The Industrial Internet@Work

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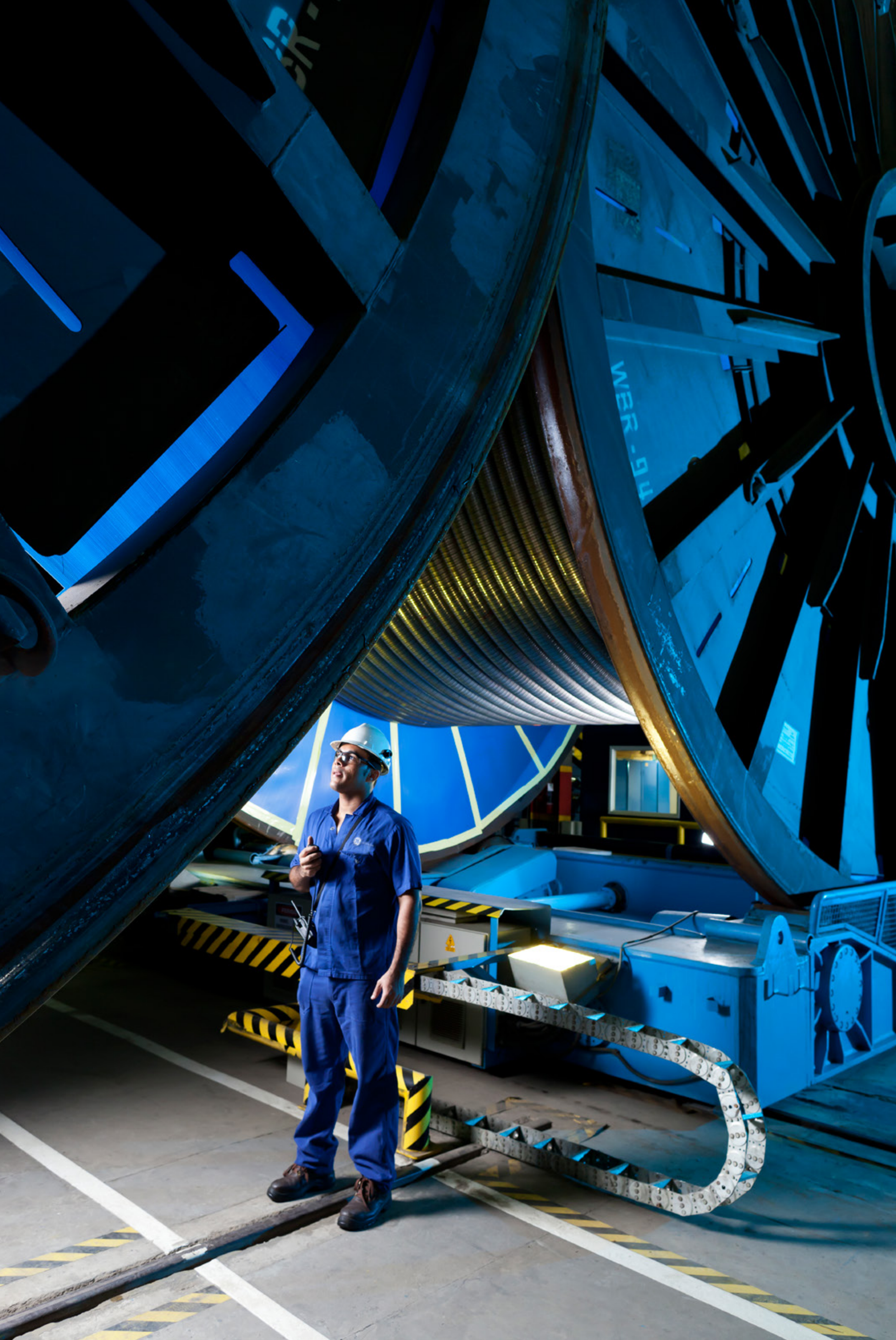


The Industrial Internet@Work

Executive Summary

The Industrial Internet

The Industrial Internet is bringing about a profound transformation to global industry, by connecting more intelligent machines, advanced analytics, and people at work. This deeper meshing of the digital world with the world of machines has the potential to bring enormous economic benefits. We have estimated that this new wave of innovation could boost global GDP by as much as $10-15 trillion over the next 20 years, through accelerated productivity growth.

Discussions of the Industrial Internet tend to focus on the machines and the data, but people at work are an equally essential element of this revolution. In fact, it is exactly by changing the way people work that the Industrial Internet will deliver its benefits in terms of greater efficiency, lower costs, and ultimately more and better jobs and rising living standards. Just as the Internet has fundamentally changed the ease with which we access information and interact with each other in our everyday lives, so the Industrial Internet will transform the way in which we can leverage information and collaborate in the workplace.

Towards Zero Unplanned Downtime

This change will affect all those who work with, service, or maintain industrial equipment, medical devices and other machines: field engineers, aircraft pilots, technicians on oil rigs, doctors and nurses, and many others. The amount of work associated with servicing the global fleet of machines, facilities, fleets, and networks is not completely quantifiable, but it is significant. Consider the power generation sector: There are 56,620 power plants that run on natural gas, oil, coal and nuclear energy around the world today with a capacity of 30 megawatts or greater, accounting for about 75 percent of the total global capacity of power plants. The gas and steam turbines in these power plants alone require about 52 million labor-hours a year to be serviced, at a cost of $7 billion. We estimate that it takes over 300 million labor-hours a year just to service the world's steam and gas turbines, aircraft engines, freight, CT and MRI scanners. The total estimated value of this work is approximately $20 billion per year. This is just a slice of the total installed base of industrial equipment that requires the attention of operators, field engineers, fleet managers and executives who either have direct or indirect interaction with complex machines. At present, much of this time and money is wasted, largely due to deficiencies in how information is gathered, stored, accessed and shared. Much of the service, maintenance, and repair work is done in a scheduled and uninformed way: carried out routinely on a set timetable because the workers lack real- time information on the state and performance of the industrial assets concerned. Or it happens in a reactive way, as technicians and engineers rush to repair a failure that might have been avoided if only they had received the relevant signals that preventive maintenance was required. Meanwhile, unplanned downtime causes economic losses that ripple across the system: power outages, grounded airplanes causing a domino effect of re-scheduling, delayed freight deliveries wreaking havoc in supply chains.

Think about how much time and effort is wasted if a fleet manager cannot retrieve information promptly at the request of a mechanic. Field engineers called out to repair gas turbines and other complex machines in remote locations need access to an enormous amount of information: the relevant technical details and instructions are currently stored in manuals running sometimes into thousands of pages, or at best in sets of CD-ROMs: just locating the necessary information can be extremely time-consuming and frustrating. And if the doctor or nurse cannot get the right information and the right equipment in time, the result is not just lower efficiency, but worse health outcomes and potentially more suffering for patients.

The Industrial Internet can change all this through software and analytics, data visualization tools, mobile collaboration devices with intuitive user interfaces, and contextually relevant information. It will enable preventive maintenance based on the actual conditions of industrial assets, bringing us toward a world of "no unplanned downtime."

A field engineer repairing a gas turbine in a remote location will access reference manuals via a single light portable device, equipped with powerful search functions, with the ability to view materials and information dynamically updated in the cloud. Should she face a difficulty, she will able to identify and contact colleagues with the required expertise and instantly connect remotely via video and audio, exchange documents and other relevant material in real time. The work she performs, and her interactions with her colleagues, will themselves be recorded and become part of a searchable database of real-life problem-solving situations that can be tapped whenever a similar situation occurs again in the future.

A technician performing maintenance on a wind turbine will then be able to access a database of similar maintenance operations; if he encounters an anomaly, he can quickly check whether similar anomalies have occurred in other instances, and learn—even see on recorded video—how they have been addressed. He could tap the expertise of more experienced colleagues as needed, instantly, and while on site—and without taking up any of their time.

The Industrial Internet is transforming the way people service and maintain industrial equipment, medical devices and other machines.

Intelligent Machines

Through self-monitoring and transmission of sensor data, intelligent machines enable preventative maintenance and move closer to the goal of "no unplanned downtime."

Transmitting Valuable Data

Real-time information on the condition of individual assets reduces the need for higher-cost scheduled maintenance.

Optimizing Operations

Operations centers engage in data segmentation and filtering for customized "fleet" views, historical analysis, real-time analysis and forecasting.

Empowering Technicians

The Industrial Internet provides workers with information and resources in real-time, improving productivity and driving more efficient work practices.

