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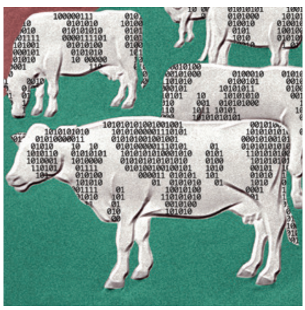

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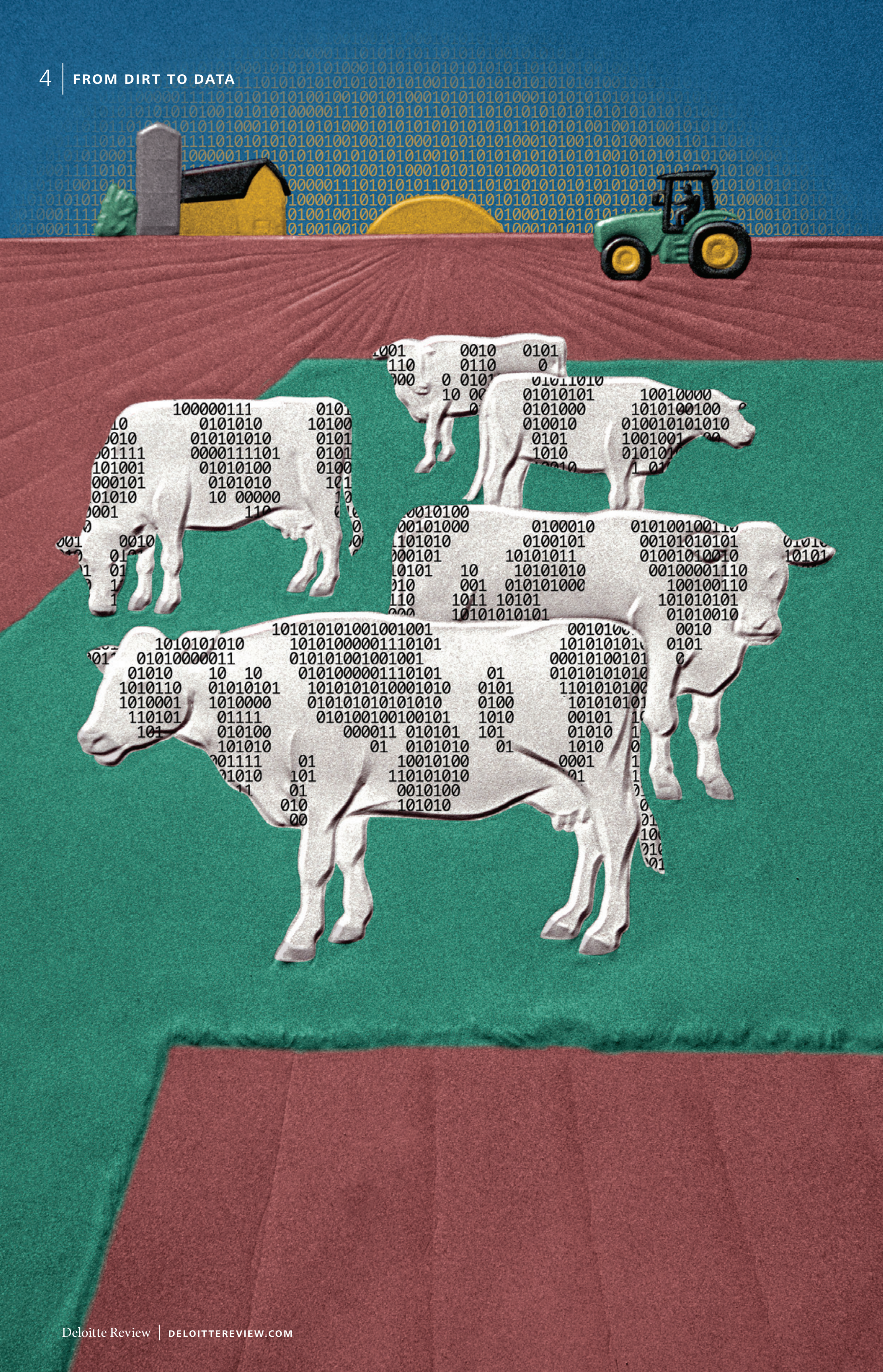
BY WILL SARNI, JOE MARIANI, AND JUNKO KAJI
> ILLUSTRATIONS BY ALEX NABAUM



