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Ambient computing

Putting the Internet of Things to work

Possibilities abound from the tremendous growth of embedded sensors and connected devices—in the home, the enterprise, and the world at large. Translating these possibilities into business impact requires focus—purposefully bringing smarter "things" together with analytics, security, data, and integration platforms to make the disparate parts work seamlessly with each other. Ambient computing is the backdrop of sensors, devices, intelligence, and agents that can put the Internet of Things to work.

THE Internet of Things (IoT) is maturing from its awkward adolescent phase. More than 15 years ago, Kevin Ashton purportedly coined the term he describes as the potential of machines and other devices to supplant humans as the primary means of collecting, processing, and interpreting the data that make up the Internet. Even in its earliest days, its potential was grounded in business context; Ashton's reference to the Internet of Things was in a presentation to a global consumer products company pitching RFID-driven supply chain transformation.[1] And the idea of the IoT has existed for decades in the minds of science fiction writers—from the starship *Enterprise* to *The Jetsons*.

Cut to 2015. The Internet of Things is pulling up alongside cloud and big data as a rallying cry for looming, seismic IT shifts. Although rooted more in reality than hype, these shifts are waiting for simple, compelling scenarios to turn potential into business impact. Companies are exploring the IoT, but some only vaguely understand its full potential. To realize that potential, organizations should look beyond physical "things" and the role of sensors, machines, and other devices as signals and actuators. Important developments, no doubt, but only part of the puzzle. Innovation comes from bringing together the parts to do something of value differently—seeing, understanding, and reacting to the world around them on their own or alongside their human counterparts.

Ambient computing is about embracing this backdrop of sensing and potential action-taking with an ecosystem of things that can respond to what's actually happening in the business—not just static, pre-defined workflows, control scripts, and operating procedures. That requires capabilities to:

- Integrate information flow between varying types of devices from a wide range of global manufacturers with proprietary data and technologies

- Perform analytics and management of the physical objects and low-level events to detect signals and predict impact
- Orchestrate those signals and objects to fulfill complex events or end-to-end business processes
- Secure and monitor the entire system of devices, connectivity, and information exchange

Ambient computing happens when this collection of capabilities is in place—elevating IoT beyond enabling and collecting information to using the fabric of devices and signals to do something for the business, shifting the focus from the novelty of connected and intelligent objects to business process and model transformation.

What is the "what"?

The focus on the "things" side of the equation is natural. Manufacturing, materials, and computer sciences continuously drive better performance with smaller footprints and lower costs. Advances in sensors, computing, and connectivity allow us to embed intelligence in almost everything around us. From jet engines to thermostats, ingestible pills to blast furnaces, electricity grids to self-driving freight trucks—very few technical constraints remain to connect the balance sheets of our businesses and our lives. The data and services available from any individual "thing" are also evolving, ranging from:

- **Internal state:** Heartbeat- and ping-like broadcasts of health, potentially including diagnostics and additional status reporting (for example, battery level, CPU/memory utilization, strength of network signal, up-time, or software/platform version)
- **Location:** Communication of physical location via GPS, GSM, triangulation, or proximity techniques
- **Physical attributes:** Monitoring the world surrounding the device, including altitude, orientation, temperature, humidity, radiation, air quality, noise, and vibration
- **Functional attributes:** Higher-level intelligence rooted in the device's purpose for describing business process or workload attributes
- **Actuation services:** Ability to remotely trigger, change, or stop physical properties or actions on the device

New products often embed intelligence as a competitive necessity. And the revolution is already well underway. An estimated 11 billion sensors are currently deployed on production lines and in power grids, vehicles, containers, offices, and homes. But many aren't connected to a network, much less the Internet.[2] Putting these sensors to work is the challenge, along with deciding which of the 1.5 trillion objects in the world should be connected and for what purpose.[3] The goal should not be the Internet of Everything; it should be the network of *some* things, deliberately chosen and purposely deployed. Opportunities abound across industries and geographies—connected cities and communities, manufacturing, retail, health care, insurance, and oil and gas.

Beyond the thing

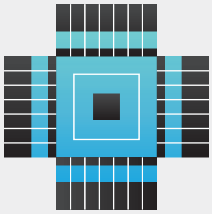
Deliberate choice and purpose should be the broader focus of ambient computing. Analytics is a big part of the focus—turning data into signals and signals into insight. Take transportation as an example. Embedding sensors and controls in 24,000 locomotives, 365,000 freight cars, and across 140,000 miles of track supporting the United States' "Class I" railroads only creates the backdrop for improvement. Moving beyond embedding, companies such as General Electric (GE) are creating predictive models and tools for trains and stockyards. The models and tools optimize trip velocities by accounting for weight, speed,

From the Internet of Things to ambient computing: A concentric system

The Internet of Things lives through sensors and actuators embedded in devices interacting with the world physically and functionally. Ambient computing contains this communication at the core, and harnesses the environment for business processes and insights.