A fleet engineer and a fleet manager sitting in an operations center will have real-time access to a much vaster set of data on the performance of fleets and networks of industrial assets, be they fleets of aircrafts or locomotives, power grids, gas pipeline networks, or systems of medical equipment in a hospital. The data will be intelligent, knowing where to appear. In the Industrial Internet era, the information workers require will find them, without their looking for it. And, as powerful analytics process performance data from industrial systems to yield intuitive visualizations that will make the insights quickly understandable and actionable. Engineers and managers can then optimize performance and address and resolve problems quickly. Managers will benefit from asset monitoring applications, which allow them to locate and assess individual assets, as well to make better decisions.

Through data analytics, mobile applications, and new collaboration tools, the Industrial Internet will help workers to gather and process more information more quickly—and to collaborate more, and more effectively. This will reduce the substantial amount of time currently wasted due to information inefficiencies. Even more importantly, it will enable a decrease in the correspondent waste of human capital: workers will be able to spend more of their time in higher value-added activities, while upgrading their knowledge, skills, and experience at a much faster pace.

How are all these capabilities brought together? The answer is through integrated digital software platforms that support a combination of information collection and storage, new analytic capabilities, and new modes of collaboration between workers. In order to augment work and integrate key applications for dynamic, responsive workflows, the Industrial Internet requires a digital platform that connects workers, data, and machines. This software platform consists of four different and interconnected architecture and technology components. These include cloud or on-premise servers to run applications and store data, mechanisms to visualize and control machines and operations, and display technologies.

Advances in technology are too often seen as a threat to workers, with the assumption that technological innovation will lead to more and more automation and therefore cause higher unemployment or push a growing share of the working population into low-satisfaction and low-pay jobs. Innovation is seen as humanity's race against the machine. But the innovations discussed in this paper will augment and enhance the abilities of workers, enabling them to work with greater efficiency, better results, and greater productivity. Workers will be racing with the new, intelligent machines of the Industrial Internet, not against them—more *Iron Man* than the Charlie Chaplin of *Modern Times*.

Training and education will be key, and companies will play a pivotal role in this area. Workers will need to master—and shape—the new technologies. New job roles will emerge, requiring new sets of skills: "digital-mechanical" engineers able to blend traditional mechanical, civil or electrical engineer training with a mastery of the latest computing techniques, because machines and data will be inextricably linked; and "business operations data analysts," business managers who combine a deep knowledge of their industry with an intimate familiarity of the latest analytical tools, and the ability to focus the power of the new enabling technologies to where they can have the maximum business impact. The education system will have to ensure that new entrants into the workforce are equipped with the right skills for a different and fast-changing workplace—starting with basic scientific and technical skills. And while we are confident that the Industrial Internet will ultimately boost employment, some workers will need to be retrained for different roles. Companies will play a major role by providing training in the use of the new software and analytics tools and mobile technologies, enabling workers to quickly upgrade their skills, improving their efficiency, job satisfaction and career opportunities.

imagination at work

Introduction

The Industrial Internet has the potential to bring about profound transformation to the global economy, as the digital world and the world of machines become more deeply enmeshed. Discussions of the Industrial Internet often tend to focus on the machines and the data. However, as we pointed out in our previous white paper, "people at work" are a central element of the Industrial Internet framework, together with intelligent machines and advanced analytics.[1]

In this paper, we look more closely at how new technologies, such as hand-held mobile devices and increasing connectivity enhance the way that people will work across the global industrial system. This transformation will affect hundreds of thousands of people support the operation and maintenance of machines, facilities, fleets, and networks. Data scientists—experts in computer science, modeling, and analytics who harness the power of big data to generate scientific and business insights—have drawn attention to the role of data and will obviously play a key part in the future of the Industrial Internet. However, the new technologies will change the work experience of myriad workers, from field engineers repairing pipeline compressors to aircraft pilots to nurses and doctors. The Industrial Internet will empower them with faster access to relevant information, relying on analytics generating new insights, mobile collaboration tools revolutionizing the way that information is shared and disseminated. Machines will play an active part in this; connected and communicative machines will be able to self-monitor, self-heal, and proactively send information to other machines and to their human partners.

These new capabilities will affect a large share of the global economy. In our previous white paper, we showed that the Industrial Internet can find direct application in a wide range of areas, from transportation to manufacturing to healthcare and other industrial sectors, accounting for 46% of the global economy. How information is collected, processed, and visualized is a central element to the Industrial Internet transformation. Consider how much time and effort is lost if a fleet manager cannot retrieve information promptly at the request of a mechanic. When repair manuals are issued on paper or on CD-ROMs, new techniques cannot be easily disseminated throughout the organization. Similar problems arise if it takes a field engineer hours or even several days to connect with an expert who can help him or her troubleshoot on a specific question. And when a doctor or a nurse faces a delay in getting the right information or the right equipment, the consequences are measured in worse health outcomes for the patient.

The Industrial Internet will empower them with faster access to relevant information, relying on analytics generating new insights, mobile collaboration tools revolutionizing the way that information is shared and disseminated.

Today industrial equipment is mostly serviced on a fixed schedule because of lack of real-time information on the state and performance of individual industrial assets. A field engineer drives to a wind farm on a specified date and inspects each and every wind turbine—and will inevitably spend valuable time inspecting machines that would anyway keep functioning smoothly for a long time. When a turbine fails, the engineer will rush out, look "under the hood," and hope he has the necessary tools and spare parts to fix the problem. Often the failure and the consequent unplanned downtime and power loss could have been avoided through preventive maintenance at just the right time. In short, work is hampered and productivity suffers when field engineers, fleet operators, doctors, and others do not get the right information contextually—at the right place and at the right time.

The Internet has already transformed people's ability to access information in their everyday lives so completely that most take it for granted and tend to forget how powerful and empowering the change has been. The Industrial Internet will similarly change industry and the workforce. Workers will gather more information more quickly, when they need it; it will enable more effective collaboration, and it will make them smarter, faster, more productive. And a key feature of the Industrial Internet is that information itself becomes intelligent: when workers need it, information will find them—they will not need to hunt for it. In a hospital, when a CT scan is performed,

the information produced will know which doctors or nurses need it and will reach them immediately.

Predictive software will reveal which industrial assets need servicing and when, thanks to information transmitted by the assets for processing via secure wireless communication. A field engineer will then reach the wind farm equipped with a hand-held device indicating which turbines need attention and what needs tuning or repair. The same device will store and transmit relevant technical information and enable the engineer to share video with a central operations center and with colleagues in other locations, instantly tapping the diverse expertise of peers.

Meanwhile, visually intuitive dashboards will enhance the management of fleets of freight trains, improving turnaround time, reducing congestion, and maximizing utilization and cargo flow. Once a hospital has electronically tagged its thousands of medical devices, a doctor or a nurse will immediately know where to locate the equipment she needs, and when specific beds, MRI machines, or CT scanners will be available. She will then be able to deliver quicker scheduling of procedures. The information collected in medical exams will know which doctors and nurses to reach—resulting in not only quicker, but also better patient care.

Machines will play an active part in this; connected and communicative machines will be able to self-monitor, self-heal, and proactively send information to other machines and to their human partners.

Such advances reduce unplanned downtime of industrial assets, and to better use the amount of time currently spent on information inefficiencies. Even more importantly, they enable us to reduce the correspondent waste of human capital: workers can spend more time in higher-value activities, while improving their knowledge, skills, and experience at a much faster pace.

Industrial Internet technologies allow for a faster diffusion and more efficient use of information on a much vaster scale than previously possible.

Advances in technology are too often seen as a threat to workers, with the assumption that technological innovation will lead to more and more automation and therefore cause higher unemployment or push a growing share of the working population into low-satisfaction and low-pay jobs. This fear is encapsulated by the idea of a "race against the machine", coined by Brynjolfsson and McAfee (2011). We hold a different view. Technological innovation has brought about the extensive mechanization of agriculture, which used to be the main sector of employment in all currently advanced economies; it has brought automation to a growing number of industries. And yet, before the great financial crisis struck, unemployment in the US was at record low levels. Concerns that innovation would breed unemployment have proved utterly wrong before. Does the Industrial Internet somehow differ from previous waves of innovation? We do not think so. In this paper, we argue that the transformation of work associated with the Industrial Internet is better characterized as a race with the new intelligent machines, not against them. It will make work experience of the future more rewarding and productive, not less.

The impact of the Industrial Internet on people at work is all the more important because it takes place in the context of a rapidly changing business landscape, characterized by:

- A maturing workforce and assets, in advanced economies
- Greater energy demands
- Urgent environmental demands
- Increased regulation and customer performance targets.

Racing with the machines will prove to be a key to success in this challenging context.

