel-efficient stoves in Darfur. And more than 100 million people in developing countries use compact fluorescent lamps as a part of Gadgil's program for utility-sponsored energy efficiency.

"It is a waste of time to try to solve problems in a small way," Gadgil told E4C. "You need to think about how will you go to scale and make lives better for at least 10 million people."

In Gadgil's day job, he directs the Environmental Energy Technologies Division of Lawrence Berkeley National Laboratory, and he's a civil and environmental engineering professor at the University of California, Berkeley. We asked him five questions (plus one).

E4C: *What motivates you to do what you do?*
AG: If there is somebody who asks why I should bother, I would tell them, Look, we are a single human society on a single planet, and we share this planet together. If the bottom four billion follow the high-carbon trajectory to prosperity that we have followed in the developed world, we could not handle the pollution. So, we better find a way to develop along a low-carbon trajectory.

It is highly inequitable that, while those of us in the developed world have access to knowledge – it is practically free – you have 4 billion other people without access to knowledge, education, shelter or adequate food on the table. The solutions are at our fingertips because we have access to knowledge and research while the people who are suffering don't. It's about empathy.

The self-centered answer is that whatever we're doing in the industrial world, we'll not by ourselves be able to stop global climate change. So, we've got to work with them.

E4C: *What promising trend do you see in technology for global development today?*
AG: The most exciting thing I see is that the best students in the best engineering schools across the United States are excited and enthusiastic about how they can make the world a better place. They're seeking a more meaningful life as engineers, saying, "we are also citizens of this planet, and how can we make this world a little better?"

E4C: *What do you think is a dead end in your field that some people just won't let die?*
AG: The dead end that I see in the field, in which people just keep trying to walk through a brick wall, so to speak, is that people don't try to understand the world view of those they're trying to help. I would say that the developing world is a museum of failed projects from developed countries because they did not answer the right question. We are very good at answering questions, but not so good at finding the right questions to answer.

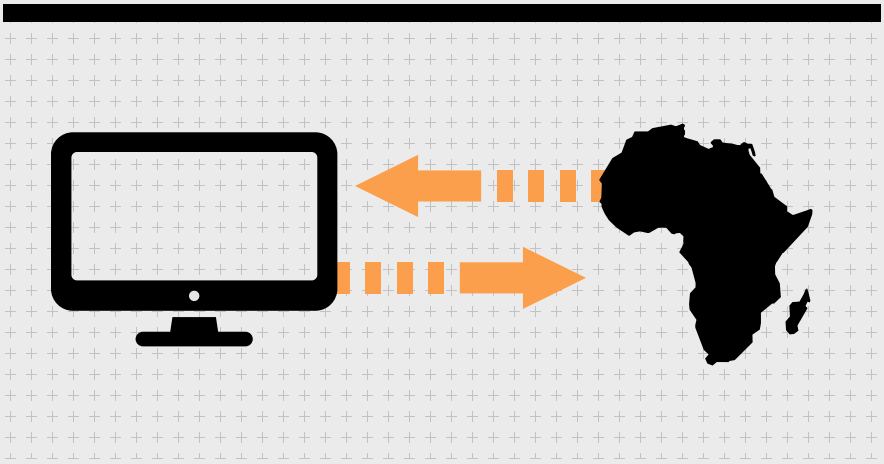
For example, in Darfur, some well-meaning people collected money to air-ship state-of-the-art dentist chairs into the refugee camp. Into tents. There was no electricity to power the chairs. The chairs are fine, but they were sent to the wrong people at the wrong time.

Sitting in the first world and creating a solution without walking in the shoes of the people you're trying to help often leads to failure. One really needs to understand the world view of the people you're trying to help.

E4C: *What has kept you awake at night?*
AG: The thing that keeps me awake at night is the problem of global sustainability and that almost nobody seems to actually do much about it. We are heading for collapse in terms of planetary sustainability and we don't seem to stop. We burden our ecosystems more and more at a faster rate, and we've exceeded the carrying capacity in some dimensions already. It worries me to think about what kind of world we are going to hand off to our children.

E4C: *Five years from now, what improvements would you like to see in the technology that you and the people you work with use?*
AG: I would like to see arsenic remediation technology in use, commercialized and out there in the world providing water to 100,000 to 1 million people every day. Affordable, commercially viable and financially viable. I would also like to see in five years out of my own research lab a way to do the same taking fluoride out of the water.

E4C: *Catch-all: Anything else you'd like to add?*
AG: I am pleased that the lemelson-MIT program recognizes this kind of work and tags it as a valuable contribution to make the world a better place. There are many awards out there for just being smart and creative, but the Lemelson award really addresses how can people help those who are impoverished and do that with the knowledge at our fingertips in the industrialized world. I am pleased that this whole topic is getting attention from something as prestigious as the Lemelson program.



AFRICOMM is mapping the future of ICT research in Africa

IN NOVEMBER LAST YEAR, the AFRICOMM conference on Internet and communications technology took the reins on technology research in Africa. They set a long-term agenda for ICT for development in Africa based on the research its participants submitted.

"We want to do research that will actually have an impact on society," says Tegawendé Bissyandé, an ICT expert at the University of Luxemburg's Interdisciplinary Centre for Security, Reliability and Trust and the AFRICOMM program chair.

THREE RESEARCH TRENDS

Three trends dominated the research presented in Blantyre, Malawi.

The first is white spaces, which are unused broadcasting frequencies between TV channels and radio stations – the fuzz on the radio and the snow on the TV screen. Research outlines how to make use of these frequencies to improve emergency services and other communications.

The second trend is the security of communications infrastructure. Research details how to improve security in notoriously vulnerable peer-to-peer communications. And there is research in encryption and cloud services security.

The third is innovation. Drones, for example, can monitor parks, pastures and wildlands to fight poaching. Another example is language. Devices and Internet tools play a role in teaching spoken languages in Africa, both at home and to the diaspora abroad.

Bissyandé has hand-picked the following research abstracts to showcase the latest research.

A GEOGRAPHIC INFORMATION SYSTEM IMPROVES DRUG LOGISTICS INFORMATION IN MALAWI

The information system seems to be one of the weakest links in the logistics of the supply chain for drugs in developing countries. District pharmacies in Malawi use a computerized information system to monitor the flow of products from warehouses to medical centers. Now, all drug logistics information reports are in tabular forms. A new Geographic Information System provides additional spatial information, such as maps of the centers.

UNIFIED SOLUTION TOWARDS DEPLOYMENT OF TV WHITE SPACE IN AFRICA

TV white spaces are seen as a key technology to enable the efficient use of scarce sub-GHz spectrum allowing for applications that may have a huge impact on Internet penetration in rural parts of Africa. Research into a carrier-grade wireless backhauling solution will help identify solutions for deployment of TV white spaces in Africa.

SPATIAL ANALYSIS OF LOCATION OF MOTHER'S CHOICE FOR DELIVERY

New research has mapped locations where mothers choose to deliver their babies. Factors such as the availability of a health facility, the distance to it and the availability of transport can affect the choice of where to deliver, the researchers have found. Other factors are demographic and cultural, such as education, the number of children that they have and the age of the mothers.

Y NUT, A PHONETIC-BASED LEARNING SYSTEM FOR SPOKEN LANGUAGES

Some languages do not have a native written version. These languages exist only in speech, so learning them without a face-to-face teacher requires audio or video technologies. New research describes the development of a phonetic database that can enhance language education and make it easier to learn basic expressions. Such a system could be useful for the survival of spoken languages in Africa and also provide automatic translation services.

FROM VILLAGE PHONE TO VILLAGE INTERNET USING DELAY-TOLERANT NETWORKS

Researchers propose a hybrid system of a long-range cellular network and a delay-tolerant network to solve communications issues in rural areas. New research describes how the technology may allow Internet development and new services that could have a positive impact on the load of urban cellular networks.

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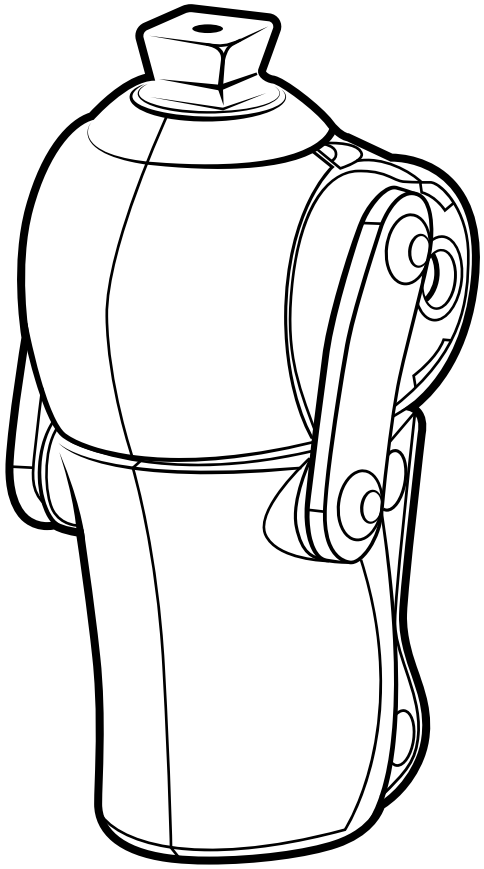
ASSESSING THE IMPACT OF REMOBILITY



After losing his leg in a traffic accident, Amin was initially fit with a locally-made prosthetic. The prosthetic was so ill-fitting he stopped using it altogether. Two years later, Amin was fit with the v1 Jaipur Knee, providing him with a better-fitting, more reliable prosthetic and improved mobility.