Sensors & connectivity

Underlying components allowing intelligence and communication to be embedded in objects.



SENSORS Temperature, location, sound, motion, light, vibration, pressure, torque, electrical current. ACTUATORS Valves, switches, power, embedded controls, alarms, intra-device settings. COMMMUNICATION From near- to far-field: RFID, NFC, ZigBee, Bluetooth, Wi-Fi, WiMax, cellular, 3G, LTE, satellite.

Device ecosystem

New connected and intelligent devices across categories making legacy objects smart.

CONSUMER PRODUCTS Smartphones, tablets, watches, glasses, dishwashers, washing machines, thermostats. INDUSTRIAL Construction machines, manufacturing and fabrication equipment, mining equipment, engines, transmission systems, warehouses, smart homes, microgrids, mobility and transportation systems, HVAC systems.

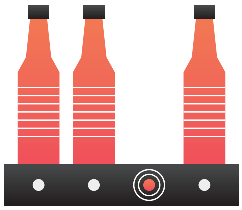
Ambient services

The building blocks of ambient computing and services powered by sensors and devices.

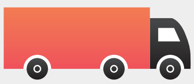
INTEGRATION Messaging, quality of service, reliability. ORCHESTRATION Complex event processing, rules engines, process management and automation. ANALYTICS Baselining and anomaly monitoring, signal detection, advanced and predictive modeling. SECURITY Encryption, entitlements management, user authentication, nonrepudiation.

Business use cases[a]

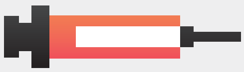
Representative scenarios by industry to harness the power of ambient computing.



BASIC Efficiency, cost reduction, monitoring and tuning, risk and performance management. ADVANCED Innovation, revenue growth, business insights, decision making, customer engagement, product optimization, shift from transactions to relationships and from goods to outcomes.



LOGISTICS Inventory and asset management, fleet monitoring, route optimization.



HEALTH & WELLNESS Personalized treatment, remote patient care.

MECHANICAL Worker safety, remote trouble-shooting, preventative maintenance.

MANUFACTURING Connected machinery, automation.

Source: [a] Deloitte Development LLC, *The Internet of Things Ecosystem: Unlocking the business value of connected devices*, 2014, http://www2.deloitte.com/us/en/pages/technology-media-and-telecommunications/articles/internet-of-things-iot-enterprise-value-report.html, accessed January 7, 2015.

fuel burn, terrain, and other traffic. The gains include faster-rolling trains, preemptive maintenance cycles, and the ability to expedite the staging and loading of cargo.[4]

The GE example highlights the need for cooperation and communication among a wide range of devices, vendors, and players—from partners to competitors, from customers to adjacent parties (for example, telecommunication carriers and mobile providers). The power of ambient computing is partially driven by Metcalfe's Law, which posits that the value of a network is the square of the number of participants in it. Many of the more compelling potential scenarios spill across organizational boundaries, either between departments within a company, or through cooperation with external parties. Blurry boundaries can fragment sponsorship, diffuse investment commitments, and constrain ambitions. They can also lead to isolationism and incrementalism because the effort is bounded by what an organization directly controls rather than by the broader analytics, integration, and orchestration capabilities that will be required for more sophisticated forays into ambient computing. Ecosystems will likely need to evolve and promote industry standards, encourage sharing through consortia, and move away from proprietary inclinations by mandating open, standards-based products from third parties.

Ambient computing involves more than rolling out more complete and automated ways to collect information about real-world behavior. It also turns to historical and social data to detect patterns, predict behaviors, and drive improvements. Data disciplines are essential, including master data and core management practices that allow sharing and provide strategies for sensing and storing the torrent of new information coming from the newly connected landscape. Objects can create terabytes of data every day that then need to be processed and staged to become the basis for decision making. Architectural patterns are emerging with varying philosophies: embedding intelligence at the edge (on or near virtually every device), in the network, using a cloud broker, or back at the enterprise hub. One size may not fit all for a given organization. Use cases and expected business outcomes should anchor the right answer.

The final piece of the puzzle might be the most important: how to put the intelligent nodes and derived insights to work. Again, options vary. Centralized efforts seek to apply process management engines to automate sensing, decision making, and responses across the network. Another approach is decentralized automation, which embeds rules engines at the endpoints and allows individual nodes to take action.