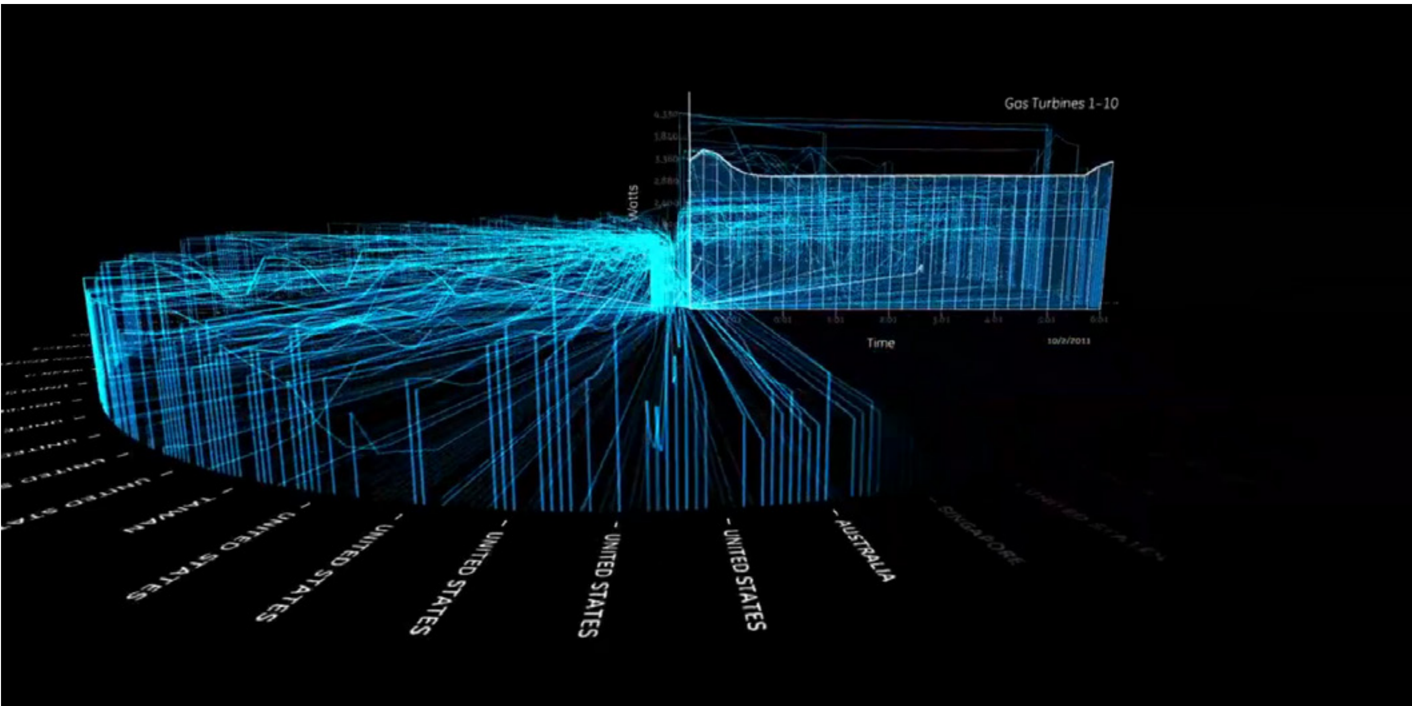
With training and education as key factors, companies and the educational system will play critical roles. Workers will need to become fluent in emerging technologies in their current positions. New workers will need the right skills for a different and fast-changing workplace. And while we are confident that the Industrial Internet will ultimately boost employment, some workers will be displaced in the transition and will need to be retrained for different roles. The education system will need to ensure that students are sufficiently equipped with basic scientific and technical skills. But companies will be able to play a major role by providing training in the use of the new software and analytics tools and mobile technologies, enabling workers to quickly upgrade their skills, improving their efficiency, job satisfaction and career opportunities.

A New Information and Collaboration Revolution

The economics and business management literature long ago recognized the central role of economies of scale in driving faster rates of product improvement and cost reductions, thereby accelerating the pace at which new technologies reach profitability and, consequently, their speed of diffusion.[2] The dynamics behind economies of scale are driven in part by the physical properties of production processes. For example, in continuous-flow manufacturing processes, production costs tend to rise in proportion to the surface area of pipes and vessels used, whereas the output rises in proportion to their volume, resulting in a decline in production costs per unit as volume expands. Another important driver of economies of scale, however, is the fact that large-scale production accelerates progress along the learning curve, as workers become more proficient at their tasks, and companies find better ways of organizing the production process.

The Industrial Internet opens up another dimension across which economies of scale can be realized: information. Accelerated adoption of electronic sensors in industrial equipment (and beyond) combined with declining costs of data storage generate large quantities of new information; moreover, smart analytics deliver better management, organization, and retrieval of data – allowing access to large quantities of existing information. Connectivity, both wired and wireless, is rapidly improving, facilitating the transmission of this growing mass of data around the world, linking together intelligent machines and humans in powerful information network. And as we mentioned earlier, information itself has situational awareness, moving purposefully across this increasingly dense network. In other words, Industrial Internet technologies allow for a faster diffusion and more efficient use of information on a much vaster scale than previously possible.

When workers need it, information will find them—they will not need to hunt for it.



The paramount importance of information sharing appears extensively in the academic literature. Most research focuses on the role of efficient information-sharing in organizations. (Appendix A provides a more detailed review of the literature.) These studies have found that the efficient diffusion of information has a powerful impact on performance—moreover, that the diffusion itself depends on network effects and on the incentives perceived by individuals. In some cases, workers may hesitate to seek out information for fear of showing ignorance, or they might fear giving up an advantage. The time and effort necessary to obtain or give information also play a role. Information is costly to collect, process, and disseminate. This is true for both individual workers and for organizations more broadly.

The advancements of the Industrial Internet at work yield powerful transformations in this arena. One obvious advantage is the larger amount of information with greater accessibility. This is a deceptively simple change, and it would be easy to underestimate its potential impact. The industrial world relies increasingly on very complex, sophisticated machines. Servicing these machines involves a large body of specialized knowledge currently stored and distributed in field manuals that in some cases could fill a library. For a combined cycle gas turbine, for example, the field procedures run to well over 1,000 dense pages. The ability for a worker to access this information via one light, portable electronic device is invaluable. Updating manuals becomes easier and more cost effective, so that workers have the most up-to-date and accurate information—literally at their fingertips.

A second key benefit lies in the development of new advanced collaboration tools. The Industrial Internet at work will give workers the ability to interact remotely and in real time with colleagues. A field engineer in a remote location will be able to identify and contact colleagues with the relevant expertise, instantly communicate with them remotely via video and audio, and exchange relevant material. This will have several powerful effects. First will be increased speed and efficacy in solving problems by leveraging a greater amount of expertise. Second, collaboration will be observable, making it easier to measure and reward teamwork that yields better performance. This, in turn, provides greater incentive for collaboration. Thirdly, interactions can be recorded, building a searchable database of real-life situations that can be tapped whenever a similar challenge occurs again in the future.

New collaboration tools should therefore provide a greater incentive for more knowledgeable and experienced workers to share their expertise with colleagues. But as the information and experience accumulated in real-life situations becomes recorded, stored, easily accessible, and searchable, an increasing amount of expertise will become a common resource that can be accessed on demand. This will speed up learning and minimize mistakes. For example, a new technician performing maintenance on a wind turbine will be able to access a database of similar maintenance operations. If she encounters an anomaly, she can quickly check whether similar anomalies have occurred in other instances, and learn—perhaps via video or other media—how they have been addressed.

This feature of the Industrial Internet at work spurs greater productivity. In advanced industrial countries, many sectors have a large cohort of highly experienced nearing retirement. Their knowledge, sometimes referred to a "tribal wisdom", is largely undocumented—the equivalent of the oral traditions of ancient times. Very few of the newer workers are ready to step into their shoes. This gap has been brought about by two sequential factors. First, in the decade prior to the financial crisis, the industrial world has witnessed a growing preference for services versus manufacturing.[3] Second, over the past several years, high unemployment rates have disproportionately affected younger workers. This leads to a paradoxical challenge: while high unemployment remains the most pressing economic and social challenge, a number of industrial sectors might soon be limited by the lack of qualified workers. The Industrial Internet helps more seasoned workers share their knowledge and skills with the newer cohorts of workers, filling an otherwise unbridgeable gap.