FROM DIRT TO DATA

The second green revolution and the Internet of Things

BY WILL SARNI, JOE MARIANI, AND JUNKO KAJI
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The first "green revolution"—a series of rapid technological and agronomic advances that took place after World War II—transformed agriculture, saving over a billion people from starvation[1] and setting the stage for the world's population to increase from 3 billion in the late 1960s to an estimated 7.3 billion today.[2] Despite this phenomenal growth, however, there are significant challenges to the continued expansion of this first green revolution, and in some ways it has been the victim of its own success.

Increased water use for irrigation, soil degradation, and chemical runoff are just some of the unintended consequences impacting the landscape. The deterioration of the agricultural resource base due to these factors is thought to have contributed, in part, to a slowdown in yield growth that began in the mid-1980s. These environmental costs suggest that the long-term success of the first green revolution may be at risk.[3]

Meanwhile, the need to produce more food remains urgent. The world population is expected to reach nearly 11 billion by 2050, representing an increase in agricultural demand of approximately 70 percent—a figure that can only be met with a new revolution in agriculture.[4]

NORMAN BORLAUG

The first "green revolution" was led by Norman Borlaug, an American agronomist who is considered to have "saved more lives than anyone who has ever lived" through his achievements.[5] These included the development of high-yielding varieties of cereal grains and the distribution of hybridized seeds, synthetic fertilizers, and pesticides to farmers.[6] Borlaug's contributions, as well as the widespread buildout of irrigation infrastructure and the adoption of modern management techniques, greatly increased yields without requiring an expansion in agricultural land.[7]

Fortunately, we are on the cusp of another full-scale green revolution, one with the potential to address some of the unintended consequences of its predecessor—including those related to both resource use as well as the economic and social well-being of farmers in emerging economies. In one sense, the first green revolution's unintended consequences were due to new methods of farming: new seeds, new fertilizers, new techniques. To avoid the same kinds of unintended consequences as we search for new increases in production, the second revolution will likely be driven not by new techniques but rather by technology—by giving farmers the data to help make better decisions. In short, this second green revolution will likely be catalyzed by the set of connected technologies collectively called the Internet of Things (IoT).

This second green revolution will likely make use of very different tools and techniques than the first. It will likely be grounded in the use of data to inform more efficient and effective farming practices and drive associated environmental and social benefits. Technologies such as advanced sensors and monitoring equipment can now allow farmers to monitor crops more precisely and continuously than in the past. The data collected by these technologies can enable farmers to make more effective and strategic decisions that increase productivity with reduced impacts on the environment.

From manipulating the growing environment to produce low-potassium lettuce to attaching sensors to cows to identify potentially sick animals, there is little question that the second green revolution holds the potential for remarkable results.[8] To manage all this, IoT technologies will likely take center stage on the farm of the future.

IOT AND AGRICULTURAL PRODUCTION

New insights, new productivity

Historically, the agricultural sector could rely upon a relative abundance of resources such as water and nutrients to increase yield. Farmers and companies managed goals predicated upon that abundance, and relied upon the expectation of an ongoing flow of these inputs. However, the world continues to face an unprecedented demand for food and increased competition for these critical resource inputs. To meet this demand, the IoT should consider going beyond simply improving existing agricultural processes; it must introduce innovation that breaks traditional trade-offs. The good news is that this seems feasible: It is estimated that, with new techniques, the IoT has the potential to increase agricultural productivity by 70 percent by 2050.[9]