In many cases, though, ambient computing is a sophisticated enabler of amplified intelligence[5] in which applications or visualizations empower humans to act differently. The machine age may be upon us—decoupling our awareness of the world from mankind's dependency on consciously observing and recording what is happening. But machine automation only sets the stage. Real impact, business or civic, will come from combining data and relevant sensors, things, and people so lives can be lived better, work can be performed differently, and the rules of competition can be rewired.

Insurance Industry Perspective

Prashanth Ajjampur

The risk-adverse nature of insurance companies typically results in a meticulous, slow-paced adoption of new capabilities and technologies. However, one of the areas where insurers are moving quickly and are poised to capitalize on is in deriving value from the Internet of Things. Significant opportunity exists for insurance companies to create value by embracing the potential of the IoT, which is already transforming operating models, underwriting approaches, and loss-control practices for some companies.

Evolving customers and operating models

More consumer data is tracked today than ever before. As a result, consumers are more familiar—and more aware—that their data is being tracked. They embrace wearable devices, such as Fitbit or Jawbone fitness trackers, to record exercise levels and sleep patterns; are installing smart thermostats to track and automatically adjust temperature; and smart alarms that do much more than just beep when an incident occurs. These technologies are paving the way to help reduce much of the risk that often prompts insurance purchases.

Additionally, the IoT is making it easier for companies outside of the insurance industry to enter the insurance market and become strong competitors. Companies already experienced with analyzing real-time customer data obtained from sensors and devices are now deploying mass customization and microtargeting to promote products and services in new areas, such as insurance. Google's initial foray into the United Kingdom automobile insurance market over the past two years is an example of companies from other industries dipping their toes into the traditional insurance marketplace.[i] The company's experience in the UK positioned it to enter the US insurance market with its Google Compare Auto Insurance service[ii] (with the impact still to be determined.)

Underwriting paradigm shift

Traditionally, underwriting risk has been a reflection of historical patterns of behavior. But with the development and growth of the IoT, insurers now have a more accurate picture of their risk exposure. Access to real-time data on insured behaviors and environmental characteristics is enabling more precise, personalized, one-to-one underwriting, and transforming the art and science of underwriting.

Home insurers such as State Farm and Pure Insurance have given customers incentives to embrace ambient computing. Policyholders who have smart home technologies, including smart thermostats that can help prevent water pipes from freezing or smart security systems that make their homes safer, are receiving discounts on their homeowners insurance. These technologies are already beginning to provide insurers with a rich pool of real-time data about various policyholder environments. As these technologies develop further capabilities and gain mainstream adoption, the insurance industry can expect to have a wealth of data that can enable more sophisticated risk underwriting. The result: more valuable data for the insurer, and, more personalized policies and pricing reflecting each policyholder's specific usage and needs.

Similarly, the IoT is stretching telematics beyond devices that monitor driving behaviors to devices that promote safe, low-risk driving habits. The ability to provide active feedback to drivers—when they are speeding, braking too hard, cornering aggressively, or displaying other high-risk driving behaviors—has the potential to change driving behaviors materially. The result: safer drivers, lower frequencies and severities of accidents, and ultimately a reduced loss ratio for insurers (not to mention lower premiums for policyholders).

The implications of ambient computing on the insurance industry stretch beyond simply personal life experiences. Applications in commercial lines include high-tech sensors in agricultural fields to provide farmers with data on crop health, soil condition, environmental conditions, and pest infestations. Access to this data provides insurers with an opportunity to become business partners with their agricultural clients by offering services that better analyze data to help farmers improve productivity while gaining a more accurate picture of the risk exposure.

Controlling losses

IoT capabilities are providing insurers with more sophisticated ways to control underwriting losses. For example, the average cooking fire claim damage is around $30,000[iii] and even if provided with the best possible customer experience, it's simply a claim that no homeowner ever wants to experience. To lower the average cost per claim and help homeowners reduce the impact of household fires, insurers have begun partnering with home security and monitoring services to "wire" homes to prevent fires before they have the opportunity to cause significant damage.

Additionally, the IoT has the potential to provide insurers with more accurate and more timely data to prevent losses. For example, USAA has a patent for a data recorder that can be installed in homes for observation. The device can track the temperature, wind speed, and mechanical vibrations as they affect the house, as well as humidity, which could cause mold in the walls. Based on these recordings, the device can identify conditions that "have led to damage or destruction of the building" or can "forecast the possibility of future damage or destruction."[iv] With real-time data, insurers not only have the ability to prevent claims, but also streamline claims processing and better detect and manage fraud.