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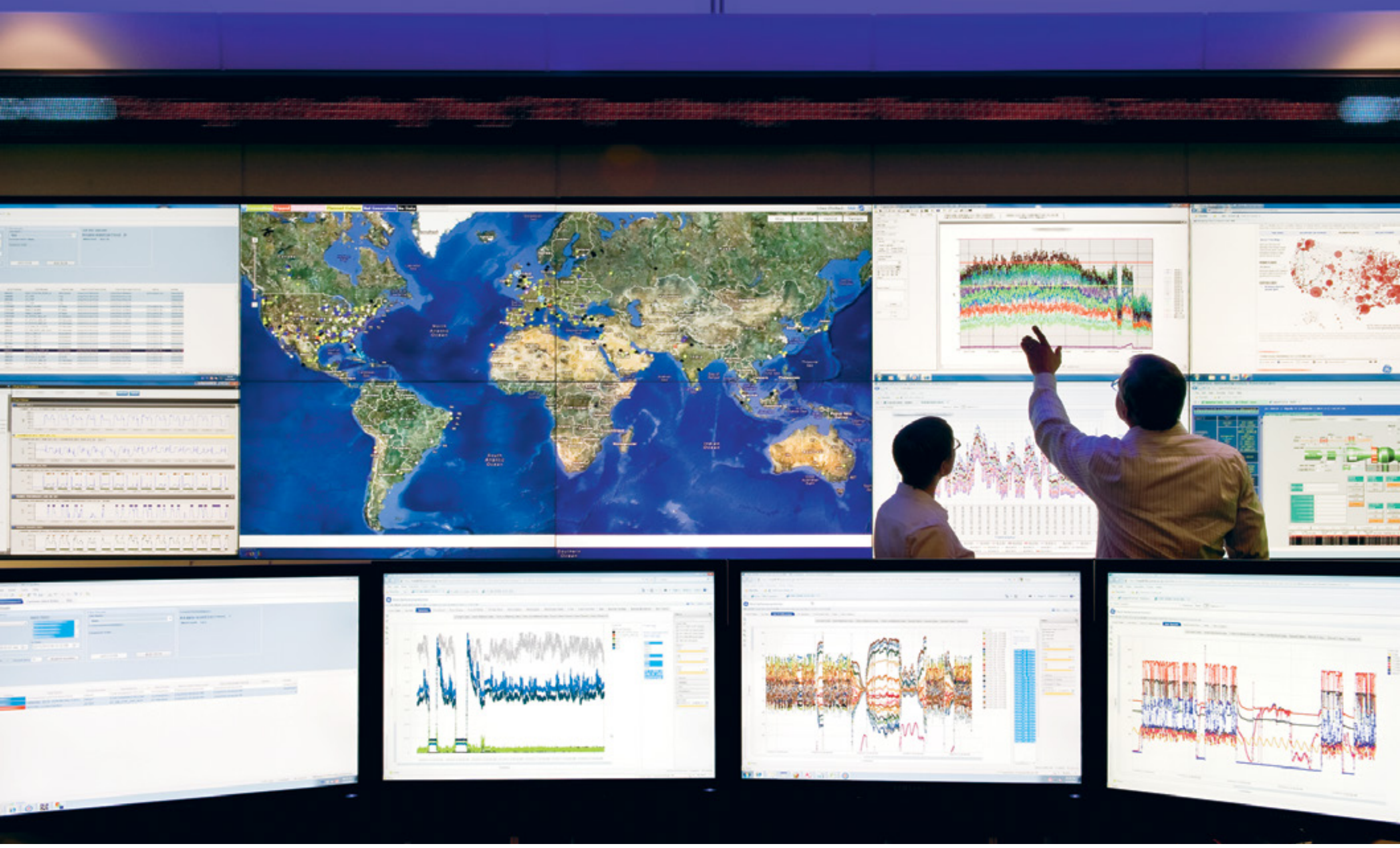

Skeptics will no doubt argue that if information is power, no amount of new technology will persuade workers to share it—human nature will trump innovation. We disagree. We have already been surprised by the extent and speed with which people have embraced information-sharing tools in the social space, overriding the presumption of a strong human preference for privacy. Moreover, crowdsourcing and open competitions have already shown that in a professional environment, individuals have a strong desire to test and demonstrate their abilities and knowledge, driven both by a competitive spirit and by the satisfaction of contributing to a team effort. We believe the same dynamics will kick in with the Industrial Internet at work.

The rest of this paper examines four key questions. First, how large is the opportunity? To give a sense of the scale we estimate the number of labor-hours associated with servicing the key element of power generation, aviation, freight transportation, and imaging machines in healthcare. Second, where does the work get done? Here we explore locational context—where the largest percentage of the work occurs, be it in the field, service centers or operations centers. Third, who does the work? While there are myriad job roles in different industries, the core aspects can be captured in five key categories. Last but not least, how are all these capabilities brought together?

Crowdsourcing and open competitions have already shown that in a professional environment, individuals have a strong desire to test and demonstrate their abilities and knowledge, driven both by a competitive spirit and by the satisfaction of contributing to a team effort.

We believe the same dynamics will kick in with the Industrial Internet at work.

1. Evans and Annunziata, Industrial Internet: Pushing the Boundaries of Minds and Machines, November, 2012.

2. Economies of scale have been recognized and discussed in the academic economic literature for a long time. In our context, a useful reference is Junius (1997); The Economist (2008) also provides a brief overview of the concept.

3. Spence and Hlatshwayo (2011) show that in the U.S., almost the entire net job creation during nearly two decades prior to the financial crisis (1990-2008) is accounted for by the services sector.

The Opportunity by the Numbers

One area where the Industrial Internet will make a huge difference is the servicing of the vast quantities of machines, facilities, and fleets that comprise the global industrial system. Millions of different types of equipment need to be operated and maintained, requiring diverse levels of expertise, tools, and time to ensure proper operation. While it is impossible to know precisely how many machines exist within this ever-expanding industrial, we can look at some specific segments to get a sense for the scale of time, money, and effort invested in maintaining these complex machines.

Table 1 provides an illustrative list of the labor-hours required each year to service complex machines in several key industry categories.

We estimate that it takes approximately 313 million labor-hours a year to service steam and gas turbines, aircraft engines, freight, and CT and MRI scanners across the world. The total estimated value of this work is approximately $20 billion per year. These numbers are based on a basic review of maintenance time and costs across these machines.

Steam and Gas Turbines

Approximately 56,620 power plants run on natural gas, oil, coal, and nuclear energy around the world today with a capacity of 30 megawatts or greater. The total global capacity of these thermal and steam electric power plants is approximately 4,156 gigawatts (GW), which represents about 75%of the total global capacity of power plants.

The gas and steam turbines in these power plants alone require about 52 million labor-hours a year to be serviced. This amounts to about $7 billion a year of labor costs, not including tools and equipment costs.

Commercial Jet Aircraft

According to Jet Information Services, there were approximately 21,500 commercial jet aircraft and 43,000 jet engines were in service around the world in 2011. Just maintaining the jet engines on these aircrafts requires about 205 million labor-hours annually. This is the equivalent of about $10 billion annually in labor costs. And as economic growth continues to boost the size of the middle class in large emerging market countries, demand for air travel will grow, and the number of aircrafts in operation will expand correspondingly, driving the maintenance time and cost figures even higher.

Locomotives

There are approximately 120,000 diesel-electric powered rail engines worldwide. These locomotives require about 52 million labor-hours to service annually. This is the equivalent of about $3 billion annually in labor costs. Today, the rail industry employs more than 7 million people globally and moves about 9.6 trillion freight tonne-km globally each year.[4]

Health Care

Health care delivery involves maintaining and servicing vital equipment. Examples include computer tomography (CT) scanners and magnetic resonance imaging (MRI) machines, used to visualize internal structures of the body. Globally there are approximately 105,000 CT scanners and MRI machines. They require about 4 million labor-hours to service annually. This is equivalent to about $250 million of labor costs to service annually.

Table 1. **Valuing the Opportunity: Estimated Time and Labor Cost**

Industry		Segment	Time to Service (Labor-hours per year)	Estimated Value (Billion US dollars)
	Power	Steam & Gas Turbines	52 Million	$7B
	Aviation	Aircraft Engines	205 Million	$10B
	Rail	Freight	52 Million	$3B
	Healthcare	CT + MRI Scanners	4 Million	$250M

Source: GE estimates, 2013

These examples are only a portion of the millions of machines and critical systems that need to be monitored, maintained, and serviced to support the global industrial system; yet they account for over 300 million labor-hours every year, for an estimated cost of over $20 billion. If the time needed for maintenance and servicing can be reduced, the scope for savings in both costs and human capital will be substantial. Once engineers servicing a freight locomotive have faster access to data on a mobile device, with powerful software analytics and visualization tools that will help interpret the data through an intuitive user interface, they will be able to complete tasks much faster, and with greater confidence and satisfaction. When field technicians repairing a gas turbine in a remote location are able to communicate in real time with colleagues across the world, show them the problem and get their expert suggestions via a mobile collaboration tool, they will be able to complete repairs much faster. Software, analytics, and mobile collaboration tools will help industrial workers to significantly reduce the time and costs detailed above, as well as in other sectors across global industry.

Software, analytics, and mobile collaboration tools will help industrial workers to significantly reduce the time and costs detailed above, as well as in other sectors across global industry.