To refine the design of a stable and affordable prosthetic knee for amputees living in low-income areas, the authors created a survey that was suitable for everyone in the value chain.

Amin lost his leg in a traffic accident in India when he was just six years old. His family struggled to find an appropriate prosthetic leg. Eventually Amin was fit by a prosthetist who charged so much money that Amin's father went into debt. The family's entire community pooled their funds to pay for the prosthetic limb.

Cost wasn't the only problem. Amin traveled 15 hours to reach the clinic and the prosthetist spent only 15 minutes fitting him—not nearly enough time. A proper prosthetic fitting usually takes anywhere from a few days to a few weeks with a custom cast and socket made during a multistage process. Additionally, a patient should ideally receive receive at least

03

KRISTA DONALDSON, D-Rev's CEO, has been a Silicon Valley "40 Under 40" winner, and a TEDx and Clinton Global Initiative speaker. She is listed in Fast Company's Co.Design 50 Designers Shaping the Future, and the Public Interest Design 100. She is a Rainer Arnhold Fellow and a Pop!Tech Social Innovation Fellow. **SAMUEL HAMNER** is design engineer at D-Rev and motivated by designing solutions that reduce poverty and improve access to healthcare and education in the developing world. Hamner earned his PhD in mechanical engineering at Stanford University.

VINESH NARAYAN joined D-Rev's ReMotion as product manager after co-designing a low-cost elbow prosthetic in a Stanford University course on medical device design. Narayan holds a Master's degree in Management Science & Engineering from Stanford University with a concentration in Entrepreneurial Design. **NICOLE RAPPIN** is the operations manager at D-Rev, focusing on organizational efficiency, and an Impact Associate for the ReMotion Knee. Nicole holds a dual-degree from Carnegie Mellon University in Cross Cultural Communication and Music History & Culture.

INDIA, INDONESIA, GUATEMALA

Total unmet need for prosthetic knee joints, based on estimated rates of above-knee amputees and country populations. The number of above-knee amputees in need of a prosthetic knee are 6.7 million in Asia (mainly China and India), 1.7 million in Africa, and 0.7 million in South America.

Andrysek, J. Prosthet. Orthot. Int., 2010., UNFPA The State of World Population 2011., WHO World Report on Disability, 2011

a few days of training to acclimate to the new limb. Without this attention, Amin's prosthetic socket was ill-fitting and the prosthetic knee noticeably misaligned—Amin's gait was awkward and uncomfortable.

Amin's case is not unusual. Remobilizing amputees with prosthetics in a resource-limited setting is a complex challenge. Nearly 3.3 million amputees need a new prosthetic knee each year, with vehicle-related accidents being the major cause of new amputations. We've seen that even where care is available, it can be difficult for people with little money to access such care—clinics tend to be far away from rural communities and are cost-prohibitive to reach. But more than that, if care is accessible (through loans and days of travel like Amin and his father endured), the quality of care can be sorely lacking. We see a significant trade-off between affordability and performance.

The World Health Organization estimates that only 5 to 15 percent of amputees are able to access care in developing countries, and in many of those cases, the outcomes are often like Amin's. This translates into about 9.5 million above-knee amputees living in developing countries without access to reliable prosthetics and the mobility they can provide.

At Design Revolution (D-Rev), a non-profit product development company headquartered in San Francisco, Calif., we are working to provide life-changing solutions for people like Amin by developing the ReMotion Knee. Our goal is to provide products that improve people's health and/or increase their incomes, enabling them to lift themselves out of poverty.

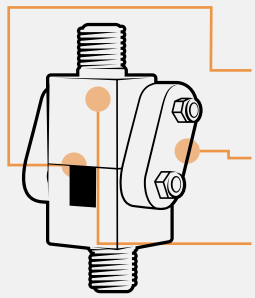
The ReMotion Knee started as a student project at Stanford University in 2008. The JaipurFoot Organization (BMVSS), one of the world's largest producers and fitters of low-cost prosthetics, sponsored the student team to design a higher-performing knee joint than their existing single-axis knee.

After the students developed prototypes of a low-cost, polycentric knee, BMVSS began fitting it and reported improved gait quality and patient satisfaction. Since then, the JaipurKnee—the first version of the ReMotion Knee—has been locally manufactured in India by BMVSS. Three students continued to work on the project independently and in 2011 merged their nascent company with D-Rev to globally scale production and distribution of the prosthetic knee.

While the polycentric prosthetic knee is not new—the concept has been around for at least 50 years—our goal is to make an affordable, high-quality knee, which can be reliably delivered to clinics that have not had easy access to mobility aids. The retail price for the knee is $80; a comparable device in the western market ranges from $500 to $10,000. The International Committee of the Red Cross has a knee for about $150, but their device is a single-axis knee, which is less stable than the polycentric design of the ReMotion Knee.

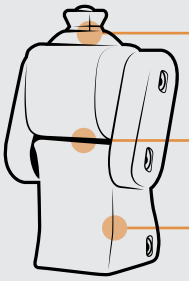
In the fall of 2013, we launched field trials with the latest version of the ReMotion Knee to refine and finalize the design, and just as importantly, better understand the impact of the knee through data collection. We want to know how it affects an amputee's life, not just to report to our funders or measure our effectiveness, but also to maintain the feedback loop critical for informed iteration and improvement. We see this feedback loop as not only allowing us to create a high-quality user-centric knee, but to best learn how to maximize our impact. For instance, Amin

THREE GENERATIONS OF REMOTION



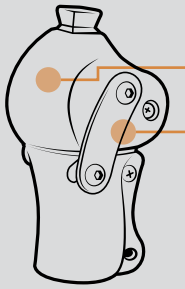
VERSION 1 (2008)

- Being able to squat and sit cross-legged is critical in India.
- Polycentric knee mechanism is highly stable, mechanically simple, and reliable.
- With careful implementation, building the knee out of plastic instead of metal could result in huge reductions in cost, but not in strength



VERSION 2 (2010 - 2011)

- **2010** Disabled persons are highly stigmatized in many developing nations, leading many patients to be sensitive to anything that calls attention to their disability.
- **2011** Most clinics around the world use a standard set of connectors to connect and assemble prosthetic components into a full limb.



VERSION 3 (2011 - 2012)

- **2011** Donated prosthetic components, while affordable, are difficult to source and take considerable effort to manage. Reliability of supply, ease of ordering and predictable lead times are just as important as an affordable price.
- **2012** Adoption and impact depend on patients and prosthetists recognizing the knee as a desirable, quality product, not something that they are settling for as the cheapest option.

Iterative design insights to improve each version. *Country names indicate where the design insight was learned.*

was fit with a JaipurKnee when he was eight years old, two years after being fit with his misaligned knee. In terms of impact, we know that the knee is relatively affordable, stable, and fits Amin's needs, but also that his family remains in significant debt from his first knee.

Creating a survey to assess a person's quality of life can be challenging. How do we put a number to the struggles and triumphs of people wearing a prosthetic knee?

In tracking amputees and their use of the ReMotion Knee, it became clear getting a fuller representation of people's lives called for a blend of quantitative and qualitative feedback. We collect quantitative data to objectively assess the efficacy of the medical device using standard mobility tests such as the 10 Meter Walk Test and the Timed Up and Go Test. This data allows us to compare the ReMotion Knee with a patient's previous device and see if a patient's mobility is improving over time.

Beyond mobility, amputees have told us that they want independence, respect, and self-reliance—critical components to maximizing impact that mobility metrics alone cannot capture. So we also seek qualitative data, particularly empathetic user feedback. User stories and modifications also provide us with critical contextual data on the product, so that we can better address barriers to its adoption.

