The Internet of Things

More objects are becoming embedded with sensors and gaining the ability to communicate. The resulting information networks promise to create new business models, improve business processes, and reduce costs and risks.

Michael Chui, Markus Löffler, and Roger Roberts

In most organizations, information travels along familiar routes. Proprietary information is lodged in databases and analyzed in reports and then rises up the management chain. Information also originates externally—gathered from public sources, harvested from the Internet, or purchased from information suppliers.

But the predictable pathways of information are changing: the physical world itself is becoming a type of information system. In what's called the Internet of Things, sensors and tiny devices (actuators) embedded in physical objects—from roadways to pacemakers—are linked through wired and wireless networks, often using the same Internet Protocol (IP) that connects the Internet. These networks churn out huge volumes of data that flow to computers for analysis. When objects can both sense the environment and communicate, they become tools for understanding complexity and responding to it swiftly. What's revolutionary in all this is that these physical information systems are now beginning to be deployed, and some of them even work largely without human intervention.

Michael Chui is a senior fellow with the McKinsey Global Institute, Markus Löffler is a principal in McKinsey's Stuttgart office, and Roger Roberts is a principal in the Silicon Valley office.

Pill-shaped microcameras already traverse the human digestive tract and send back thousands of images to pinpoint sources of illness. Precision farming equipment with wireless links to data collected from remote satellites and ground sensors can take into account crop conditions and adjust the way each individual part of a field is farmed—for instance, by spreading extra fertilizer on areas that need more nutrients. Billboards in Japan peer back at passersby, assessing how they fit consumer profiles, and instantly change displayed messages based on those assessments.

Yes, there are traces of futurism in some of this and early warnings for companies too. Business models based on today's largely static information architectures face challenges as new ways of creating value arise. When a customer's buying preferences are sensed in real time at a specific location, dynamic pricing may increase the odds of a purchase. Knowing how often or intensively a product is used can create additional options—usage fees rather than outright sale, for example. Manufacturing processes studded with a multitude of sensors can be controlled more precisely, raising efficiency. And when operating environments are monitored continuously for hazards or when objects can take corrective action to avoid damage, risks and costs diminish. Companies that take advantage of these capabilities stand to gain against competitors that don't.

The widespread adoption of the Internet of Things will take time, but the time line is advancing thanks to improvements in underlying technologies. Advances in wireless networking technology and the greater standardization of communications protocols make it possible to collect data from these sensors almost anywhere at any time. Ever-smaller silicon chips for this purpose are gaining new capabilities, while costs, following the pattern of Moore's Law, are falling. Massive increases in storage and computing power, some of it available via cloud computing, make number crunching possible at very large scale and at declining cost.

Putting the Internet of Things to work

Information and analysis

1

Tracking behavior

Monitoring the behavior of persons, things, or data through space and time.

Examples:

Presence-based advertising and payments based on locations of consumers

Inventory and supply chain monitoring and management

None of this is news to technology companies and those on the frontier of adoption. But as these technologies mature, the range of corporate deployments will increase. Now is the time for executives across all industries to structure their thoughts about the potential impact and opportunities likely to develop from the Internet of Things. We see six distinct types of emerging applications, which fall in two broad categories: first, information and analysis and, second, automation and control.

Information and analysis

As the new networks link data from products, company assets, or the operating environment, they will generate better information and analysis, which can enhance decision making significantly. Some organizations are starting to deploy these applications in targeted areas, while more radical and demanding uses are still in the conceptual or experimental stages.

1. Tracking behavior

When products are embedded with sensors, companies can track the movements of these products and even monitor interactions with them. Business models can be fine-tuned to take advantage of this behavioral data. Some insurance companies, for example, are offering to install location sensors in customers' cars. That allows these companies to base the price of policies on how a car is driven as well as where it travels. Pricing can be customized to the actual risks of operating a vehicle rather than based on proxies such as a driver's age, gender, or place of residence.

Or consider the possibilities when sensors and network connections are embedded in a rental car: it can be leased for short time spans

2

Enhanced situational awareness

Achieving real-time awareness of physical environment.

Example:

Sniper detection using direction of sound to locate shooters to registered members of a car service, rental centers become unnecessary, and each car's use can be optimized for higher revenues. Zipcar has pioneered this model, and more established car rental companies are starting to follow. In retailing, sensors that note shoppers' profile data (stored in their membership cards) can help close purchases by providing additional information or offering discounts at the point of sale. Market leaders such as Tesco are at the forefront of these uses.