Better data = Better decisions

For decades, insurance companies have craved data. Their thesis: The more data procured, the better chance of predicting the likelihood and severity of losses.[v] The emergence of the IoT, telematics, and external data sources has only increased insurers' appetite for data. In just a few short years, insurance companies have started to capitalize on the IoT by embracing the real-life and real-time output generated from these technologies.

Now the questions are: When do insurers begin driving the design and sales of these smart devices? Who will be the first to partner with a product like Google Nest to inform the data collection process? Who will take the concept of, for example, Progressive's Snapshot telematics program and expand it across personal and commercial lines?

Footnotes

[i] Richard Evans, "Google adds car insurance to price comparison service", *The Telegraph*, September 10, 2012, http://www.telegraph.co.uk/finance/personalfinance/insurance/motorinsurance/9533097/Google-adds-car-insurance-to-price-comparison-service.html, accessed May 12, 2015.

[ii] Google, "Compare Auto Insurance", https://www.google.com/compare/autoinsurance/form?p=home, accessed May 12, 2015.

[iii] "Nationwide: Average Cooking Fire Claim Tops $30,000", *Insurance Journal*, October 9, 2012, http://www.insurancejournal.com/news/national/2012/10/09/266014.htm, accessed May 12, 2015.

[iv] Ajith Sankaran, "Internet of Things: A bane or boon for the insurance sector?", The Future of Commerce, October 8, 2014, http://www.the-future-of-commerce.com/2014/10/08/internet-of-things-a-bane-or-boon-for-insurance-sector/, accessed May 12, 2015.

[v] Stuart Rose, "Analytics And The Analytical Insurer", Society of Actuaries, October 2013, https://www.soa.org/News-and-Publications/Newsletters/Compact/2013/october/Analytics-And-The-Analytical-Insurer.aspx, accessed May 12, 2015.

Lessons from the front lines

From meters to networks

ComEd, an Exelon company that provides electricity to 3.8 million customers in Northern Illinois,[6] is in the midst of a $2.6 billion smart grid project to modernize aging infrastructure and install smart meters for all of its customers by 2018.[7] The primary goals of this undertaking are to enhance operational efficiency and to provide customers with the information and tools to better manage their energy consumption and costs. Featuring advanced meter infrastructure (AMI), the new meters reduce electricity theft and consumption on inactive meters, reduce the number of estimated electric bills, minimize energy loss, and reduce the need for manual meter reading. Numerous operational efficiencies and benefits are emerging. For example, on Chicago's south side, AMI meter reading has increased the percentage of meters read from 60 percent to 98 percent. Last year, ComEd was given the green light by the Illinois Commerce Commission to accelerate its smart meter installation program, thus making it possible to complete the project three years ahead of schedule.[8]

The smart grid effort will also improve ComEd's ability to maintain its overall infrastructure. Real-time visibility into transformers, feeders, and meters will help the company detect, isolate, and resolve maintenance incidents more efficiently. Other smart grid components will improve communications among field services technicians, operators, and even customers. Analytics, residing atop integration and event processing layers, will form an integral part of the company's ambient computing platform. Security and privacy capabilities will help protect against attacks to critical infrastructure by providing the company with remote access to individual meters and visibility into usage for any given residence or commercial location.

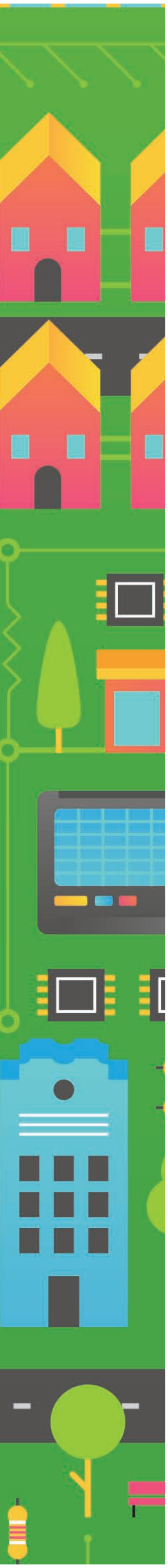
ComEd is also developing a suite of services that will make it possible for customers to view their own energy usage (including itemized energy costs per appliance). The goal of these services is to help individuals proactively regulate their own power consumption and achieve greater efficiency during periods of peak power usage.

As the smart grid project progresses, ComEd leaders remain strategic and flexible. When opportunities to accommodate future technological advances emerge, they adapt their approaches accordingly. For example, when it installed a network of AMI access points, the company decided to place the network physically higher than needed at the time. Why? Because doing so could make it possible to repurpose the existing residential mesh network, should the opportunity ever arise. And one year later, the company is piloting new LED streetlights powered by the repurposed mesh network.