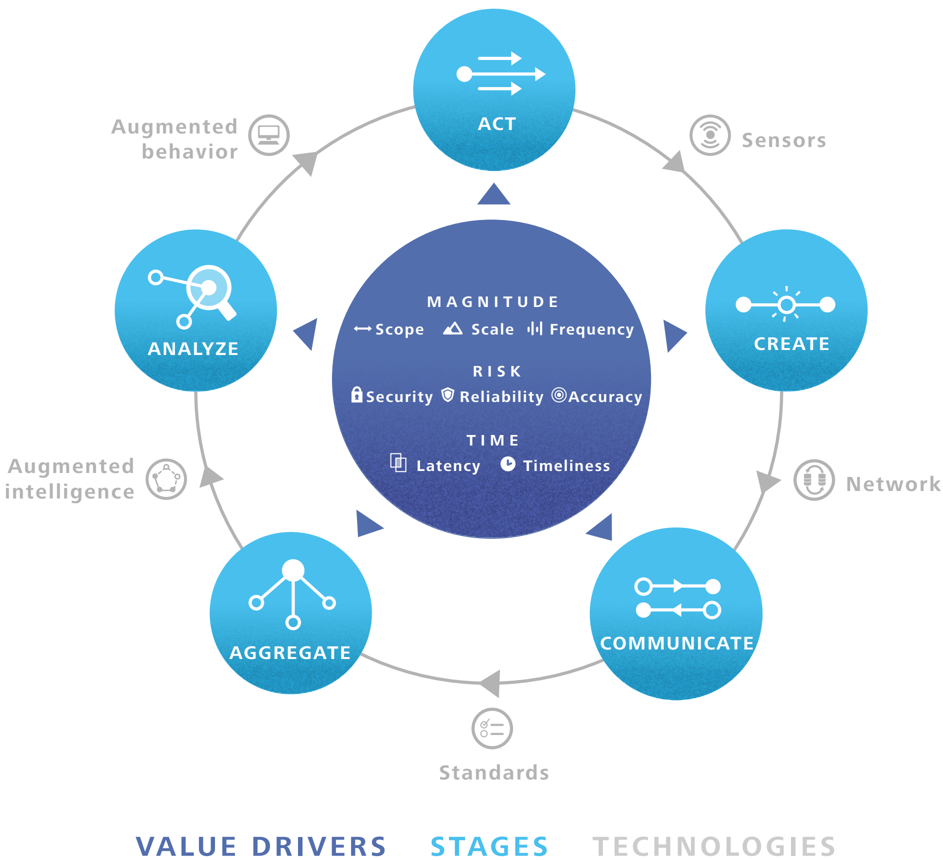
The IoT's ability to collect and correlate resource data means that the agricultural sector can develop solutions *to do more with less*—for instance, by enabling automated precision agriculture.[10] In other words, the IoT's ability to make visible detailed resource data enables farmers to increase the efficiency with which they apply scarce and costly inputs. In addition, IoT-enabled farmers can also reap benefits in improved environmental and social performance in areas such as sustainable

THE INFORMATION VALUE LOOP

The suite of technologies that enables the IoT promises to turn almost any object into a source of information about that object. This creates both a new way to differentiate products and services and a new source of value that can be managed in its own right.

Realizing the full potential of the IoT motivates a framework that captures the series and sequence of activities by which organizations create value from information: the Information Value Loop.

Figure 1. The Information Value Loop



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To start with the obvious, the value loop is a *loop*: An action—the state of behavior of things in the real world—gives rise to information, which then gets manipulated in order to inform future action. For information to complete the loop and create value, it passes through the *stages* of the loop, each stage enabled by specific *technologies*. The amount of value created by information passing through the loop is a function of the value drivers identified in the middle. Falling into three generic categories—magnitude, risk, and time—the specific drivers listed are not exhaustive but only illustrative. Different applications will benefit from an emphasis on different drivers.

agriculture, fair wages, and humane labor practices, which are increasingly important to food manufacturers, retailers, and consumers.[11]

To do so, it is crucial to collect new data on a real-time basis and make these data readily available for analysis and action to stakeholders along the food value chain. One of the more powerful developments in this regard is NASA's Gravity Recovery and Climate Experiment (GRACE) mission. GRACE, launched in 2002, uses two spacecraft to map variations in the Earth's gravity field. The gravitational research is, in part, collecting relevant agricultural data on factors such as groundwater availability and stress as they relate to global agricultural production areas. Maps developed using the GRACE data are able to identify the difference between climate-related drought conditions and the depletion of aquifers through groundwater extraction that exceeds recharge. However, currently, this information is typically only available in specialized scientific journals. By making this information more available to farmers, the IoT, drawing on GRACE as a sensor, could help farmers make more efficient and effective use of water resources.[12]