In the business-to-business marketplace, one well-known application of the Internet of Things involves using sensors to track RFID (radio-frequency identification) tags placed on products moving through supply chains, thus improving inventory management while reducing working capital and logistics costs. The range of possible uses for tracking is expanding. In the aviation industry, sensor technologies are spurring new business models. Manufacturers of jet engines retain ownership of their products while charging airlines for the amount of thrust used. Airplane manufacturers are building airframes with networked sensors that send continuous data on product wear and tear to their computers, allowing for proactive maintenance and reducing unplanned downtime.

2. Enhanced situational awareness

Data from large numbers of sensors, deployed in infrastructure (such as roads and buildings) or to report on environmental conditions (including soil moisture, ocean currents, or weather), can give decision makers a heightened awareness of real-time events, particularly when the sensors are used with advanced display or visualization technologies.

Security personnel, for instance, can use sensor networks that combine video, audio, and vibration detectors to spot unauthorized

3

Sensor-driven decision analytics

Assisting human decision making through deep analysis and data visualization

Examples:

Oil field site planning with 3D visualization and simulation

Continuous monitoring of chronic diseases to help doctors determine best treatments individuals who enter restricted areas. Some advanced security systems already use elements of these technologies, but more far-reaching applications are in the works as sensors become smaller and more powerful, and software systems more adept at analyzing and displaying captured information. Logistics managers for airlines and trucking lines already are tapping some early capabilities to get up-to-the-second knowledge of weather conditions, traffic patterns, and vehicle locations. In this way, these managers are increasing their ability to make constant routing adjustments that reduce congestion costs and increase a network's effective capacity. In another application, law-enforcement officers can get instantaneous data from sonic sensors that are able to pinpoint the location of gunfire.

3. Sensor-driven decision analytics

The Internet of Things also can support longer-range, more complex human planning and decision making. The technology requirements—tremendous storage and computing resources linked with advanced software systems that generate a variety of graphical displays for analyzing data—rise accordingly.

In the oil and gas industry, for instance, the next phase of exploration and development could rely on extensive sensor networks placed in the earth's crust to produce more accurate readings of the location, structure, and dimensions of potential fields than current data-driven methods allow. The payoff: lower development costs and improved oil flows.

As for retailing, some companies are studying ways to gather and process data from thousands of shoppers as they journey through stores. Sensor readings and videos note how long they linger at individual displays and record what they ultimately buy. Simulations based on this data will help to increase revenues by optimizing retail layouts.

In health care, sensors and data links offer possibilities for monitoring a patient's behavior and symptoms in real time and at relatively low cost, allowing physicians to better diagnose disease and prescribe tailored treatment regimens. Patients with chronic illnesses, for example, have been outfitted with sensors in a small number of health care trials currently under way, so that their conditions can be monitored continuously as they go about their daily activities. One such trial has enrolled patients with congestive heart failure. These patients are typically monitored only during periodic physician office visits for weight, blood pressure, and heart rate and rhythm. Sensors placed on the patient can now monitor many of these signs remotely and continuously, giving practitioners early warning of conditions that would otherwise lead to unplanned hospitalizations and expensive emergency care. Better management of congestive heart failure alone could reduce hospitalization and treatment costs by a billion dollars annually in the United States.

Automation and control

Making data the basis for automation and control means converting the data and analysis collected through the Internet of Things into instructions that feed back through the network to actuators that in turn modify processes. Closing the loop from data to automated applications can raise productivity, as systems that adjust automatically to complex situations make many human interventions unnecessary. Early adopters are ushering in relatively basic applications that provide a fairly immediate payoff. Advanced automated systems will be adopted by organizations as these technologies develop further.

1. Process optimization

The Internet of Things is opening new frontiers for improving processes. Some industries, such as chemical production, are installing legions of sensors to bring much greater granularity to monitoring. These sensors feed data to computers, which in turn analyze them and then send signals to actuators that adjust processes—for example, by modifying ingredient mixtures, temperatures, or pressures. Sensors and actuators can also be used to change the position of a physical object as it moves down an assembly line, ensuring that it arrives at machine tools in an optimum position (small deviations in the position of work in process can jam or even damage machine tools). This improved instrumentation, multiplied hundreds of times during an entire process, allows for major reductions in waste, energy costs, and human intervention.

Putting the Internet of Things to work

Automation and control

1

Process optimization

Automated control of closed (self-contained) systems

Example:

Maximization of lime kiln throughput via wireless sensors

Continuous, precise adjustments in manufacturing lines

In the pulp and paper industry, for example, the need for frequent manual temperature adjustments in lime kilns limits productivity gains. One company raised production 5 percent by using embedded temperature sensors whose data is used to automatically adjust a kiln flame's shape and intensity. Reducing temperature variance to near zero improved product quality and eliminated the need for frequent operator intervention.