4. UIC - (2011 data) http://libraries.ge.comdownload?fileid=297227744101&entity_id=10376733101&sid=101

Where the Work Gets Done

The time required for the servicing of industrial equipment, and the associated costs, are partly driven by the environment where these activities have to take place. A significant portion of work takes place out in the field, where workers travel to the machine or site. Another portion occurs in service centers, where machines are brought to common shops to be worked on. Finally, an important part of the work is done in control centers. Each of these locations is discussed briefly below.

Out in the Field

"The Field," can refer to locations near urban centers or in very remote locations. Especially in remote locations, as one would expect, there is significant work and costs associated with installing and commissioning new units – and with ensuring performance. A portion of field operations focuses on de-commissioning or replacing equipment and sites. Efficient field operations are essential to minimizing unplanned downtime, which can reduces costs and disruptions to end-users (as in the case of power outages).

The amount of time spent on field operations varies. Large industrial facilities that operate continuously, such as major power plants and refineries, required field service engineers based full-time at a specific site. Smaller facilities and machines, will send technicians on site as needed, for regularly scheduled maintenance or for equipment failures, so field engineers are organized in teams to deliver responsive service, on-call. These teams need to have deep domain expertise about new and legacy technology and the ability to identify conditions or components that impair the performance of machines or cause unscheduled shutdowns or damage. They also perform audits, as well as tuning and modeling services designed to optimize performance, availability, or to improve maintenance and planning.

Service Centers

Thousands of service centers are located around the world dedicated to maintaining, repairing, and upgrading equipment in a timely manner. This reflects the advantages inherent in servicing machines in the field, versus others where transporting machines to service centers is more efficient. Service centers have more specialized machine tools and diagnostic equipment than those available in the field. They also have the facilities to safely undertake chemical and mechanical cleaning as well as services such as welding or heat treatment. Service centers can also control for dust and other contaminants in a way that is difficult, if not impossible, out in the field. This specialty equipment permits troubleshooting supported by product domain experts, and repair technology centers of excellence. These advanced repair processes not only support the goal of maintaining operations, but also extend life and enhanced quality and reliability of components.

The service centers are staffed with individuals who have mastery of the latest repair and maintenance techniques. Aircraft engines, gas turbines, diesel engines, and other complex machines are supported by a global network of strategically located service centers that reduce logistics costs and facilitate turnaround times. Local management of proactive maintenance plans is focused on optimizing availability.

Operations Centers

Operations centers, as the name suggests, are central locations designed to operate facilities such as a specific power plant or refinery, fleets of locomotives or aircraft, or networks such as power grids and gas pipelines. Although the industrial sectors may differ, there are similarities to the basic functioning. The type of work carried out in operation centers can be divided into three areas. First, there is operational insight. This includes tracking and measuring key operating parameters such as hours, starts, and trips; data trending, such as core operational data (vibration, combustion, etc.) and performance and reliability analysis. Second, diagnostic and optimization tools are used to evaluate alarms and events. Third, activities around fleet benchmarking involve collecting and analyzing information across industrial plants

and across different levels of analysis; it consists in assessing the performance of classes of plants or specific regions, or evaluating how a specific plant or group of plants is running compared to the all the plants in operation. Thus, the operation centers engage in data segmentation & filtering for customized "fleet" views, historical analysis, real-time analysis, and forecasting. All of this contributes to identifying proactive opportunities for unit improvements. Operations centers may also provide logistics management such as ordering materials, managing inventory, warehousing, handling importing/exporting processes, and determining and meeting daily parts requirements. This is where the power of advanced analytics becomes most evident.

It is evident that the servicing and maintenance of industrial equipment is an extremely distributed process, with activities taking place in a variety of locations, often thousands of miles apart. Mobile collaboration and communications therefore prove extremely powerful in this context.

The other important element that emerges from this section is that, as machines become increasingly interconnected, larger portions of the industrial sector are getting linked together into networks. Software analytics will therefore become more important in enabling better management of logistics and operations across these networks, as well as rapid troubleshooting.

Who Does the Work: Job Categories

The activities described in the previous section are carried out by workers fulfilling a wide range of specific job roles. While in any particular location or industry, responsibilities may cross over, in general these job roles can be classified in five key categories: operator, fleet engineer, fleet manager, operations & maintenance manager, and executive.

Operator

The Operator is on the frontline of the organization—in the field acting as the eyes, ears, and hands of the asset. Operators are hands-on, working on-site or adjacent to the asset. Operators monitor and adjust assets as needed. They have extensive firsthand experience with machines and their associated tools and interfaces. They rely on multiple data streams and key performance indicators (KPIs) to construct a holistic understanding of asset operation. Their activities include:

- Monitoring systems and interpreting data in real-time to quickly and safely correct conditions
- Developing a comprehensive understanding of asset function and common states
- Identifying variances that could disrupt performance
- Demonstrating informed judgment when calling in additional resources to ensure smooth operation

Operators must react to operational concerns in real-time, following best practices to facilitate the long-term system health. Their priority is to obtain accurate, calibrated information, then to carefully interpret the data, looking beyond the surface information to understand the root causes of possible malfunctions. And they need to maintain calm and focus in crisis situations. To do this, they rely on a keen sense of how physical assets and interfaces should work and their ability to absorb and interpret data in various forms. This professional instinct is honed through years of experience in the field, confronting a variety of unexpected situations. But it also requires operators to stay current with the latest technology and best practices.

The Industrial Internet can enhance the capability of Operators to perform their job tasks. One improvement is the integration of collaboration and mobile technologies. Real-time collaboration channels connecting a field operator to peers, as well as to fleet engineers and managers, can reduce the cycle time to resolve problems.

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Fleet Engineer/Diagnostician

The Fleet Engineer/Diagnostician has the most extensive knowledge of and experience with individual assets. From onsite analysis to reports and KPIs from team members, fleet engineers/diagnosticians take a holistic approach to evaluating asset operations and effective problem solving.

Fleet Engineers/Diagnosticians have a firm grasp of theory and practice applied to timely problem solving related to the assets comprising the fleet. They act as intermediary between frontline operators and managers, supplying performance data from asset level to part level. They are in constant communication with the team, especially when troubleshooting operational concerns. When faced with unreliable data—such as slow information systems or outdated resources—Fleet Engineers/Diagnosticians must acquire the necessary information quickly to mitigate risks. Their key responsibilities include:

- Mitigating risk and anticipating problems at an individual asset level

Table 2. **Work Roles**

	Operator	Fleet Engineer	Fleet Manager	O&M Manager	Executive
Responsibilities	Operate, monitor and maintain machines & assets	Evaluate asset operations & troubleshoot operational problems	Long-term financial decisions & operational investments	Purchasing decisions; plan assets maintenance cycles; personnel management	Mitigating risk; maximizing ROI; defining short- & long-term strategies
Interaction with Machines	Direct interaction with assets	Data interaction with assets; intermediary btwn operators	Direct interaction with assets	Direct interaction with assets	Not physically involved in day to day asset operations
Data Exposure	Real-time & short-term operational data	Performance data from part level to asset level	Broad operational & financial data of the entire fleet of assets	Historic & real-time performance & financial data	Diverse & incomplete data

- Troubleshooting operational problems as they arise and referencing technical resources when needed
- Providing required equipment and parts to facilitate asset maintenance and repairs
- Developing a deep understanding of asset operations that is communicated to management in order to inform long-term planning and investment decisions
- Seeking out opportunities for improving asset operations and performance
- Disseminating information about asset performance and function to the rest of the team

Fleet Engineers/Diagnosticians need to assess operation problems, diagnose symptoms, and determine next steps. They must have an intimate understanding of asset function, of related technical literature, and vendor information to augment firsthand knowledge and aid in informed decision-making. They act as a repository of asset knowledge for the team based on their extensive familiarity with the assets and relevant reference materials. This knowledge informs technical and business decisions at an executive level, with an eye to improving efficiency at a technical, process, and maintenance level, for both individual assets and the fleet / network as a whole.

Fleet Engineers/Diagnosticians will find benefits in the use of collaborative visualization tools. Such tools can help them identify where potential problems are likely to occur and to prevent them before they happen. Adding on the latest in improved user experience design can make visualization of big data easier and more effective.

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Fleet Manager

The Fleet Manager maintains a broad operational and financial view of the entire fleet of assets, whether they are wind turbines or locomotive engines. For long-term financial decisions and operational investments, fleet managers rely on their industry experience and KPIs gathered from a variety of sources to ensure best practices across the entire fleet.