Bringing IoT technologies closer to earth, aerial drones are also an example of how new sensors are making data more readily available. Drones can be a very useful tool for agricultural companies in that they provide aerial data and imagery for large expanses of land, delivering insights into the health of the land and potential problem areas. One company working to simplify the creation and analysis of drone data is DroneDeploy. The company's eponymous software program for mobile phones significantly simplifies multiple aspects of drone usage for mapping land and monitoring applications. The software creates flight plans, pilots the drone on the plan, and then automatically analyzes the pictures it takes to construct a 3D map of the land.[13] This eliminates the need for users to learn how to fly a drone for mapping purposes, reduces the cost of software required to process aerial imagery data, and shortens the time it takes processing software to analyze the imagery and deliver insights. Because of this, DroneDeploy may offer opportunities to agricultural companies to cut significant time and costs associated with managing large areas of land without the technological learning that both drone use and data processing can often require.[14]

Not just more, but better

Beyond increasing agricultural productivity, IoT technologies can improve the nutritional value of food.[15] For example, Fujitsu has produced a raw lettuce with less than 80 percent of the potassium content of traditionally grown lettuce; high potassium is unhealthy for people on dialysis or suffering from chronic kidney disease. The hardware sensors used by Fujitsu in this project are similar to those used in a semiconductor plant—in fact, Fujitsu's test bed is a converted chip manufacturing plant. The data collected by sensors throughout the building are used to adjust the controls for the climate, light, and other conditions needed to grow low-potassium lettuce.[16]

Beyond merely lettuce, the IoT is also being applied to livestock to improve care quality and herd productivity. Writtle College's Jonathan Amory has attached sensors to dairy cows to help farmers identify illnesses earlier, with the aim of reducing animal suffering and increasing milk yields. By analyzing the cows' movement patterns, researchers were able to identify individual animals that had fallen ill. They could then provide treatment only to those animals that needed it, which not only improved the quality of life for that animal but also lowered the risk of contagion across the herd, increasing overall productivity.[17] Such a targeted approach to veterinary care can have the added benefit of reducing the need for herd-wide preventative antibiotics, which have been shown to contribute to drug-resistant bacteria.[18]