With ambient computing advancing more rapidly each year, ComEd's leaders are keeping their options open and the new smart grid system as flexible as possible in order to take advantage of new improvements, devices, and opportunities that may emerge.

Home sweet conscious home

The makers at Nest Labs view embedded sensors and connectivity as a means to an end, not as ends unto themselves. Their vision is one of a "conscious home" that emphasizes comfort, safety, and energy savings. Many products in the broader Internet of Things space focus on raw technology features. However, Maxime Veron, Nest's head of product marketing, downplays the technology aspects of Nest's offerings, noting: "The



fact that your device is connected does not automatically make it a better product."

A case in point is the Nest Learning Thermostat—a next-generation wall thermostat that uses occupancy sensors, on-device learning, cloud-based analytics, and Web services to learn an occupant's schedule and integrate into his or her life. The company designs customer experiences that focus on usability from the point of installation: The thermostat features snap connectors for wiring, includes a carpenter's level built into the base of the unit to ease finishing, and comes with a multi-head screwdriver to help installers more easily replace legacy hardware. The thermostat's operation similarly evokes the qualities of ambient computing in that the complexity of sensing, learning from occupant behavior, and self-tuning settings remains largely invisible to the user. Veron notes, "We don't want to give you something to program."

Nest Labs is looking beyond any single device toward broader platforms and services. The company launched a partner program to allow third-party products to interact with Nest products. The goal is to create more intuitive ways to learn about and respond to specific user behavior and preferences. For example, your car can alert the Nest Thermostat to begin cooling your home at a certain point during your evening commute. Upon your arrival, the house is comfortable, but you haven't wasted energy cooling it all day long. Nest Labs' second product, Nest Protect, is a smoke and carbon monoxide alarm that can send a message to a mobile device about what it has detected, turn off heating by a gas furnace when it detects a possible CO leak (if the customer has a Nest Thermostat as well), and link to the company's Dropcam video camera to save a clip of what was happening when the alarm initiated.

These scenarios involve not just connectivity and interoperability, but also advanced levels of orchestration and analytics, as well as sophisticated but simple user experiences. Nest Labs, acquired by Google in 2014, has kept the majority of its development in-house, believing that applying the same standards and rigor to its design process from beginning to end—including hardware, software, external data inputs, sensors, and app development—will ultimately result in a more powerful experience for customers inhabiting a "conscious home."

No more circling the block

Many of us have had a parking experience so bad that we avoid the area in the future, opting for restaurants or stores that do not require a frustrating parking lot tour. And because parking tickets and meter fees are often considerable sources of revenue for cities overseeing public parking and for organizations that own parking lots and structures, opportunities to address commuter frustration, pollution, and lost sales revenue through better parking regulations may be mismanaged or ignored altogether. Enter Streetline, Inc., a San Francisco Bay-area company that helps to solve parking-related challenges from the ground up (literally) through its mesh networking technology, real-time data, and platform of parking applications.

The Streetline approach is composed of three layers. First, when deploying its platform in a new location, Streetline installs sensors which determine space occupancy or vacancy in individual parking spaces. The second layer is a middleware learning platform that merges real-time and historical sensor data to determine the validity of a parking event (a true arrival or departure) and relays the current status of each space to the system's backend. An inference engine weeds out false positives such as a garbage can left in a space, or a driver pulling into a parking spot for a moment and then leaving. Finally, there is the application layer that includes a variety of mobile and Web-based tools that deliver up-to-the-minute parking information to commuters, business owners, city officials, and parking enforcement officers in or near the deployment area.

Streetline's Parker™ app guides motorists to open parking spaces, which can decrease driving times, the number of miles traveled, and motorist frustration. Through integration with leading mobile payment providers, the Parker app enables drivers to "feed" parking meters electronically—without the hassle of searching for quarters. Furthermore, motorists can add time to their meter remotely before time expires to avoid parking tickets. ParkerMap™ makes it possible for companies to create online maps of available parking spaces in a given area, along with lot hours and parking rates. Using the ParkerData™ Availability API, cities can publish parking information on dynamic signage, strategically placed around a city. Combined, these different methods of way-finding help consumers find parking more quickly, increasing parking space turnover—and thereby potentially driving increases in foot traffic and sales among local merchants. In fact, studies have revealed that smart parking systems can improve the local economy, as evidenced by a 12 percent increase in merchant sales tax revenue in one of Streetline's customer cities.[9] Moreover, the cities, universities, and companies that own parking in a given area can get access to information about utilization and consumer trends, as well as recommendations for better parking policies and pricing. Law enforcement also has access to similar information, helping enforcement officers increase their productivity and efficiency by as much 150 percent.[10]

Streetline's products are deployed in 40 locations globally, and the company is currently exploring ways to increase the pace of adoption through new use cases, sponsorships, and a monetized API. It is also exploring the capture of new data types including ground surface temperature, noise level, air quality, and water pressure, to name a few.