Fleet Managers research and communicate essential information to their teams, often being on-site to build familiarity with individual assets. Further information is distilled from other sources, such as trade journals, peers, industry reports, and established best practices. A “big picture” approach facilitates coordinated purchasing and maintenance for individual assets and the fleet as a whole. They strive to mitigate financial risks (real-time pricing of resources, hedging, etc.) and operational risks (physical investments, coordinating downtime) across the entire fleet. They must stay current on industry, technical, and operational advances and best practices and share this with the rest of the team. They assess asset performance via internal auditing, and report asset status, performance, and roadmaps to various stakeholders. Their key responsibilities include:

- Maintaining a long view of future costs associated with asset life cycle, performance improvements and long-term financial investments
- Balancing costs against risk when making investment decisions
- Reducing financial and operational risks and making informed forecasts and projections by maintaining a comprehensive understanding of the fleet based on research and experience
- Cultivating an intimate knowledge of each individual asset as well as its relationship to and impact on the rest of the fleet
- Enabling collaboration within the fleet to identity and spread best practices
- Keeping abreast of the latest operational and industry advances to ensure assets adhere to industry standards

One of many Industrial Internet aspects of interest to Fleet Managers are dashboards to support predictive maintenance of assets and fleets. These dynamic and intuitive dashboards allow a shift from the traditional reactive and scheduled maintenance to more efficient condition-based maintenance operations.

Dynamic and intuitive dashboards allow a shift from the traditional reactive and scheduled maintenance to more efficient condition-based maintenance operations.

Operations & Maintenance Manager

The Operations & Maintenance Manager is responsible for asset maintenance, as well as the immediate needs and long-term development of the workforce operating on the industrial machines. O&M managers rely on data gathered on site and from industry sources to inform business and operational decisions and goals.

O&M Managers operate in a mostly reactive role, responding to events as they arise. They take the lead when restoring balance to the system after a disruption. They are tasked with solving immediate problems and helping their crews learn from disruptions in order to better prepare for future situations. They remain in constant communication with their crews and vendors, scheduling work and training personnel on asset function, tools, and best practices, as well as disseminating best practices to the team. O&M Managers make informed purchasing decisions, plan maintenance cycles for assets and proactively seek out areas of improvement for crews and systems. They develop a network of vendors and resources to facilitate procurement and inventory management. Their key responsibilities include:

- Maintaining a long view of future costs associated with asset life cycle, performance improvements and long-term financial investments
- Balancing costs against risk when making investment decisions
- Reducing financial and operational risks and making informed forecasts and projections by maintaining a comprehensive understanding of the fleet based on research and experience
- Cultivating an intimate knowledge of each individual asset as well as its relationship to and impact on the rest of the fleet
- Enabling collaboration within the fleet to identity and spread best practices
- Keeping abreast of the latest operational and industry advances to ensure assets adhere to industry standards

Executive

The Executive is responsible for taking a comprehensive approach to asset operations management and business performance. Executives make difficult decisions that reflect an understanding of diverse and often incomplete data and provide the basis for defining short- and long-term strategies of the organization. Ultimately, the executive is responsible for mitigating risk and maximizing return on investment.

While Executives might not be physically involved in the day-to-day operations of the machines, they rely on a deep understanding of the assets, as well as on reports from their teams keep them up-to-date. Executives also act as advocates for assets and operations in discussions with board members and legal teams and in business negotiations. Executives must be fluent in performance, financial, and regulatory data.

Executives need to be aware of current asset status and operations in order to define a long-term vision for the business and maximize return-on-investment (ROI) via optimized short- and long-term investments.

Executives need to be aware of current asset status and operations in order to define a long-term vision for the business and maximize return-on-investment (ROI) via optimized short- and long-term investments. Their key responsibilities include:

- Defining and monitoring short- and long-term performance goals to ensure business objectives (profitability, ROI, etc.) are met
- Overseeing all system planning and operations
- Gathering and integrating data from a variety of inputs into the decision-making process
- Communicating organizational direction and decisions to stakeholders
- Coordinating clear communication between and among various groups both internal and external to the organization

Enabling Work:
Industrial Internet Applications

As we discussed in the previous sections, the workforce of the modern industrial sector encompasses a wide range of professional roles, operating in multiple and very different environments to perform a large number of complex and delicate tasks to ensure the efficient functioning of industrial assets. All this requires quickly absorbing, interpreting, and reacting to a large but often incomplete set of data, at times in high-pressure situations.

The Industrial Internet will play a powerful role in helping the industrial workforce cope with these challenges, by deploying a range of tailored applications, software solutions, and hardware products that will enable both centralization and decentralization: centralized operations and monitoring and decentralized field work and maintenance. In this section we discuss the main categories of applications through which the Industrial Internet will transform the way people work.

Problem Solving and Troubleshooting

Problem solving and troubleshooting, as well as optimization of asset and systems performance, will be supported by powerful software able to leverage big data to identify correlations, causal relationships, and sensitivities that have so far gone undetected. This where the hard work is done, exploiting greater amounts of information to identify better strategies for assets and system utilizations. But to be really useful, this complex information needs to be conveyed to the right people at the right time, and in a way which is sufficiently intuitive, easy to grasp, and therefore quickly actionable. Analytics dashboard products communicate asset and business performance through charts and other data visualizations. In short, they help users make sense of their data—a picture is often worth a thousand words, especially when time is of the essence.

A central theme of the Industrial Internet strategy is optimizing asset, operational and business performance. This distinction is useful when considering the appropriate performance indicators and data visualizations to include in an analytics dashboard application and how to group them, and also when predicting how different audiences might use these features.

Asset performance might include utilization or maintenance summaries, or detailed performance metrics, such as turbine start times. Business performance might include information pertaining to a fleet's financials, such as operational expenditures or fleet-wide fuel efficiency. There is a corresponding expectation that different audience types will be more likely to view one set of information than another. For example, executives are more likely to be concerned with business performance than fleet engineers/operators are.

In addition to business and asset distinctions, analytics dashboard applications should allow users to work at different levels of detail, from system-level overviews to groups of related analytics to more detailed and rigorous visualizations exposing a single data type.

Data Collection and Insights

Insights dashboards tell users how to improve asset and business performance. Discussed in the previous section, analytics help users understand a problem. Insights dashboards will then provide possible strategies to address the problems, informed by industry expertise. Insights dashboards surface recommended plans of action to users based on their specific data. In the Industrial Internet domain, these recommendations contribute to asset or business optimization and might consist of a maintenance plan or process recommendation.

Analytics and insights have a tight relationship. The former deliver performance metrics for one or more

assets; the latter identify actions to improve those metrics. Despite their correlation, they have been presented as separate applications in an attempt to give application teams flexibility when it comes to monetizing their applications. Some businesses may want to charge for insights and, as such, offer them as an add-on to a baseline application.

Situational Awareness

Asset Monitoring applications are the most fundamental way users track their fleets. They let users quickly find assets, inspect their status, and acquire more detailed information.

The Industrial Internet is a system based on intelligent assets. As such, accessing basic asset information is at the foundation of any Industrial Internet software product. When users need to track a significant number of assets, asset monitoring will be at the center of the solution.

Asset monitoring applications let users quickly and easily find assets in their fleets. This includes being able to select assets by unique identifiers or common metadata such as model type or operational status, then being able to monitor these assets across the fleets.

A number of data attributes should be available for a given asset: status; past, present and future events, such as faults and maintenance; and raw sensor data in formats appropriate for the expected users. Other asset data may be appropriate depending upon the asset type—for example, location within a map if the asset is mobile like an aircraft engine or locomotive.

This formulation of asset monitoring is deliberately simple; it's only about locating assets and viewing their basic information.

With its growing number of collaboration tools, great care must be taken to reduce redundant or unsustainable modes of collaboration.

Collaboration

Collaboration features help users share information within an Industrial Internet product. They are intended to supplement existing channels of communication, not replace them. Collaboration typically occurs as part of planning or troubleshooting processes, often among users with varying levels of expertise and across multiple sites. In the context of Industrial Internet software products, collaboration is about sharing relevant data between different users of an application. A central goal of any collaboration application is to preserve the integrity of the shared data and enhance communication.

With its growing number of collaboration tools, great care must be taken to reduce redundant or unsustainable modes of collaboration. Multiple channels are available —voice and video telephony, email, instant messaging, and other asynchronous tools—and a primary research goal of product teams is to determine if and how to integrate content from their applications into existing channels.

Collaboration involves facilitating multi-party analysis of an individual chart, data grid, or a row, column, or cell within a data grid. Sharing time ranges of data and complex or real-time views falls into more advanced collaboration use cases.


THE SURGERY CENTRE
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Enabling Technologies for Workforce Productivity

There are a number of enabling technologies that are making possible new levels of workforce productivity and informed decision-making. Many of them, such as collaboration and social software, represent innovations from the consumer and business worlds that are being extended and enhanced to support the unique requirements of the Industrial Internet. Others, such as intelligent machines that interact with their human operators in new ways, are emerging directly from the requirements of the industrial sectors. Some of them are in relatively early stages of adoption, but they will become increasingly commonplace as businesses seek to leverage the Industrial Internet to operator their operations more efficiently and effectively.