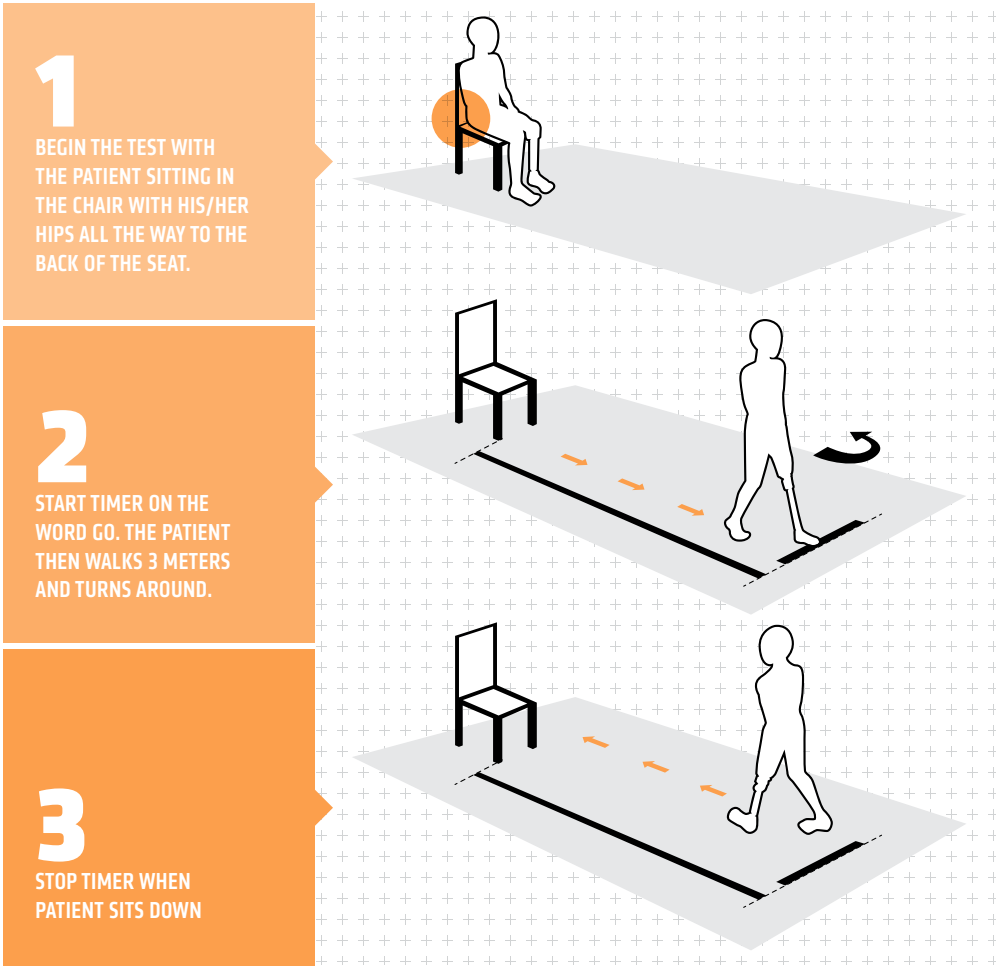
For example, early work on the original JaipurKnee showed that social stigma is an overarching issue for many amputees. We saw users customizing their JaipurKnee to reduce any noise it might make and to make the device look more like a natural knee under clothing.

Part of the design challenge for the ReMotion Knee is taking into account everyone in the customer value chain who will interact with

and could potentially benefit from the product. That goes beyond the amputee to include the prosthetist who fits and aligns the leg system, the technicians who build and repair the components, community rehabilitation workers who reach out to patients, hospital administrators who are making purchasing decisions, family members who may accompany the amputee to the clinic, and everyone with a stake in the success or failure of remobilizing the amputee and using the device.

The needs of the prosthetist are particularly important. The prosthetists we meet are often overburdened, with more patients needing care than their clinics can provide. Prosthetists have little time to experiment with new products or processes. Ultimately, for the product to get traction and create impact, the knee must work within existing systems for prosthetic fitting and have features that prosthetists are accustomed to. To meet this need, we've created a knee with a standard "pyramid adapter" connection, along with adjustable friction, thus giving the prosthetist the ability to dynamically align the knee.

Beyond the fitting process, the knee and other components must reliably reach each prosthetics clinic, no matter where the clinic is located. Some clinics we've visited have waited up to eight months to receive orders of prosthetic components. Scheduling the fitting of a patient can become a waiting game, as clinics wait for missing components to arrive. Some clinics rely on donations of used knee joints from the U.S. and other western markets. The supply of donated parts is unreliable, erratic, and can be costly to an organization's limited resources, because it requires significant effort to manage and refurbish a wide range of inventory.



Example of instructions from the patient survey for the Timed Up and Go (TUG) test. The TUG test, measures the time it takes a person to stand up from a chair, walk three meters, return to the chair, and sit back down. TUG is a basic gait test that captures many aspects of mobility in a single timed measure.

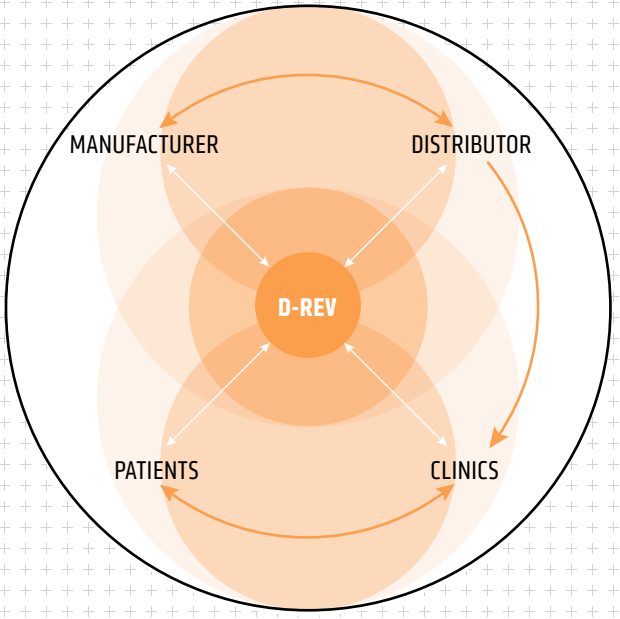
Deathe, A. B., and W. C. Miller. The L Test of Functional Mobility: measurement properties of a modified version of the timed "Up & Go" Test designed for people with lower limb amputations. Phys. Therapy 85:626–635, 2005.

FIELD TRIALS

In the fall of 2013, we launched field trials to test the latest version of the ReMotion Knee with patients at four clinical sites in India, Indonesia, and Guatemala. (These trials are on-going at press time.) Our assessment tool—the survey that drives these trials—went through a product design process just like the knee itself. We treated our partner clinics as the end-users of this product, mapped process flows, and considered their voice and needs during the survey design process. The steps we took in designing the survey have broad applicability in creating survey instruments for resource-limited settings.

We began by conducting an extensive literature review of existing surveys evaluating prosthetic performance. We had hoped to adopt standard metrics that would allow us to compare the ReMotion Knee to other prosthetic knees on the market. We found, however, that almost all studies of prosthetic performance took place in high-income areas, and those surveys do not address the needs and concerns of patients living in our target markets—those living on less than $4 per day. The majority of prosthetics patients in high-income areas were older diabetic patients, whereas our target end-users are younger and active (the average age of the subjects enrolled so far is 35). Also, the questions and measures were inappropriate contextually. For example, one question asked an amputee about the ease of stepping up onto curbs, which doesn't make sense in our target regions because curb height can be variable or, in some cases, curbs don't exist at all.

ReMotion Knee Customer Value Chain



Each stakeholder is part of the feedback loop in the design process

Variability in the capacity across the clinics we partner with is also a challenge. The number of skilled prosthetists and technicians, as well as the administrative capabilities, differs from clinic to clinic. Some clinics are permanent and some temporary. While field trials require rigor and strict control, actual data collection from people requires adaptability and flexibility, so that we can quickly pivot on the ground to efficiently manage a quality process and respond to hurdles.

The survey we developed requires that prosthetists spend at least an extra 30 minutes interviewing each patient, that the clinic set up an area for timed gait-testing, and that clinic administrators add on an additional filing system to maintain patient confidentiality. Our experience is that any product, including user surveys, that doesn't fit with users' existing behavior and expectations, will not be adopted. We've learned through experience that the quality of the data collected may suffer if we ask the subjects and clinicians to do too much beyond their typical operations.

We worked closely with clinics to translate the survey into local languages. Language, in itself, is an interesting design challenge—there aren't always lingua franca equivalents for technical medical terms. Our translators worked to interpret appropriate colloquialisms, and we iterated with individual clinics to best update the material to local norms and phrasing. Most clinics asked that technical and medical jargon remain in English, even if English was not the prosthetists' first language, resulting in a series of hybrid translations—a lesson consistent with previous experiences we've had with technical language across a wide range of geographies. We also adapted some of the contexts of the questions to better fit our patient profile. For example, we eliminated questions about swinging a golf club, hitting a puck with a hockey stick, and throwing a bowling ball.