What began as a desire to make life a little easier for motorists in the congested streets of San Francisco is quickly becoming a foundational layer for the emergence of smarter cities and the Internet of Things worldwide.

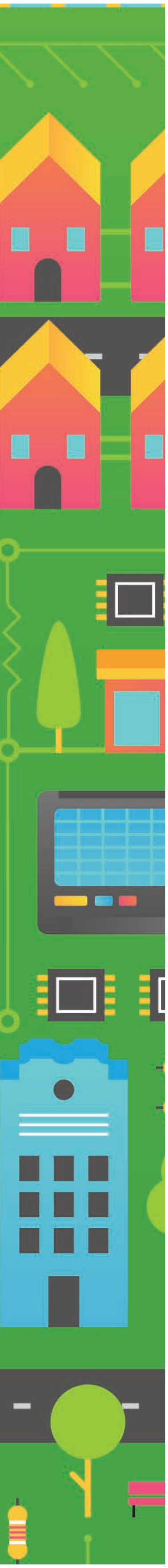
Products to platforms

Bosch Group knows a thing or two about disruptive technologies and their business potential. As the world's third-largest private company, it manufactures a wide range of products, from consumer goods to industrial equipment, including some of the building blocks of ambient computing—shipping roughly 1 billion microelectromechanical systems (MEMS) sensors in 2014. Recognizing the potential of the Internet of Things (IoT), its vision has been embedding connectivity and intelligence in products across its 350-plus business units.

In 2008, the company launched Bosch Software Innovations (Bosch SI), a business unit dedicated to pioneering IoT and ambient computing solutions for industrial environments. "We are trying to bring 130 years of manufacturing experience to connectivity," says Troy Foster, Bosch SI CTO Americas. Bosch SI approaches its mission from an enterprise software perspective—looking beyond the device to enable the kind of business intelligence, processes, and decision making that drive value from data.

To that end, Bosch SI's IoT platform is composed of four primary software components: a machine-to-machine layer, business process management, business rules management, and an analytics engine. The IoT system was designed to accommodate growing data volumes as sensors get smaller and cheaper, spurring wider deployment. Configurable rules allow evolving, actionable insights to be deployed.

For example, Bosch SI is currently developing preventative maintenance



solutions that leverage IoT predictive analytics capabilities to analyze system and performance data generated by sensors embedded in industrial equipment. The goal is to predict equipment failures and perform maintenance proactively to address potential issues. Costs mount quickly when a manufacturing line goes down or mining equipment in a remote location fails; preventing incidents can save customers considerable sums of money.

Other examples include improved visibility of deployed equipment in the field—from factory equipment to vending machines. Bosch SI also helps automobile manufacturers and their suppliers refine and improve their products. To do that, they need data from cars in operation to understand how components such as a transmission system, for example, perform. Traditionally, they only got that information when the car was in for maintenance. Now sensors and telematics can convey that data directly to the manufacturers. Using similar technology, Bosch helps insurance companies move to usage-based coverage models instead of using hypothetical approximations of risk.

Beyond improving existing products and processes and helping manufacturers work more efficiently, the IoT is enabling new business models. "We are looking at many different pieces including smart homes, micro grids, and usage-based car insurance, to name a few," Foster says. "Many business ideas and models that were considered prohibitively expensive or unrealistic are viable now thanks to advances in IoT."

My take

Richard Soley, PhD
Chairman and CEO, Object Management Group
Executive director, Industrial Internet Consortium

As head of the Object Management Group, one of the world's largest technology standards bodies, I'm often asked when standards will be established around the Internet of Things (IoT).[11] This common question is shorthand for: When will there be a language to ease interoperability between the different sensors, actuators, and connected devices proliferating across homes, business, and society?

In developing IoT standards, the easy part is getting bits and bytes from object to object, something we've largely solved with existing protocols and technologies. The tricky part relates more to semantics—getting everyone to agree on the meaning and context of the information being shared and the requests being made. On that front, we are making progress industry by industry, process area by process area. We're seeing successes in use cases with bounded scope—real problems, with a finite number of actors, generating measurable results.

This same basic approach—helping to coordinate industrial players, system integrators, start-ups, academia, and vendors to build prototype test beds to figure out what works and what doesn't—is central to the charter of the Industrial Internet Consortium (IIC).[12] The IIC has found that the more interesting scenarios often involve an ecosystem of players acting together to disrupt business models.