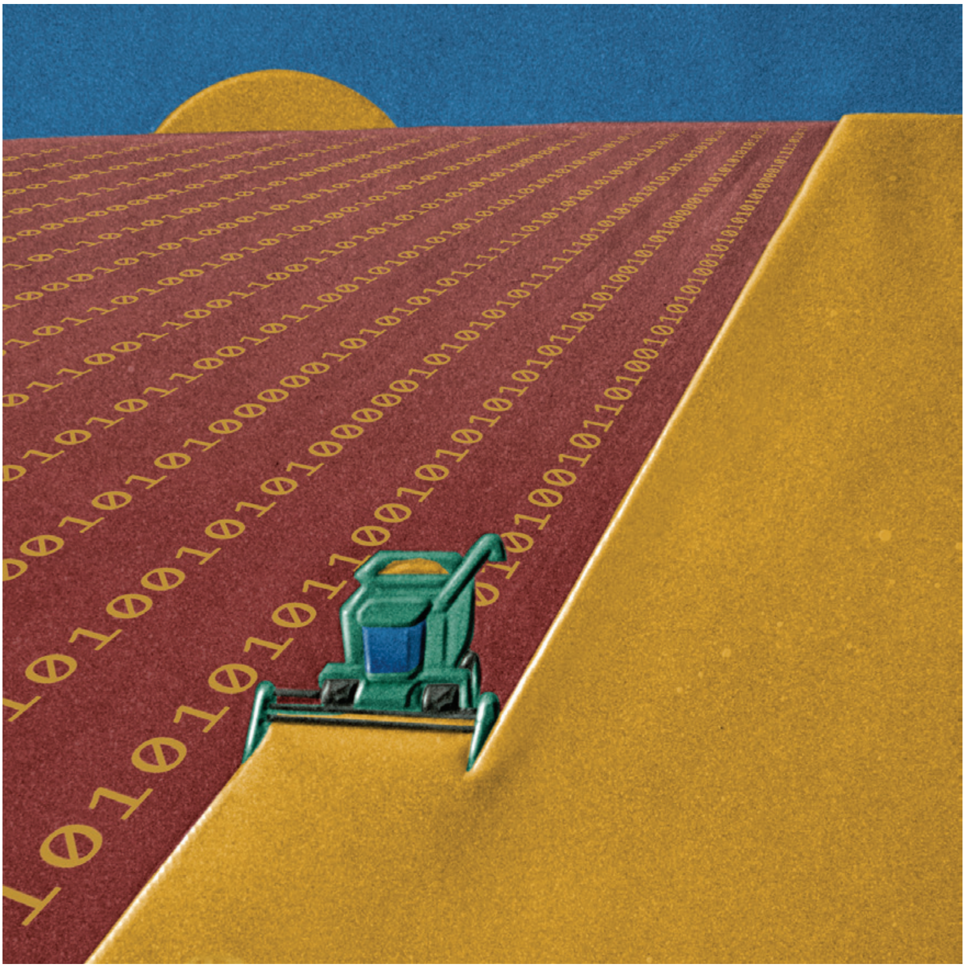
VALUE FOR ALL: MODELING VALUE CAPTURE USING THE IOT VALUE LOOP

The World Economic Forum (WEF) recently identified the IoT as one of its 21 "tipping points," or moments when a specific technological shift hits mainstream society.[19] According to WEF, the IoT is expected to reach its tipping point by 2022, although some might expect the tipping point to come much sooner given the pressing increase in agricultural demand and the associated resource scarcity challenges.[20] However, achieving that tipping point relies on all users of the IoT, whether large company, smallholder farmer, food manufacturer, retailer, or consumer, being able to capture value. (For more information on how value capture can impact technology adoption, see "Power struggle" in *Deloitte Review* issue 17.[21])

As the IoT proves its value in industry after industry, the main questions now for stakeholders in the nascent agricultural IoT ecosystem—farmers, food and beverage manufacturers, distributors, retailers, and technology companies—are how to commercialize and scale the technologies, and who will pay for their development and deployment.[22] To address these issues, innovative partnerships coupled with technology innovation will need to occur in ways that extend the depth and complexity of stakeholder relationships across the agricultural value chain.

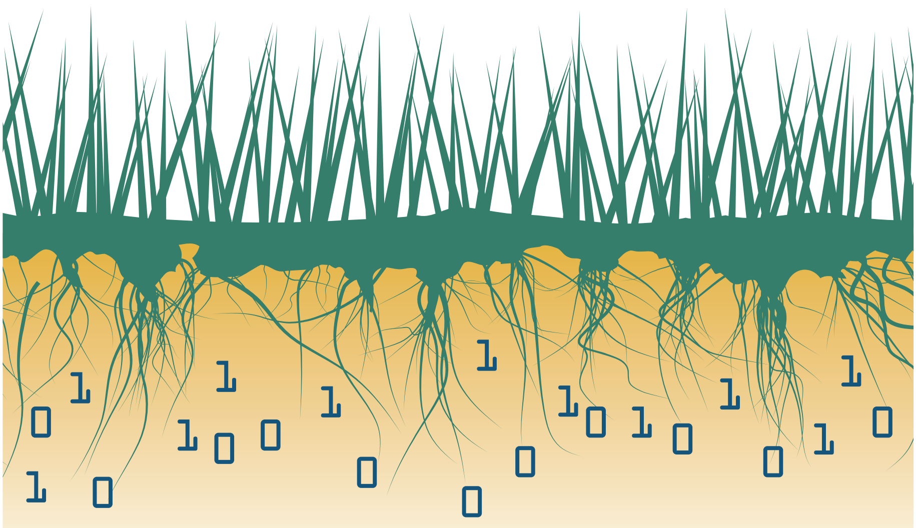
Large-scale industrial farmers

For agribusiness, food and beverage companies, and technology companies—as well as for investors—the question of finding value in the IoT is largely one of corporate strategy: identifying where to play and how to win. The key step for the producers and users of the technology that make IoT solutions work is to find the IoT applications that create the most value.