Once a survey is designed with intention, fit to local context, tested, translated into the appropriate language (or mix of languages), it is a product, but it is still an unused one. In any ethnographic study there is an acute tension between drawing out truth and paying respect to the user. How do we understand a user's very personal and emotional experience and translate that through a survey into a line on a spreadsheet without diminishing his or her reality? This question gets to a central tension in product development; as personal stories can convey what a gait test cannot.

One of the more emotionally challenging amputees that we met during field trials lost her leg about a year ago in Guatemala. Her immobility made it impossible for her to continue her job as a cook, and she has been struggling with her inability to work ever since. Like many patients, she was emotional throughout the interview process, but when we began to talk about her work history she broke down into tears. One of the Guatemalan clinicians we were working with immediately put the paperwork aside and wrapped her in a hug.

When asked to rate her satisfaction with her current device on a scale of 1 to 10, she just shook her head and said, "I'm devastated." The smiling and frowning faces on our Likert scale just did not adequately capture the real life they were designed to represent. The story reminds us to acknowledge this tension and ultimately prioritize patient care and respect.

FUTURE STEPS

Product integration is a key challenge to achieving scale. Almost all of the clinics D-Rev staff visited have reported problems with consistent delivery of components. Issues range from an inconsistent supply of donated devices to a dizzying array of barriers for importation and customs. In order to achieve scale, we realize that we must remove as many of these barriers as we can to make the ordering and delivery of prosthetic components seamless. Devices need to work with a variety of different prosthetic systems, as different clinics around the world have adopted different systems to fit amputees.

We must also be aware of the different profiles of clinics operating in low-income regions, from "parachute prosthetists" that visit a clinic a few times a year, to large government-run facilities ensnared in red tape. We have seen hospitals that will only order all of their components, tools, and materials from a single company because the approval process for ordering new equipment is so complex. Even if a new device provides better performance at a lower cost, these large institutions will be reluctant to change their entire systems.

1.

SCREENING CHECKLIST

A screening checklist is used to determine if patient satisfies all requirements to be included in the study.

2.

CONSENT FORM

A consent form is read to the patient. This form explains the patient's rights. If the patient agrees to be in the study, the prosthetists signs as a witness.

3.

PATIENT ROSTER

Each patient's personal information is recorded on a roster. The patient is then assigned a survey packet, which has a patient ID number. This step is required to maintain patient confidentiality.

4.

PATIENT SURVEY

The patient survey includes questions pertaining to: (1) Gait, Fit Quality, Level of Mobility, and Device Functionality, (2) History of Devices, Work, and Life Events, and (3) Satisfaction with the ReMotion Knee and previous devices.

5.

GAIT TESTS

A series of gait tests are conducted, including the 10 meter walk test and the Timed Up And Go test. These tests are used to quantitatively assess the mobility of each patient, and are conducted with the ReMotion Knee and the patient's previous device.

6.

ELECTRONIC SURVEY RETURN

Once the survey is completed, an electronic copy of the forms is uploaded to a secure server shared between the clinic and D-Rev.

The process for conducting patient surveys as a part of the ongoing field trials of the v3 ReMotion Knee. The trials are being conducted over six months at four clinics in Indonesia, India, and Guatemala. The survey is administered at both the initial fitting and follow-up assessment. This process was developed to both provide strict patient confidentially, in compliance with the Stanford Institutional Review Board, and fit into the existing work flow of our partner clinics.

Finally, it's crucial that we realize that every country is different. The same rules, regulations, and hurdles that we face in one country may be completely different in each new country we enter. Thoughtful due diligence, including customer and market research, is required for us to navigate that process.

After we complete field trials for the latest version and incorporate the knowledge gained into the design of the prosthesis, we will begin centrally manufacturing the ReMotion Knee and distributing it to clinics globally. We aim to be on the market by the end of 2014.

As we scale production, we'll also roll out a large-scale system of impact data collection incorporating the lessons we've learned from our field trials. We aim to distill the data to the key aspects of patients and clinics that are most critical for increasing adoptability and improving mobility. We hope this will instigate a new era of impact assessment that includes new methods of data collection, analysis, and learning.

Throughout each phase of designing, delivering, and evaluating the ReMotion Knee, we have been user-obsessed—every person that interacts with the product is critical to remobilizing an amputee. Like links in a chain, if one link breaks, the entire chain comes apart, and the product won't reach the patients who need it.

This user-obsessed mindset requires us to clearly identify and understand each critical aspect to reliably deliver an effective medical device from importation to impact assessment. Without understanding how the product will reach customers and how to evaluate its effectiveness, the best technology alone cannot provide mobility for amputees in need.

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CASE STUDY

REMOTE MONITORING OF OFF-GRID POWER SYSTEMS

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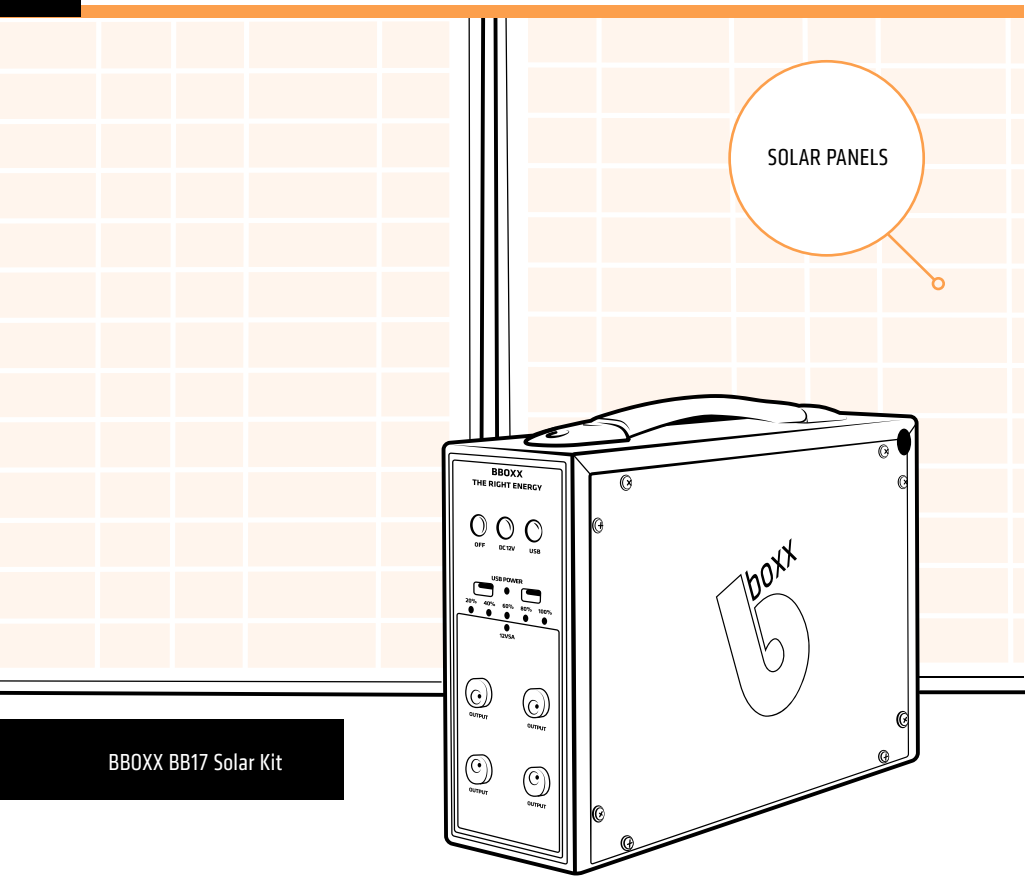
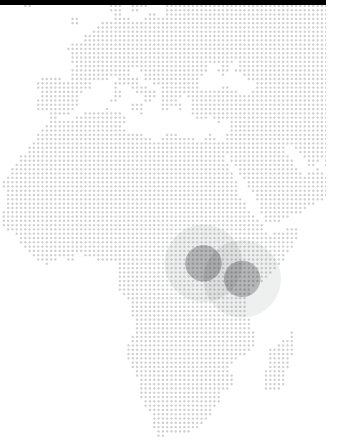


BBOXX BB17 Solar Kit

CHRISTOPHER BAKER-BRIAN
co-founded "e.quinox" in 2008 and BBOXX in 2010, providing affordable energy products and services in developing countries. He is responsible for product development, supply chain and BBOXX's manufacturing and technology partnerships. Baker-Brian earned an M.Eng degree in Electronic and Electrical Engineering from Imperial College London.