Take, for example, today's self-driving cars, which are not, in and of themselves, IoT solutions. Rather, they are self-contained, autonomous replacements for drivers. However, when these cars talk to each other and to roadway sensors and when they can use ambient computing services like analytics, orchestration, and event processing to dynamically optimize routes and driving behaviors, then they become headliners in the IoT story.

The implications of self-driving cars talking to each other are profound—not only for taxicab drivers and commuters, but also for logistics and freight transport. Consider this: Roughly one-third of all food items produced today are lost or wasted in transit from farm to table.[13] We could potentially make leaps in sustainability by integrating existing data on crop harvest schedules, grocery store inventory levels, and consumer purchasing habits, and analyzing this information to better match supply with demand.

The example that excites and scares me the most revolves around maintenance. The IoT makes it possible to reduce—and potentially eliminate—unexpected maintenance costs by sensing and monitoring everything happening within a working device, whether it be a jet engine, medical device, or distribution system. Rather than reacting to mechanical or system breakdowns, engineers could work proactively to address problems before they become full-blown malfunctions. Companies could deploy systems in which nothing fails. Imagine the impact on industry. Business models based on replenishment/replacement cycles would need to be overhauled. Manufacturers of spare parts and providers of repair services might potentially disappear completely, as the focus of maintenance shifts from objects to outcomes. The list of possible ramifications is staggering.

When the future-state level of interconnectivity is realized, who will own each step along the supply chain? End-to-end control affords significant opportunity, but it is rarely achieved. When the IoT evolves, I imagine it will resemble the newly integrated supply chains that emerged in the 1980s and 1990s. While no one controlled the entire supply chain, it was in everyone's interest along that chain to share and secure information in ways that benefited all parties.

My advice to companies currently considering IoT investments is, don't wait. Begin collaborating with others to build prototypes and create standards. And be prepared—your IoT initiatives will likely be tremendously disruptive. We don't know exactly how, but we do know this: You can't afford to ignore the Internet of Things.

Cyber implications

Enabling the Internet of Things requires a number of logical and physical layers, working seamlessly together. Device sensors, communication chips, and networks are only the beginning. The additional services in ambient computing add even more layers: integration, orchestration, analytics, event processing, and rules engines. Finally, there is the business layer—the people and processes bringing business scenarios to life. Between each layer is a seam, and there are cyber security risks within each layer and in each seam.

One of the more obvious cyber security implications is an explosion of potential vulnerabilities, often in objects that historically lacked connectivity and embedded intelligence. For example, machinery, facilities, fleets, and employees may now include multiple sensors and signals, all of which can potentially be compromised. CIOs can take steps to keep assets safe by considering cyber logistics before placing them in the IT environment. Ideally, manufacturing and distribution processes have the appropriate controls. Where they don't, securing devices can require risky, potentially disruptive retrofitting. Such precautionary steps may be complicated by the fact that physical access to connected devices may be difficult to secure, which leaves the door open to new threat vectors. What's more, in order to protect against machines being maliciously prompted to act against the interests of the organization or its constituencies, IT leaders should be extra cautious when ambient computing scenarios move from signal detection to actuation—a state in which devices automatically make decisions and take actions on behalf of the company.

Taking a broad approach to securing ambient computing requires moving from compliance to proactive risk management. Continuously measuring activities against a baseline of expected behavior can help detect anomalies by providing visibility across layers and into seams. For example, a connected piece of construction equipment has a fairly exhaustive set of expected behaviors, such as its location, hours of operation, average speed, and what data it reports. Detecting anything outside of anticipated norms can trigger a range of responses, from simply logging a potential issue to sending a remote kill signal that renders the equipment useless.

Over time, security standards will develop, but in the near term we should expect them to be potentially as effective (or, more fittingly, ineffective) as those surrounding the Web. More elegant approaches may eventually emerge to manage the interaction points across layers, similar to how a secured mesh network handles access, interoperability, and monitoring across physical and logical components.

Meanwhile, privacy concerns over tracking, data ownership, and the creation of derivative data using advanced analytics persist. There are also a host of unresolved legal questions around liability. For example, if a self-driving car is involved in an accident, who is at fault? The device manufacturer? The coder of the algorithm? The human "operator"? Stifling progress is the wrong answer, but full transparency will likely be needed while companies and regulators lay the foundation for a safe, secure, and accepted ambient-computing tomorrow.