Cloud Computing enables new service delivery models for the information and applications that drive workforce productivity and better decision-making. In the cloud model, centralized data centers that provide relatively low-cost storage and computing can be used to remotely collect and manage data from equipment, track maintenance records, analyze performance, and serve up video, manuals, and other aids to field-force automation in a consistent and manageable way. The cloud model also makes it possible to leverage these advanced productivity applications without having to make the up-front capital investment to build and manage their own data centers and application infrastructure. And, in the same way that cloud-based sales force automation solutions provide the flexibility to rapidly provision new sales people without a lot of up-front time and expense, the cloud model provides industrial operators the same flexibility to expand and contract their workforce as business requirements change.

Mobility is playing an increasingly important role in workforce productivity. Wireless connectivity and the explosion of smart phones, tablets, and related devices are putting real-time information and collaboration tools into the hands of workers everywhere from factory shop floors to hospital operating rooms and offshore oilrigs. As the availability and performance of the global communications fabric continues to expand and mature, the deployment of these technologies and the sophistication of the applications they support continues to grow.

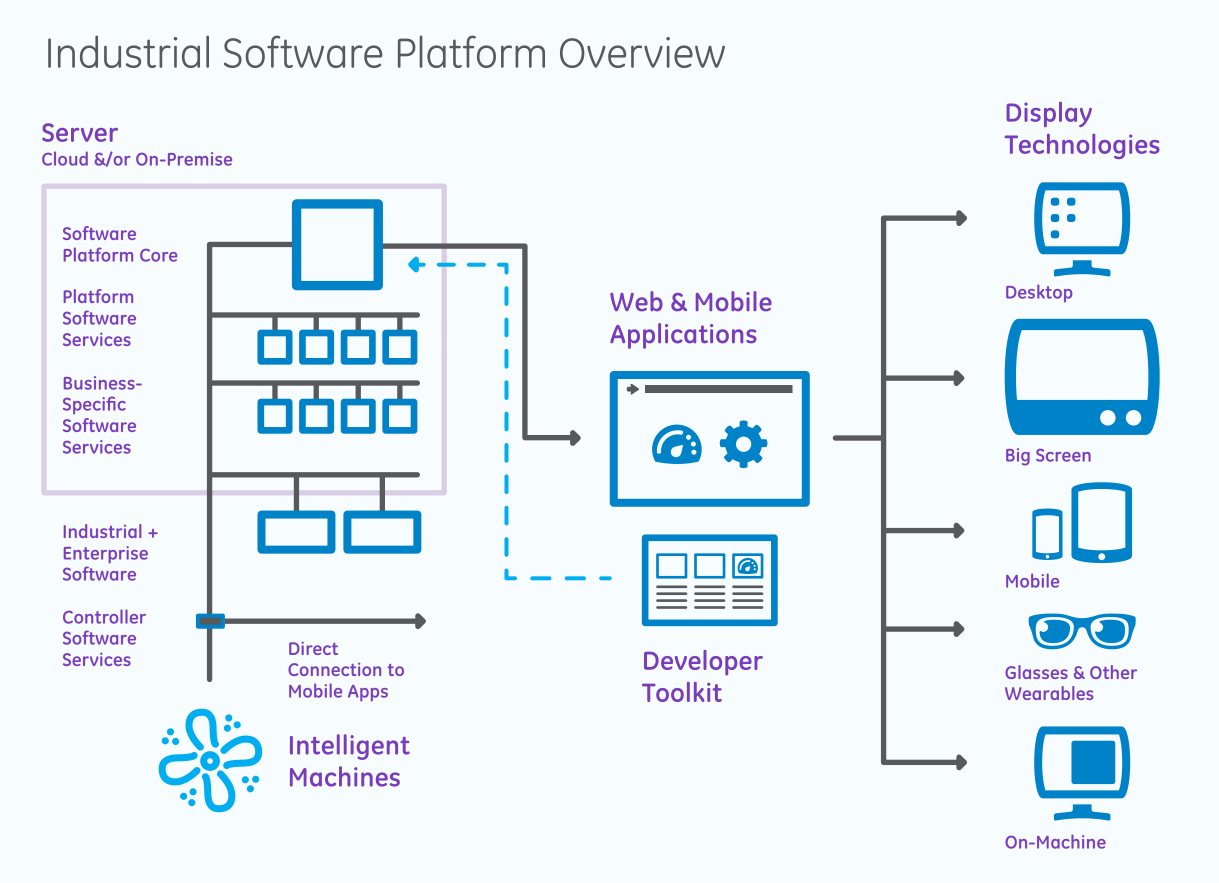
Intelligent Machines are the cornerstone of the Industrial Internet, and the software and analytics onboard today's generation of intelligent machines offer significant potential to transform workforce productivity. Field technicians can connect their mobile computing devices directly to the machines they are servicing and get current status and maintenance records for that machine. Sensors on industrial equipment can wirelessly stream performance data to centralized servers on premise or in the cloud, where it can be analyzed in real-time and then accessed by plant operators to make better decisions about utilization and optimization.

Presence and Location-Awareness technologies leverage the Industrial Internet and advanced software to track the location and availability of machines, people, and other resources. This information can be used to optimize logistics and scheduling to optimize workforce effectiveness and resource utilization. For example, hospitals can use these technologies to track the location of the thousands of medical devices required to deliver patient care, such as portable ultrasound machines, patient beds, and IV units. In large industrial industries, the data from intelligent machines can be analyzed to detect problems and the nearest technician to the site can then be routed to address the problem.

Collaboration and Social Software connects industrial workers and executives to each other and to the machines, systems, and information they need to perform their roles. When combined with other technologies such as cloud service delivery, mobile computing, and presence awareness, collaboration software enables scenarios such as streaming how-to videos to on-site workers, or connecting them in real-time to remote experts who can walk them through complex procedures or diagnostic decisions by "seeing" what the on-site worker is seeing.

Virtual Reality and Data Visualization technologies are increasingly being used in Industrial Internet solutions to replace the traditional tabular spreadsheet look typical of yesterday's industrial software with lifelike 3D renderings of equipment, systems, and operations. Advanced data visualization technologies help operators and executive spot patterns and trends and make better decisions more rapidly.

Figure 1. **Digital Platform**



Source: GE Software COE, 2013

Wearables and Robotics will play an increasingly important role in workforce productivity. From ruggedized wrist-mounted computing devices to safety glasses that display performance data on their lenses to advanced headsets equipped with 3D displays and cameras that collect real-time images and video, there is an explosion of new wearable technologies that will become increasingly important tools for efficiency and effectiveness in the industrial sectors. Personal robotics will increasingly be deployed to assist field force workers in completing complex and precise tasks. In the same way that robotics are augmenting surgeons in performing complex but repetitive surgical procedures, personal robotic solutions will increasingly be leveraged to augment the skills and efficiency of field force workers.

These and other enabling technologies are increasingly being used in various combinations to capture the efficiency gains and optimization possible through the Industrial Internet.

Future of Work

In this paper, we have shown how the global industrial sector relies on a wide range of professional roles performing complex operations, and we have discussed how key applications of the Industrial Internet will augment and in some cases fully transform the way these workers perform their tasks. At the same time, it is increasingly clear that the Industrial Internet will also require employees with new capabilities. In addition to the technical skills in mechanical or electrical engineering, there will be need for a wave of new technical, analytical, and leadership roles that are explicitly cross-discipline. The following job categories illustrate some of the new talent categories created by the Industrial Internet:

It is increasingly clear that the Industrial Internet will also require employees with new capabilities. In addition to the technical skills in mechanical or electrical engineering, there will be need for a wave of new technical, analytical, and leadership roles that are explicitly cross-discipline.

Next Gen Engineering

There will be a growing need for a variety of roles that blend traditional engineering disciplines such as mechanical engineering with information and computing competencies to create what might be called "digital-mechanical" engineers.

Data Scientists

Data scientists will create the analytics platforms and algorithms, software, and cyber security engineers, including statistics, data engineering, pattern recognition and learning, advanced computing, uncertainty modeling, data management, and visualization.

Business Operations Data Analysts

Taking full advantage of the Industrial Internet will require a fundamental change in the way that business operations are organized. Business Operations Data Analysts will be business managers who combine a deep knowledge of their industry with an intimate familiarity of the latest analytical tools; this combination will allow them to direct the power of the new enabling technologies where they can have the maximum business impact and ROI payoff.

User Interface Experts

Industrial design field of human-to-machine interaction, to effectively blend the hardware and software components required to support minimal input to achieve the desired output; and also to ensure that the machine minimizes undesired output to the human.