Perhaps the best-known examples come from traditional agriculture players. One such company has instrumented tractors and farm equipment, enabling owners to know their precise location via Global Positioning System and numerous other parameters. The same company has also created multiple online portals to aggregate individual farmers' data from all over the world. For the individual farmer, these data, enhanced by up-to-date weather conditions, can help the farmer make better-informed decisions on planting, harvesting, and other actions that impact crop yields. At a community level, websites aggregate data from a wide range of equipment in order to better understand equipment performance: fuel usage, productivity levels, and estimates of when and how equipment might break down. The broader community of information can be used to understand how to get even better results from specific equipment.[23]

On the other hand, new entrants to the industry, such as technology company Granular, are exploring how industrial farmers can capture value with IoT technologies, not only for field production but to run their businesses. Granular is a farm management cloud software company that has created a system by which farms are able to manage their business "off the field." Granular's technology allows farmers to plan, budget, and manage cost and inventory from one integrated platform. By incorporating data from IoT-enabled equipment, farmers can incorporate real-time data such as crop yields into those decisions. Improved yield information provides a feedback mechanism for farmers to adjust inputs accordingly. The system also benchmarks business performance in order to improve the overall cost of production, allowing farmers to make informed decisions about additional investments in the technology or equipment that runs the farm.[24]



Even if not directly engaged in its production, perhaps no other stakeholder group is more concerned with food than consumers. Consumers, after all, feel the greatest impact from the availability of high-quality food—or its lack. In this respect, consumers can capture value not only by having enough food on the table but also by knowing more about what they are eating and its origin.

Smallholder farmers

Additional value can be created when one considers the role of agriculture in emerging economies. In these economies, the IoT can provide value not only through increased resource efficiency and crop productivity, but also by providing social value and financial benefits for smallholder farmers.

Examples of where IoT deployments have created social value include the Grameen Foundation's Community Knowledge Worker (CKW) program in

Uganda, which aims to give farmers smartphone technology to help address animal health risks; and the Rainforest Alliance's pilot project to provide data and information on agricultural best practices to coffee growers in Guatemala. Working with the Cisco Foundation, the Grameen Foundation provides smallholder farmers with smartphones on which they can access information about weather, crop and animal diseases, and market prices.[25] These projects show that information about the world is among the most critical needs for smallholder farmers.

While current solutions such as CKW rely on hand-entered data, the potential for these solutions to improve quality of life when paired with true IoT-enabled sensors is massive.[26] The IoT could provide farmers not just reference information but also real-time data about the health of their crops or the price of their livestock, improving not just agricultural productivity but also the farmer's social well-being.

Consumers

Even if not directly engaged in its production, perhaps no other stakeholder group is more concerned with food than consumers. Consumers, after all, feel the greatest impact from the availability of high-quality food—or its lack. What's more, they also generate the demand that drives so much change within the industry—witness the trend toward organic or locally sourced food, for instance.[27] In this respect, consumers can capture value not only by having enough food on the table but also by knowing more about what they are eating and its origin.

The IoT has already been applied to certain portions of the food supply chain. Specifically, it is already helping suppliers keep products fresh by monitoring temperature during transit and even adjusting shipping routes to shorten transit times.[28] Beyond this, consumers can directly benefit from this type of tracking in the food supply chain. For example, tagging and tracking fish can help verify its provenance as sustainably sourced, helping to prevent illegal catch being passed off as legitimate.[29] This not only helps promote healthy fish stocks but also delivers value to consumers, who gain confidence that they are doing their part by purchasing responsibly. This consumer demand, in turn, can provide direct economic incentive for farmers, fishers, and others to implement the IoT technologies that can provide the other productivity and quality benefits listed above.

WHERE ARE THE BOTTLENECKS?

To realize the IoT's full benefit for all stakeholders across the value chain, a certain critical mass of information must flow through the Information Value Loop. By visualizing where bottlenecks are currently limiting information flow, we can start to see what must be improved to achieve the full benefits of the IoT.