Finally, advanced design and engineering of feedback environments will likely be required to help humans work better with machines, and machines work better with humans. Monitoring the performance and reliability of ambient systems is likely to be an ongoing challenge requiring the design of more relevant human and machine interfaces, the implementation of effective automation algorithms, and the provisioning of helpful decision aids to augment the performance of humans and machines working together—in ways that result in hybrid (human and technical) secure, vigilant, and resilient attributes.

Where do you start?

MANY don't need to be convinced of ambient computing's opportunities. In a recent survey, nearly 75 percent of executives said that Internet of Things initiatives were underway.[14] Analysts and companies across industries are bullish on the opportunities. Gartner predicts that "by 2020, the installed base of the IoT will exceed 26 billion units worldwide; therefore, few organizations will escape the need to make products intelligent and the need to interface smart objects with corporate systems."[15] Other predictions measure economic impact at $7.1 trillion by 2020,[16] $15 trillion in the next 20 years,[17] and $14 trillion by 2022.[18] But moving from abstract potential to tangible investment is one of the biggest hurdles stalling progress. Below are some lessons learned from early adopters.

- **Beware fragmentation.** Compelling ambient computing use cases will likely cross organizational boundaries. For example, retail "store of the future" initiatives may cross store management, merchandising, warehouse, distribution center, online commerce, and marketing department responsibilities—requiring political and financial buy-in across decision-making authorities. Because the market lacks end-to-end solutions, each silo may be pursuing its own initiative, offering at best incremental effect, at worst redundant or competing priorities.

- **Stay on target.** Starting with a concrete business outcome will help define scope by guiding which "things" should be considered and what level of intelligence, automation, and brokering will be required. Avoid "shiny object syndrome," which can be dangerously tempting given how exciting and disruptive the underlying technology can seem.

- **User first.** Even if the solution is largely automated, usability should guide vision, design, implementation, and ongoing maintenance plans. Companies should use personas and journey maps to guide the end-to-end experience, highlighting how the embedded device will take action, or how a human counterpart will participate within the layers of automation.

- **Eyes wide open.** Connecting unconnected things will likely lead to increased costs, business process challenges, and technical hurdles. Be thoughtful about funding the effort and how adoption and coverage will grow. Will individual organizations have to shoulder the burden, or can it be shared within or across industries and ecosystems? Additionally, can some of the investment be passed on to consumers? Although business cases are needed, they should fall on the defensible side of creative.

- **Network.** With the emphasis on the objects, don't lose sight of the importance of connectivity, especially for items outside of established facilities. Forrester Research highlights "a plethora of network technologies and protocols that define radio transmissions including cellular, Wi-Fi, Bluetooth LE, ZigBee, and Z-Wave."[19] Planning should also include IPv6 adoption,[20] especially with the public IPv4 address space largely exhausted and the aforementioned billions of new Internet-enabled devices expected in the next 10 years.

- **Stand by for standards.** Standards help create collaborative and interoperable ecosystems. We expect that IoT standards for interoperability, communication, and security will continue to evolve, with a mix of governmental bodies, industry players, and vendors solving some of the challenges inherent in such a heterogeneous landscape. Several IoT-focused standards bodies and working groups including the AllSeen Alliance, Industrial Internet Consortium, Open Interconnect Consortium, and Thread Group have formed in the last two years.[21] Having preliminary standards is important, but you shouldn't hold off on investing until all standards are finalized and approved. Press forward and help shape the standards that impact your business.

- **Enterprise enablement.** Many organizations are still wrestling with smartphone and tablet adoption—how to secure, manage, deploy, and monitor new devices in the workplace. That challenge is exponentially exacerbated by ambient computing. Consider launching complementary efforts to provision, deploy policies for, monitor, maintain, and remediate an ever-changing roster of device types and growing mix of underlying platforms and operating systems.

Bottom line

AMBIENT computing shouldn't be looked at as just a natural extension of mobile and the initial focus on the capabilities of smartphones, tablets, and wearables—though some similarities hold. In those cases, true business value came from translating technical features into doing things differently—or doing fundamentally different things. Since ambient computing is adding connectivity and intelligence to objects and parts of the world that were previously "dark," there is less of a danger of seeing the opportunities only through the lens of today's existing processes and problems. However, the expansive possibilities and wide-ranging impact of compelling scenarios in industries such as retail, manufacturing, health care, and the public sector make realizing tomorrow's potential difficult. But not impossible. Depending on the scenario, the benefits could be in efficiency or innovation, or even a balance of cost reduction and revenue generation. Business leaders should elevate discussions from the "Internet of Things" to the power of ambient computing by finding a concrete business problem to explore, measurably proving the value, and laying the foundation to leverage the new machine age for true business disruption.

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