KENYA & UGANDA



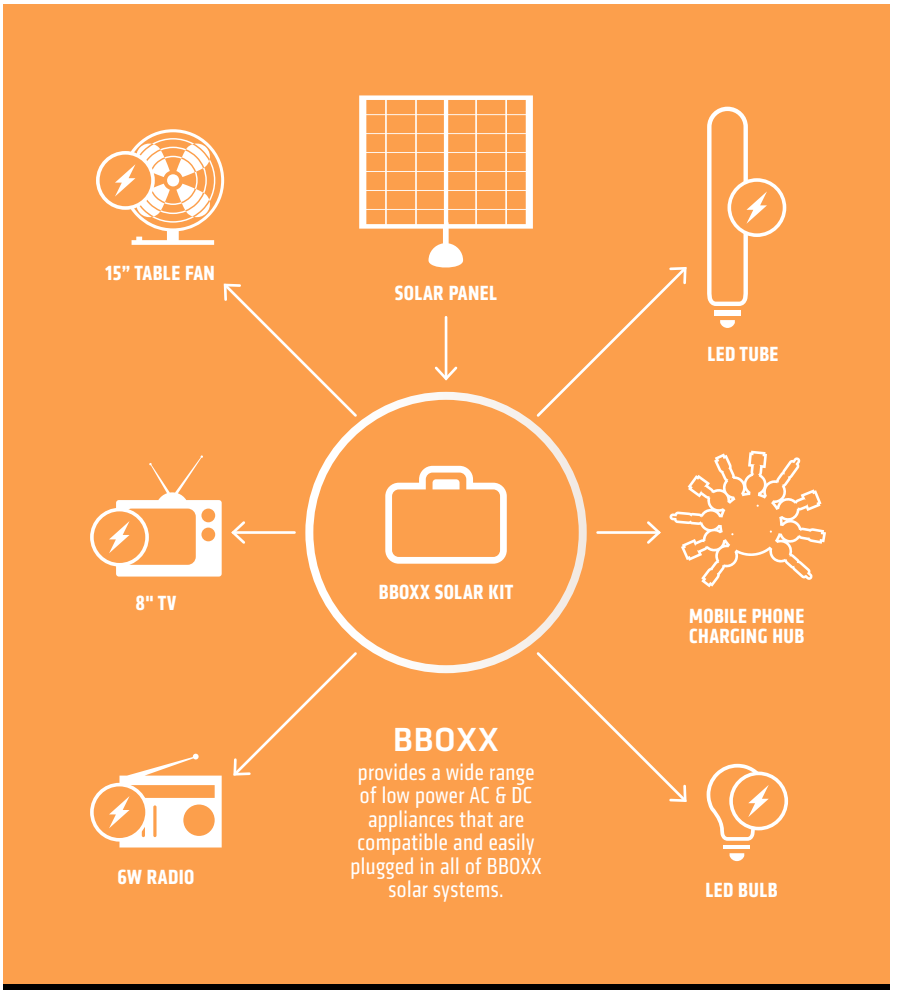
One means of bringing electricity to rural areas is via distributed solar power systems, but they have formidable upfront costs. Wireless control systems can enable companies to offer the hardware as a service paid by the month.

Traditional electricity grids, the sort that are ubiquitous in developed countries, have struggled to meet the challenges posed by attempting to electrify rural communities across the developing world. In many parts of Africa, which have economic growth rates as high as 8 percent per year, electricity demand is growing and large-scale infrastructure investments needed to build out electrical grids is not feasible. Rather than continuing to depend on kerosene and other liquid fuels for their basic energy needs, many such communities look to off-grid solar power.

Until recently, the high cost of solar panels made customer-owned solar panels prohibitively expensive. One way to reduce upfront costs to individuals is the "solar energy kiosk," in which a solar panel charges a battery pack used by an entire community.

My first experience in developing solar power for Africa was through the building of these energy kiosks. Together with Mansoor Hamayun and Laurent Van Houcke, who were also electrical and electronic engineering students from Imperial College London, in 2009 we started the charity e.quinox, through which we began to develop and distribute solar-powered battery packs to off-grid locations in Africa.

We developed the idea of a "solar kit" that comes with its own portable solar panel, a control unit/battery, lights, phone-charging equipment, a USB charger, and the like.



BB17 Solar Kit Accessories

We initially went to Rwanda, and while there connected with their ministry of energy and other energy-minded organizations. Armed with knowledge gleaned from firsthand observations of what we saw on the ground, we went back to the U.K. and developed our energy kiosk, which supplies small power systems charged from a central location in a community. We built the first kiosk in Rwanda in 2009 which gave power to over 60 local households in one village.

The kiosks were popular—we received requests from 200 more households in the initial village—but they were soon outdated. When we started the project, solar panels cost about $6 or $7 per watt, making it cheaper to centralize the generation of electricity. However the price of solar panels manufactured in China soon fell dramatically, to about $0.80 per watt, which makes the panels much more affordable for individuals.

Whilst the solar kiosk "rental" model works well in certain communities and provides a platform to carry out maintenance and administrations, kiosks are a large investment and are difficult to scale quickly across many markets. Since it's cheaper to simply install solar panels on customer's roofs than to build a separate building to house the panels, we developed the idea of a "solar kit" that comes with its own portable solar panel, a control unit/battery, lights, phone-charging equipment, a USB charger, and the like. Some kits come with low-power TVs and radios and, in hotter climates, fans.

The donor-focused and donor-led nature of e.quinox meant that the enterprise was ultimately limited, as there was no business incentive for us to grow. In order to achieve scale, we created a for-profit enterprise, BBOXX, with the ability to partner with other global players and use investor capital where necessary to achieve greater impact. Within four years of founding the company, the team had built a global supply chain for

its solar kits that have now electrified over 100,000 people in the developing world. We manufacture parts in China, which means we can manufacture at scale. We ship to 40 different countries, with a main focus on East Africa.

ACHIEVING SCALE

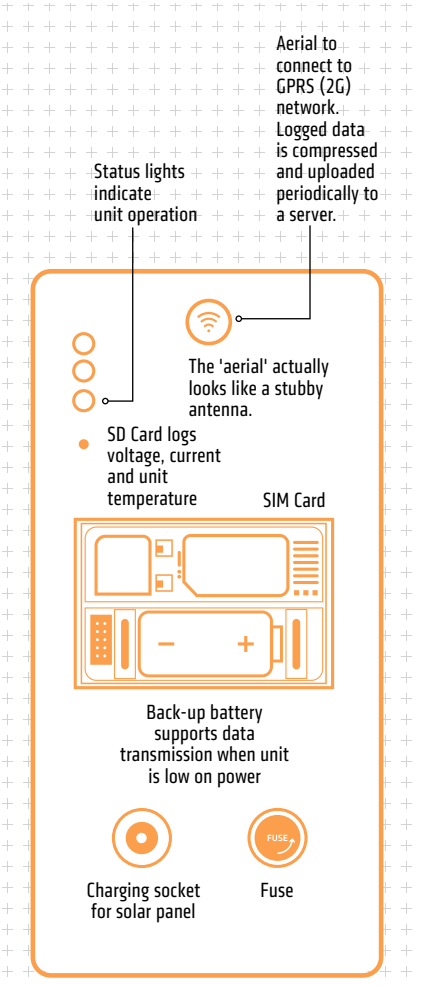
Despite an initially rapid growth rate in our first years of operation, several barriers remained for us to reach true scale. Three barriers in particular were constraining product demand across the developing world.

First, end-customers have a limited access to capital. While many customers in the developing world can, over the course of a few months, scrape together the cash needed to pay for small solar-based LED lights typically used for reading, cooking and other household activities, off-grid solar kits of any useful size remain out of reach for most consumers. And it is these more expensive kits that can power a much wider range of devices, and thus can generate additional income for their owners and allow them to be engaged in their own businesses.

The traditional solution to this issue of constrained capital has been to work with local financial providers to offer loans to customers. Despite several attempts to partner with organizations across the continent, we have struggled to find committed players in this sector who have the market reach, the willingness to lend to a relatively new market, and the in-depth knowledge and contact with its customers to offer a competitive solution to the problem of end-customer financing. Our solution here was to do it ourselves and to only partner where necessary.

In providing customers with the ability to use a wide variety of solar-powered appliances, we quickly realized that another problem had emerged: It was increasingly difficult to design and provide systems in mass volume that were tailored to the unique needs of individuals. For example, a small shop owner who operates our product during daylight hours has a completely different load profile from a large household that tends to use most of its electricity in the evening so as to run entertainment and lighting systems. Our early models were "dumb" in as much as they couldn't connect to the Internet and send information from the customers back to us. They just took power from the panels and converted it to electricity that was stored in a battery for use by the customer.

Such differences in load profiles are very difficult to accurately capture with traditional paper and pen surveys or customer interviews, and yet they are crucial to assisting in the design and development of the next generation of products. Hence, capturing in detail what our customers really want to do with our products is an important step in developing the right products for this vast consumer market.