Kenneth Zuckerberg, executive director and senior analyst in Rabobank's Food and Agribusiness Research and Advisory team, captures the challenges in this way:

> *Over the long term, Rabobank believes that "smart farming" (that is, the combination of data, technology, smart connected devices, and precision farming techniques) has the potential to create in excess of $10 billion of value in the United States. Before that value can be realized, however, there are several bottlenecks that the agricultural industry needs to overcome. First, the existing first generation of data-intensive products does not yet offer enough tangible benefits over the cost of investment to justify customer adoption. Second, most farms lack a basic, reliable, and secure technological infrastructure to efficiently access the requisite cloud and enterprise services associated with digital agriculture. And third, the large farm input players that have already made significant investments in data-driven precision and prescriptive farming services need to embrace open architecture platforms to enable data collection, monitoring, analysis, interpretation, and action by farmers that purchase unbundled products and services from an assortment of vendors.*[30]

Currently, the most obvious and largest bottleneck in the IoT value loop framework is at the *communicate* stage due to the limited infrastructure and connectivity challenges faced by farmers in developing countries—and even within the United States. While sensors may already be able to gather data about the water provided to crops or the location of livestock, communicating that information reliably and consistently back to the cloud or Internet gateway in remote environments poses a serious challenge. Even in the United States, many rural areas are not served by the same major Internet service providers that cover suburban and urban areas; instead, farmers often get their Internet access through wireless ISPs, DSL providers, satellite service, or even by leveraging 4G networks, sometimes at extremely high costs.[31] Similarly, the need to communicate over long ranges and, often, difficult terrain typically requires high-power transmitters, which are also costly.[32]

To create a truly functional IoT value loop in the second green revolution, farmers will need to have access to reasonably priced, reliable, low-power, long-range communications. Luckily, there is already work under way to break those trade-offs within communications to produce new types of radios for IoT applications.[33]

Solving one challenge, however, may reveal the next. Once farmers are able to effectively *communicate* data about their land and crops to the Internet, the bottleneck may move to the next stage or stages—perhaps to the need to *aggregate* data together so that individual farmers may benefit from the data of all. With access to aggregated data, even a smallholder farmer is not limited to a few acres of experience, but can gain a wider view of the world to help understand weather or disease patterns that may impact planting or crop care decisions.

The main challenges here are the questions of who owns the data and how to organize and use it. And there is always the potential for abuse, says Jeroen van der Sommen of communications nonprofit Akvo:

> *At a time when more than 500 million smallholder farmers run 80 percent of farmland in Africa and Asia, the path to IoT adoption needs to be forged with care. Will corporations and governments fill these smallholders' land with sensors sending data to headquarters, or will these technologies be used to improve skills, understanding, and opportunities for farming communities? We need to be mindful that these processes and technologies could drive a new era of agricultural partnership or simply reinforce exploitation through a new layer of technology.*[34]

Finally, another barrier to the agricultural IoT lies in the ease of use for the farmer—the *act* stage of the IoT value loop framework. The value loop will be disrupted if IoT technologies are not easy for farmers to use; a high level of difficulty for users could mean that technologies are not regularly used or abandoned altogether. In addition to general ease of use, integration of various sensors and platforms into a single package will be important. If different parts of the greater agricultural IoT system are not integrated, there will be too many independent applications for farmers to manage, which could lead to abandonment. This technical integration is key, for if farmers abandon the technology, the IoT will not be able to improve productivity and help feed the world population.[35]

ENGAGING THE ENTIRE STAKEHOLDER ECOSYSTEM

While there is great excitement about the IoT's potential to fuel the second green revolution, key issues remain, including the question of how early-stage IoT companies can commercialize at scale and the overall question of who will pay for the technologies to be deployed. In the agricultural sector, both represent unique challenges not lost on early-stage investors. For instance, the adoption of new technologies in agriculture is particularly challenging due to thin profit margins and relatively long payback periods.

Furthermore, when technology adoption is tied to savings in resources such as water, the disincentive to change current practices can be daunting. For example, from a technical standpoint, IoT technologies can easily be applied to agricultural water use: The resource can be measured in both quality and quantity, and automated systems can be used to allocate it in an effective manner. However, the persistent low price for water in the agricultural sector, even in areas of drought, can be a barrier to IoT adoption, as farmers have little financial incentive to strategically manage their water usage. According to Marc Robert of Water Asset Management, "When the underlying pricing of water rises to reflect its full business value, the case for IoT adoption to drive water efficiency in agriculture will become compelling."[36]

Many individual farmers have little economic incentive and lack the funds to implement new technologies alone. Rather, solving the issues of who will pay for the technology and how to scale adoption will likely require the engagement of the entire food ecosystem: farmers (smallholders and large-scale), food manufacturers, food retailers, and consumers. To enable this, traditional thinking about stakeholder relationships will not be enough. What are needed are not just new IoT technology solutions but also innovative partnerships.