2. Optimized resource consumption

Networked sensors and automated feedback mechanisms can change usage patterns for scarce resources, including energy and water, often by enabling more dynamic pricing. Utilities such as Enel in Italy and Pacific Gas and Electric (PG&E) in the United States, for example, are deploying "smart" meters that provide residential and industrial customers with visual displays showing energy usage and the real-time costs of providing it. (The traditional residential fixed-price-per-kilowatt-hour billing masks the fact that the cost of producing energy varies substantially throughout the day.) Based on time-of-use pricing and better information residential consumers could shut down air conditioners or delay running dishwashers during peak times. Commercial customers can shift energy-intensive processes and production away from high-priced periods of peak energy demand to low-priced off-peak hours.

Data centers, which are among the fastest-growing segments of global energy demand, are starting to adopt power-management techniques tied to information feedback. Power consumption is often half of a typical facility's total lifetime cost, but most managers lack a detailed view of energy consumption patterns. Getting such a view isn't easy, since the energy usage of servers spikes at various times, depending on workloads. Furthermore, many servers draw some power 24/7 but

2

Optimized resource consumption

Control of consumption to optimize resource use across network

Example:

Smart meters and energy grids that match loads and generation capacity in order to lower costs

Data-center management to optimize energy, storage, and processor utilization are used mostly at minimal capacity, since they are tied to specific operations. Manufacturers have developed sensors that monitor each server's power use, employing software that balances computing loads and eliminates the need for underused servers and storage devices. Greenfield data centers already are adopting such technologies, which could become standard features of data center infrastructure within a few years.

3. Complex autonomous systems

The most demanding use of the Internet of Things involves the rapid, real-time sensing of unpredictable conditions and instantaneous responses guided by automated systems. This kind of machine decision making mimics human reactions, though at vastly enhanced performance levels. The automobile industry, for instance, is stepping up the development of systems that can detect imminent collisions and take evasive action. Certain basic applications, such as automatic braking systems, are available in high-end autos. The potential accident reduction savings flowing from wider deployment could surpass $100 billion annually. Some companies and research organizations are experimenting with a form of automotive autopilot for networked vehicles driven in coordinated patterns at highway speeds. This technology would reduce the number of "phantom jams" caused by small disturbances (such as suddenly illuminated brake lights) that cascade into traffic bottlenecks.

Scientists in other industries are testing swarms of robots that maintain facilities or clean up toxic waste, and systems under study in the defense sector would coordinate the movements of groups of unmanned aircraft. While such autonomous systems will be challenging to develop and perfect, they promise major gains in safety, risk, and costs. These experiments could also spur fresh thinking

3

Complex autonomous systems

Automated control in open environments with great uncertainty

Example:

Collision avoidance systems to sense objects and automatically apply brake

Clean up of hazardous materials through the use of swarms of robots about how to tackle tasks in inhospitable physical environments (such as deep water, wars, and contaminated areas) that are difficult or dangerous for humans.

What comes next?

The Internet of Things has great promise, yet business, policy, and technical challenges must be tackled before these systems are widely embraced. Early adopters will need to prove that the new sensor-driven business models create superior value. Industry groups and government regulators should study rules on data privacy and data security, particularly for uses that touch on sensitive consumer information. Legal liability frameworks for the bad decisions of automated systems will have to be established by governments, companies, and risk analysts, in consort with insurers. On the technology side, the cost of sensors and actuators must fall to levels that will spark widespread use. Networking technologies and the standards that support them must evolve to the point where data can flow freely among sensors, computers, and actuators. Software to aggregate and analyze data, as well as graphic display techniques, must improve to the point where huge volumes of data can be absorbed by human decision makers or synthesized to guide automated systems more appropriately.

Related articles on mckinseyquarterly.com
Eight technology trends to watch
How to make Web 2.0 work

Within companies, big changes in information patterns will have implications for organizational structures, as well as for the way decisions are made, operations are managed, and processes are conceived. Product development, for example, will need to reflect far greater possibilities for capturing and analyzing information.

Companies can begin taking steps now to position themselves for these changes by using the new technologies to optimize business processes in which traditional approaches have not brought satisfactory returns. Energy consumption efficiency and process optimization are good early targets. Experiments with the emerging technologies should be conducted in development labs and in small-scale pilot trials, and established companies can seek partnerships with innovative technology suppliers creating Internet-of-Things capabilities for target industries.

The authors wish to thank their McKinsey colleagues Naveen Sastry, James Manyika, and Jacques Bughin for their substantial contributions to this article.