Rear of BB17 unit showing the monitoring hardware.

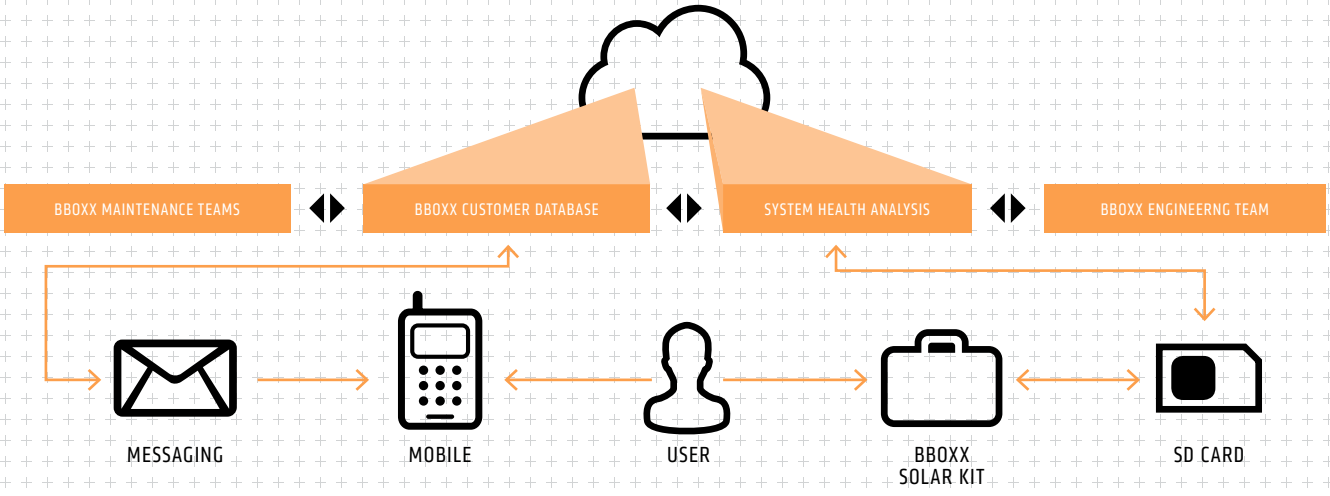
It was increasingly difficult to design and provide systems in mass volume that were tailored to the unique needs of individuals.

Finally, we see battery storage as a main barrier to achieving mass electrification. The majority of new deployments in Africa, including microgrid systems but mainly off-grid systems, depend on battery packs. This is often the major life-limiting component of a product and the one that ultimately determines the lifespan of a system.

This is a complex area, intensely researched in universities and business sectors, and driven by Western demands for improved performance and reduced cost in electric vehicles and off-grid energy storage applications. Such research has helped us to understand the battery market trends and technologies for the foreseeable future. However, there are gaps in this knowledge base when it comes to their use in developing world conditions and usage profiles, which all have a direct effect on the performance of a battery over its lifetime.

REMOTE DATA CAPTURE

To overcome those barriers and to provide a commercial platform upon which BBOXX could increase the number of units produced, in 2013 we developed a remote monitoring and control system. This system was designed to enable our products to remotely connect to a central server over the local general packet



Remote Monitoring and Customer Relationship Scheme

radio service (GPRS), or 2G, network that has achieved widespread coverage in many African countries, due to the explosion in popularity of mobile phones. The remote monitoring and control system works by continuously measuring the battery voltage, charging/discharging current, and the battery temperature, then logging and compressing that data to a small on-board memory chip and periodically uploading the compressed data to a server.

The data can be analyzed to better understand how the product is being used by the customer. The system also includes the ability to send alarm signals to the server when, for example, the unit experiences unusual electrical signals or is tampered with or misused in any way.

During the development phase of the remote monitoring and control system, BBOXX partnered with Oxford University and London-based energy storage specialists Synergy Energy to better understand the real life effects of batteries in the field and how our customers use them. Charging and discharging profiles were analyzed, as were how environmental conditions such as increased temperatures affect the lifespan and performance of a battery unit.

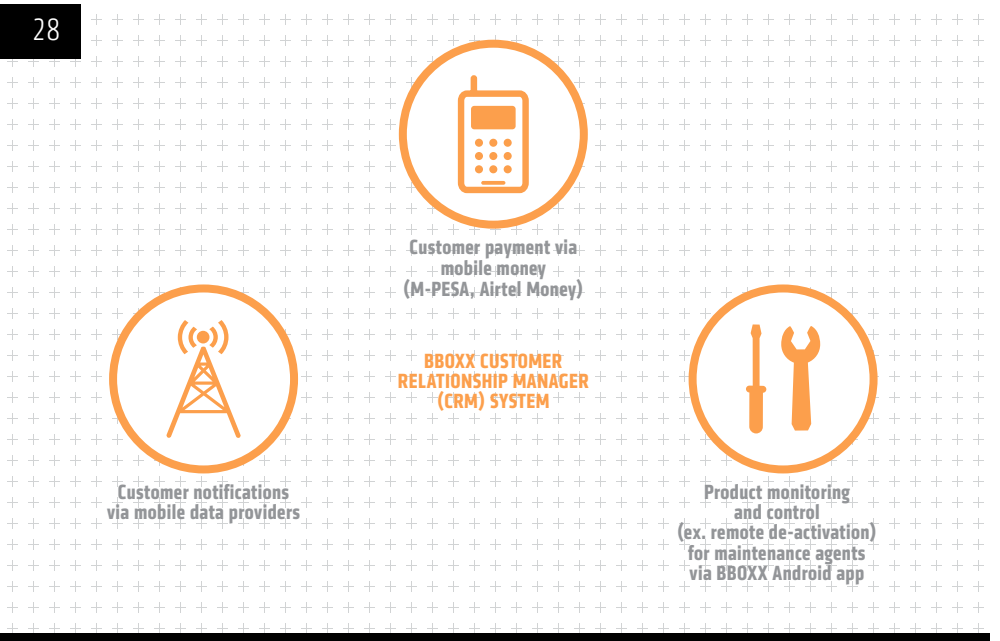
Thanks to the ability to capture data at a higher resolution than previous attempts to monitor similar products, we obtained a more detailed understanding of how, when and why the customer has been using certain devices. We also had the ability to trace when a certain device such as an LED or a TV is switched on. That level of detail has, for the first time and with a high level of confidence, enabled us to understand how a wide range of customers use the products and also to distinguish usage differences between businesses, small, and large households. That understanding will allow future product offerings to be more tailored to the need of the users without increasing the burden of a greater product range on our supply chain.

The data gathered from these units is also analyzed by our partners at Synergy Energy and Oxford University to determine the expected end of life of the battery based on its current performance. The dataset gathered will be one of the largest and most complete to date and allow for highly accurate models to be validated even further. Machine learning techniques are being used to constantly improve this model as the data-set increases, allowing accurate predictions to be made based on the temperature of the battery and use of the kit by the customer.

Beyond monitoring, the system also has a commercial application to BBOXX. The system enables BBOXX to remotely deactivate units, which allows us to distribute the system on a payment plan. Instead of selling a product that requires a 100 percent upfront payment, we can offer something that can be paid for over six to 24 months.

Remote deactivation is essential in order for BBOXX to create a feasible and cost-effective business model that can be eventually backed by institutional investors.

Indeed, remote deactivation is essential in order for BBOXX to create a feasible and cost-effective business model that can be



BBOXX Customer Relationship Manager (CRM) system

eventually backed by institutional investors. Providing a pay-as-you-go service opens up the product range to markets previously excluded due to financial constraints.

The remote monitoring system also provides us with other benefits. At the logistical level, for instance, dispatching a replacement battery for a failed system from a central warehouse to an end customer located in a remote area is expensive and time consuming. Remote monitoring has given BBOXX the ability to accurately predict when a battery is going to fail and to schedule a planned maintenance visit with the customer. This is far cheaper than unplanned maintenance and provides a higher level of service to the customer, which allows for repeat orders, upgrades and other commercially beneficial services to be sold to generate new revenue streams.

BBOXX developed a customer relationship management system to mediate the interactions between product and customer. This CRM system was built to integrate the commercial and technical management tools required to run such a system with minimal customer interaction. Such interactions include enabling customers to pay on a monthly basis for the product using mobile money services such as M-PESA and Airtel Money, which have a high degree of coverage across Kenya and Uganda, our initial target countries.

In addition, integration with mobile data providers, an SMS gateway for sending notifications to customers about their product, and a custom-developed BBOXX Android app for our on-ground sales and maintenance agents has enabled BBOXX to build a system that can control all aspects of our products from one central location, minimizing operational costs that have traditionally been very high in what is a dispersed and geographically scattered marketplace.