One way to encourage such partnerships is to adopt a new way of thinking about the agricultural value chain. Traditionally, value chains have been seen as linear—built upon relatively simple business relationships between stakeholders in the production, manufacture, distribution, retail, consumer, and disposal steps. Recently, however, the consumer products industry, particularly the food and beverage sectors, have started to act as part of closed-loop value chains that entail more complex relationships among stakeholders than simple sourcing, manufacturing, buying, and selling. The creation of these more complex relationships enables stakeholders to create and capture greater value across the value chain, as well as build more sustainable and resilient systems to deliver products.[37] In terms of the IoT, a closed-loop value chain means that individual farmers need not bear the costs of technological modernization alone; the costs, and also the benefits, can be spread across the value chain.

Already, the IoT's inroads into the agricultural sector begin to make clear that a new model of the food and agriculture industries is emerging. The IoT, by giving producers, manufacturers, distributors, consumers, and others across the value chain access to new information and new insights about the world, is delivering value to a diverse variety of stakeholders and, in the process, forging new relationships between these stakeholders. For instance, the same information that helps a producer move its product to market in the shortest time can also help consumers make informed choices about nutrition and sustainability. This creates an incentive for producers, distributors, and retailers to work together in a way that creates value for all.

FUELING THE SECOND GREEN REVOLUTION

As IoT adoption increases, it has the potential to more closely tie together a variety of stakeholders in the agricultural ecosystem. To successfully take advantage of IoT technologies, farmers and companies alike should harness the connections among stakeholders across the entire value chain. All of the stakeholders within the "closed loop," including farmers, food manufacturers, distributors, retailers, technology companies, the public sector, and NGOs, must work together to alleviate the bottlenecks to information flow as they arise.

It is possible to envision the mobilization of the entire agricultural value chain to address the challenges of "how to scale" and "who will pay." Imagine, for instance, that a global food manufacturer needs to increase the production of rice. Company leaders identify deploying IoT technologies as a viable way to increase agricultural yield and the sustainability and resiliency of the company's rice supply chain, along with delivering financial and social benefits to smallholder farmers. The food manufacturer engages with a global ICT company (for example, a wireless service

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provider), a global semiconductor manufacturing company focused on increasing demand for its processors, and a retailer (or retailers) with a strong commitment to sustainability who sells the manufacturer's products. Together, they establish a pilot project to deploy the IoT with a group of smallholder rice farmers. The IoT technology is funded by the corporate stakeholders, development banks active in the region, and the national government. The project is a success, and the companies build a strategy to scale—this time without the contribution from the development banks, but with the support of the government. The strategy includes passing along decreased costs throughout the value loop to all stakeholders, including consumers. The value created comes from increased rice productivity, lower supply chain risk and cost, increased supply chain transparency, and brand value from the commitment to smallholder farmers' social and environmental performance.

Collaborations like these to deploy IoT technologies will be increasingly vital if we are to put the world's farms on track to feed the estimated 11 billion people who will inhabit the earth by 2050. Despite the challenges, there is cause for optimism.

Investor Tamin Pechet, chairman of Imagine H2O and managing partner of Upwell LLC, puts it this way:

> *Solutions themselves are becoming cheaper and better. Moreover, the channels through which smart IoT products may reach customers have improved, and the pressure on growers to adopt technology has increased. Simultaneously, food and beverage companies have demanded more information and more sophisticated practices from their suppliers. These trends offer increasing hope for a smart food system.*[38]

With the IoT fueling a second green revolution, there is real and increasing hope that the world's farms will be able to feed 11 billion people by 2050—not just providing food but doing so in a way that improves environmental performance and delivers social benefits. DR

Will Sarni *is director and Social Impact practice leader, enterprise water strategy, Deloitte Consulting LLP.*

Joe Mariani *is a lead Market Insights analyst with Deloitte Services LP, and editor of Deloitte's research series on the Internet of Things.*

Junko Kaji *is acquisitions editor for Deloitte University Press, Deloitte Services LP.*

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