The remote monitoring and control system is currently built into the BBOXX BB17 solar-kit system, which have 17-amp power capacity batteries and 50-watt solar panels. BBOXX has so far deployed 100 BB17 systems, in an initial pilot project across separate sites in the west of Kenya and the west of Uganda. All of these products have been sold using a payment plan to customers who pay on a monthly basis using mobile money services.

Although the sample set from these units is small (the system has been running only for a few months), the initial results are very promising. We are already starting to see distinct groups of users emerging who vary in terms of what appliances they use on the systems and when. The data gathered from the battery analyses has already started to show how certain use patterns affect the lifespan of the batteries. Even if user pattern changes at this stage are small, the system can detect them, and as the dataset expands, root causes of these changes in battery capacity will be able to be pinpointed, analyzed and a solution to extend battery life found.

Even if user pattern changes at this stage are small, the system can detect them, and as the dataset expands, root causes of these changes in battery capacity will be able to be pinpointed, analyzed and a solution to extend battery life found.

The customer's interaction with the products has also been showing signs of changing. The use of the CRM system to send customers reminders about their monthly payments has meant a much better automated communication with the

Remote monitoring has given BBOXX the ability to accurately predict when a battery is going to fail and to schedule a planned maintenance visit with the customer.

customer, and has helped to bring down the number of late payments compared to a traditional non-automated system that BBOXX and its partners previously used. The "threat" of having the ability to remotely turn off the system in the event of nonpayment and to then locate the system using the inbuilt GPS transmitter to collect it from the customers house is also a very powerful tool, although one that thankfully has only been used sparingly to date.

In time, we hope to have a much more robust dataset as we deploy more systems. We hope to put up to 8,000 monitoring units in the field by the end of this year and over 100,000 by 2016.

LONG-TERM ELECTRIFICATION

Right now, BBOXX is shifting from testing products in the field and instead is gathering data with the systems already in place. Over the next few months we will be releasing systems that have the ability to actively change settings, to help extend battery lifespan and customize product settings to the users' individual load profiles—essentially "personalizing" the box to the way the customer is using it. In addition, the data gathered from an increasing number of unique customers will be fed back into the development cycle, allowing us to offer a much more tailored product and potentially reduce the cost of acquiring a system by cutting out or reducing the size of certain components where they are deemed to be unnecessary.

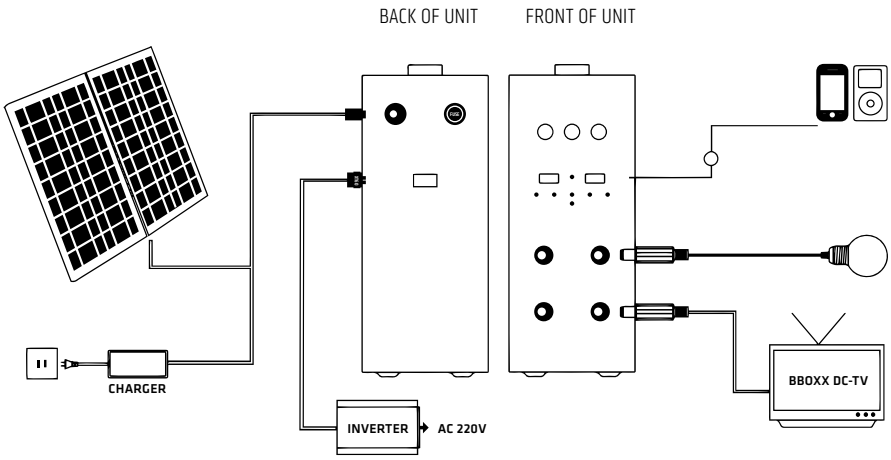
Over the coming months, battery lifespan predictions will be used to help optimize the supply chain of replacement batteries to our maintenance teams on the ground, meaning heavy and expensive replacement parts can be optimized in terms of their delivery to our growing network of distribution points across Africa.

The long-term vision for BBOXX is to electrify 20 million customers by the year 2020. This is an aggressive target, but one that we feel is not out of reach. In order to achieve this, supply chain, product range, and on-ground sales and support teams are being built to allow large volumes of products to be deployed and managed effectively by our operations teams in Africa. Tools such as the ability to remotely deactivate and locate our units will give investors' confidence in the ability to provide the capital necessary to offer up to 24-month payment plans to our customers.

Finally, the remote monitoring system ensures that we are able to offer all our users a tailored service from the minute they first turn on their product to the day it is replaced or upgraded, ensuring highest levels of customer satisfaction.

POWER
50 Watt solar panels
17 Amp power capacity batteries

MONITORING
Battery voltage, charging/discharging current and the battery temperature, logging, compressing and uploading data periodically to a server.



BB17 Solar-kit Functionality

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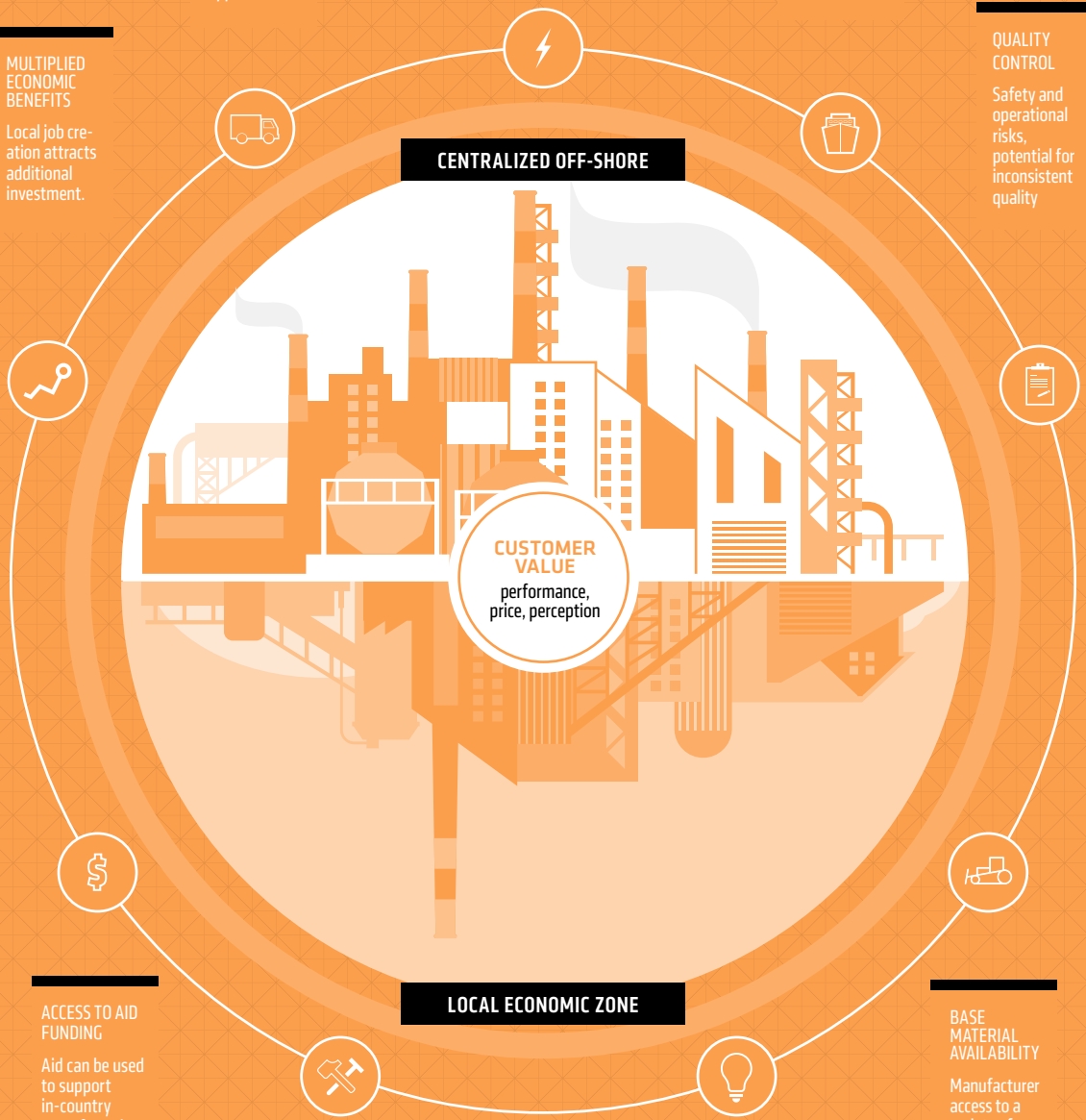
SUPPLY CHAIN FACTORS



UTILITIES

Access, reliability and cost of electricity.

THIRD-PARTY LOGISTICS

Costs of warehousing and shipping support.

SHIPPING TIME & COST

Lead time, price of fuel, and border tariffs

MULTIPLIED ECONOMIC BENEFITS

Local job creation attracts additional investment.

QUALITY CONTROL

Safety and operational risks, potential for inconsistent quality

ACCESS TO AID FUNDING

Aid can be used to support in-country manufacturing.

BASE MATERIAL AVAILABILITY

Manufacturer access to a variety of equipment and materials

HUMAN RESOURCES

Relative expense and skill of local workers.

CAPACITY BUILDING

Knowledge transfer can drive development

LOCATION MATTERS

FOR COMPANIES MAKING PRODUCTS FOR THE DEVELOPING MARKET, WHERE TO MANUFACTURE IS A SURPRISINGLY COMPLICATED QUESTION.

BY ADRIENNE DAY AND ALAN SPYBEY

Krista Donaldson, the CEO of D-Rev, recently gave a TED talk on her company's new prosthetic knee designed for those living on less than $4 a day. Donaldson stressed that products for this market need to be designed for mass production. "How do you ensure technology reaches users?" Donaldson asked. "You can have this great invention, you can have this great design, but how do you get it to the people who most need it?"

Logistics is hardly the sexiest aspect of the social-innovation sphere, but in many ways it can be the most critical. For many aspiring engineers, dreaming up the product is the fun part, and awards are dutifully doled out for the most promising designs. But the real challenge often comes in addressing the issue of, as Donaldson says, getting products in the hands of those who need them most.

Supply-chain economics is surprisingly complicated. The decision whether to manufacture in the local market or externally in a global center—say, in China or India—largely depends on the type of product and its intended customer base. It also raises some difficult questions. For example, when an organization works with manufacturers local to the community they are serving, they will almost always employ workers from the region in question. But in many cases the quality of locally manufactured products can't match what can be produced in China.

"I feel it is very hard to maintain high quality with decentralized local manufacturing," Donaldson told *Demand*. "You can do it, but there are a lot of checks and balances that need to be in place, and so we really believe the best model for the end users is often centralized manufacturing, because you can have high volume at a very high quality."

D-Rev's plan for the ReMotion Knee is to manufacture in Asia, most likely in China, and then move to an Asia-based third-party logistics company, or 3PL, that warehouses the product and ships it out to where it is needed.

Vin Narayan, who oversaw development of the ReMotion Knee for D-Rev, explained, "The idea is that the clinic [in India] will order with us, D-Rev will relay that order to the 3PL [in, say, Hong Kong], they will pick some knees from the master carton, package them and ship them directly," as they can to any country in the world.

Centralized manufacturing, much of which takes place in China, makes it easier to maintain consistent quality standards, and bulk orders placed with one factory can sometimes mean lower overall costs. But potential jobs in the sales region in question are lost, supply chains are longer, and more lead time is needed to get a product to a customer.

The decision on where to manufacture can also lead to intellectual property issues, as Sarvajal found out when launching its clean-water program in Rajasthan, India. Sarvajal provides clean drinking water to those at the base of the pyramid, offering "water ATM" equipment to local franchisees for them to operate while Sarvajal controls all aspects of production. Some of the franchisee are themselves savvy business people who know the local market and who might be capable of manufacturing the equipment from blueprints.

While there may be some advantages from decentralized manufacture, turning over the control to a local franchisee means a loss of quality control of the end product. That's a very real concern when contamination of the product (water) can be introduced at many stages in the process. Also, that sort of decentralization would mean a loss of revenue for Sarvajal—a thorny issue when the end goal is to get clean water, at scale, to people at the last mile, not to maximize profits for the company in charge.

Logistics is hardly the sexiest aspect of the social-innovation sphere, but in many ways it can be the most critical.

To avoid the problems associated with centralized manufacturing in a country like China, Burn Manufacturing CEO Peter Scott initially employed a hybrid approach when first launching the production of his Jikokoa cookstove in 2010.

"Right now we are making 'blanks'"—a flat piece stamped out of a large thin sheet, with a custom profile—"in China, then we do a lot of forming, powder-coating, assembly, riveting, and boxing in Kenya," Scott said.

That process is going to change this summer, however, when Burn opens a brand-new 20,000-square foot facility in Nairobi. "By June we'll be blanking all of our parts [in Nairobi]," Scott said, "so we'll be going from raw materials to finished goods, all within that one factory."

According to Scott, this means the creation of about 200 new jobs for local workers in Nairobi within the year, and an output of 3.5 million stoves within the next decade.

"Kenya is a more expensive place [than China] to operate," Scott said. "Electricity is more expensive and there's more corruption. But labor in Kenya is cheaper and there's a lot of aid and development money that can come in to support it too, so if we're making stoves in China, there's no grant funding in play."

LOCATION MATTERS

In contrast, the Nairobi-based KickStart, which makes irrigation pumps for local farmers, used to make products locally but moved manufacturing to China in 2007. There were two main reasons for this shift: quality control and logistics costs.

"The manufacturing processes in China are actually more efficient and better than the manufacturing processes in Kenya," says Fred Obudho, Manager of KickStart's Product Intelligence and Development Unit.

KickStart incurred considerable opportunity cost designing, fabricating and maintaining manufacturing equipment for local companies, and operating its own quality control. Logistics began to be a problem when sales outside of Kenya rose significantly. The cost of sending a container from Kenya to Malawi is similar to dispatching it from China to Malawi. Since the free on board (FOB) cost—essentially the factory price—of the Kenya pump was over $15 more than China Free on Board, producing for Malawi from Kenya would have meant a penalty for the Malawian farmer.

Though they have different approaches to supply-chain management, both Burn and KickStart are wary of local contract manufacturers.

> Centralized manufacturing makes it easier to maintain consistent quality standards.

"A contract manufacturer might not produce the quality that you want, or have the same timeline, or maybe they are interested in doing work that's more profitable [than yours]—they aren't in it for the long haul," says Scott. "So to outsource the manufacture of your key product is a very dangerous thing to do in Africa."

Other manufacturers agree. David Auerbach of Sanergy, which makes sanitation units for use in Nairobi slums, advocated local control of production. In an interview, Auerbach said ownership of the production process was essential to maintaining quality and keeping costs down.

The decision on where to manufacture sometimes hinges on the type of product being produced. For KickStart's water pumps, fine tolerances are needed to produce waterproof seals, and construction needs complicated fixtures to maintain quality. It's easier to accomplish this in a global manufacturing center. Burn's stoves, on the other hand, are designed for formed metal parts, which obviates the need for a craftsman's judgment. Parts also do not deviate in shape, and they intelligently interlock in assembly. All this makes local manufacture more feasible.

Development professionals who have made one choice for their supply chain economics recognize that different products require different logistics. KickStart's Obudho, for instance, supports Scott's decision to manufacture the Burn stoves in Kenya, even as his pumps are made in China. At one time, Obudho actually was a production manager for a German company that had switched some of the production for their stoves from China to a factory in Kenya. (The company retained the "Made in China" stamp for the East African market.)

"To me skill level is not an issue," Obudho said. "I think there are people in Kenya who can do work just as well as people in China."

Obudho underscored the importance of keeping jobs local. "I don't see any other manufacturer producing well under contract without somebody looking over their heads," he says. "If [you are] going to control the manufacturing yourself, there are a lot of advantages to doing it in Kenya."

It's important to remember, however, that the location of manufacturing is a secondary consideration. The most primary goal is to provide products that deliver real value to customers.

But what if the manufacturing and logistics model compromises the customer value proposition?

Burn, for instance, has already evolved through two distinct supply models, Peter Scott said, and is about to launch a third.

David Auerbach at Sanergy conceded that if local costs escalated, pushing up the product price by 20 percent, centralized manufacture would still be an option. Conversely, Fred Obudho at KickStart said that volume efficiencies and rising China costs could allow manufacturing to return to East Africa.

D-Rev is already agilely adopting different production and supply chain tactics to different products with different market characteristics. In contrast to the ReMotion Knee, its Brilliance infant jaundice treatment device is both manufactured under license and distributed in India.

D-Rev's Vin Narayan said that while the prosthetic knee had a distribution limited to a few rehabilitation clinics, for the infant care device, "there are thousands of potential clinics that we could be selling to." That scale called for an Indian-based partner with excellent local knowledge; D-Rev decided to motivate the company to produce high quality products by offering a significant stake in the operation.

There are any number of ways to manage the manufacturing and logistics of products for the developing world consumer. But to be successful, providing the best value for the customer must be the final deciding factor for those supply chain choices.

ADRIENNE DAY is a New York based freelance writer and Contributing Editor to DEMAND. **ALAN SPYBEY** is the director of product intelligence and development for KickStart in Nairobi.

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