Table 3 . **New Job Categories**

	Focus Area	Skills & Education
Digital-Mechanical Engineers	Ensure integration and interoperability of machines with condition based software	• Civil, mechanical, materials engineering • Computing, math, science experience • Computer science or engineering studies
Data Scientists	Develop algorithms and analytics models for optimal performance	• Ability to strategically view and apply data • Applied mathematics or science education
Business Operations Data Analysts	Combine business operations with analytical fluency to increase performance, mitigate risk and operating costs	• Operations and management experience • Fluency in basic analytical processes • Business, finance, economics studies
User Interface Experts	Industrial design with a focus on human-to-machine interaction	• Machine learning, design fluency and robotics • Communications and design education • App development skills a plus

Where will this talent come from? There are shortages today in many of the potential foundational capabilities in many geographic regions: cyber security, software engineers, analytics professionals, among others. Talent markets should eventually realign, but firms will probably need to create a talent pool of their own by drawing upon their most versatile (and adventurous) employees. Labor markets that are more "sticky" either from culture or regulation will be less able to adapt to meet these new demands.

Other alternatives for sourcing cross-discipline talent might include developing the existing resources in the native domain through collaborative approaches. Instead of building or buying talent that has multiple skills, organizations may create environments that accelerate the ability of people with different skills to interact and innovate together. On a larger scale, approaches such as crowdsourcing might be able to close some of the capabilities gaps that are sure to occur.

The changes required upstream in the educational system will need to be driven through stronger collaboration among firms and universities. There is a great need for educational programs to be developed to formalize the knowledge foundations that "data talent" will require. Today the people that manage big data systems or perform advanced analytics have developed unique talents through self-driven specialization, rather than through any programs that build a standard set of skills or principles. Co-development of curriculum, integration of academic staff into industry, and other approaches will be needed to ensure that the talent needs of the Industrial Internet do not outpace the educational system. Some programs have already started to emerge in this area, but many more will be needed.

Crafting and promoting the vision of the Industrial Internet, its value and applications, is ultimately a leadership role. These visionaries will need support from company leadership to sustain the investments through business cycles and through the peaks and troughs of specific industries. Innovation requires risk tolerance, and many aspects of the Industrial Internet may stretch firms beyond their comfort zone, and into new partnerships. Firms will need a new generation of leaders who can form and execute on the vision and build the organizations, culture, and talent that it requires.

Talent markets should eventually realign, but firms will probably need to create a talent pool of their own by drawing upon their most versatile (and adventurous) employees.

Conclusion

Like every wave of technological innovation, the Industrial Internet ultimately revolves around human beings—people at work. Even as machines become more intelligent and analytics capabilities more advanced, there are a host of activities that will require people to perform. Operating and servicing complex machines will always require mental and physical capabilities that only humans can provide. And even as the range of activities performed by machines expands, people at work are in the driving seat.

Field engineers, operations and maintenance experts as well as executives overseeing complex facilities, fleets and networks will see their work activities change through the deployment and integration of software platforms, advanced analytic capabilities and new human-machine interfaces. The benefits associated with this change are significant and result, as we have pointed out, in major improvements in how information flows and is processed. Relevant information workers need to perform their tasks will automatically reach them, sometimes on mobile devices while they are out in the field in remote locations—they will no longer need to spend hours looking for it. They will be able to collaborate remotely with colleagues in real time, exchanging documents, getting any support they might need to complete the task at hand. With industrial assets constantly feeding data to powerful software, engineers and managers in operations centers will benefit from sharper analytical insights enabling them to optimize the operation of individual industrial assets as well as entire systems and networks of assets: power grids, gas pipelines networks, fleets of aircrafts or trains, entire hospitals.

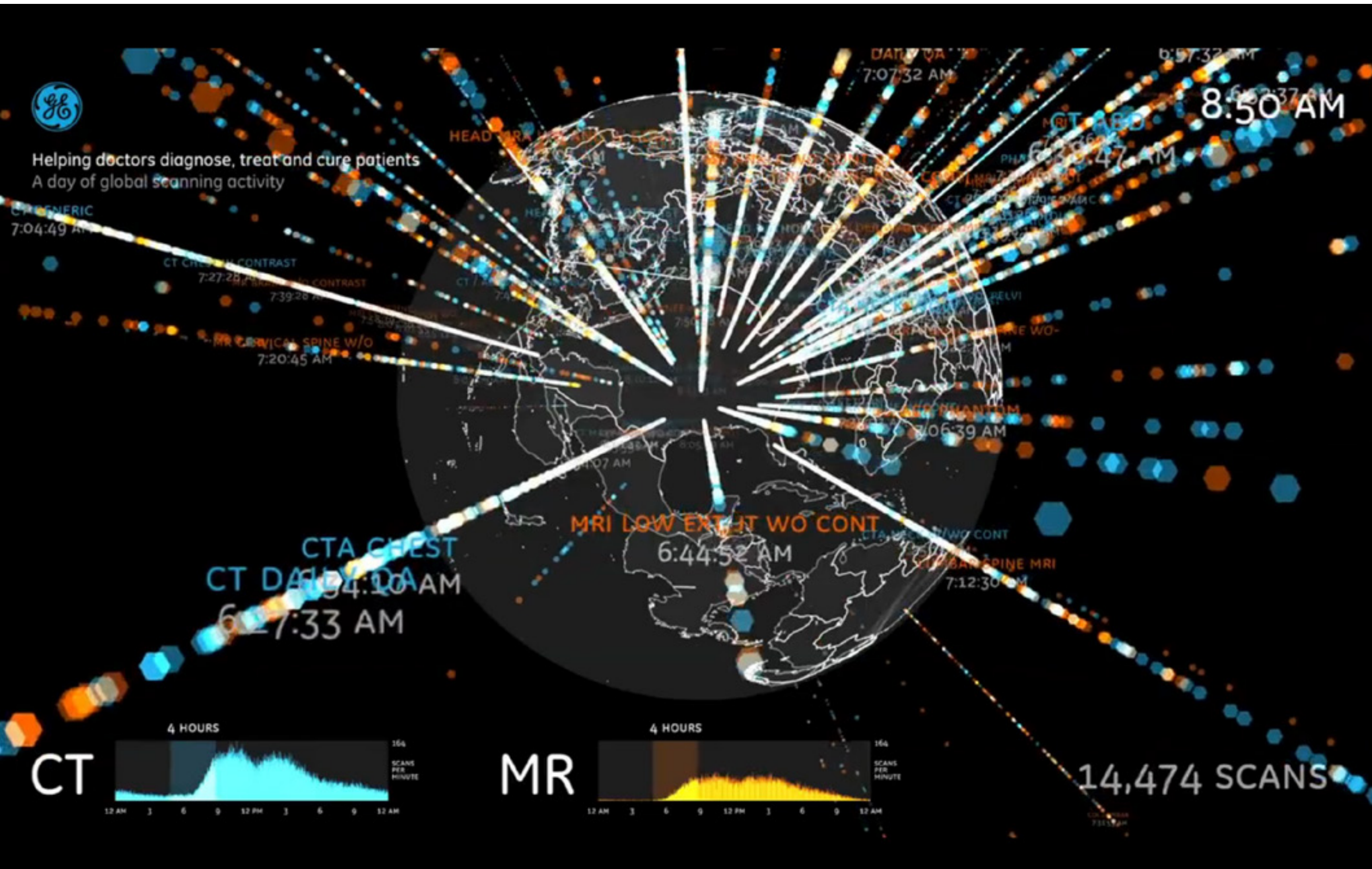
There will also be the benefit of enhanced prediction. Maintenance and servicing will be carried out in a preventive way, based on the current status of individual industrial assets. The field engineer will give his attention to the gas turbines that need it, before they break down. This will bring us closer to a world of no unplanned downtime for power plants and no aircraft stranded on the ground for mechanical failures. It will dramatically improve capacity utilization. It will also reduce the time which is today lost by performing maintenance and servicing on a predetermined timetable for lack of information on the actual status of the assets.

The scope for enterprise efficiency that can be gained from these innovations is considerable. Additional efficiency gains will come from operations optimization, as every industry will have its version of air traffic control: this will improve logistics and delivery times, make supply chains more efficient and more resilient to disruptions, allow hospitals to deliver faster and better health care to their patients.

Most significantly, workers will see their jobs become more rewarding as they will have easier and faster access to information and be better able to collaborate; they will learn and upgrade their skills at a faster pace, while becoming more efficient and productive. New jobs will be created, both by the need to develop and manage the new technologies (data scientists, user interface experts, and next-generation engineers) and by the overall boost to economic growth. The education system will need to adapt and equip students with new skills for this rapidly changing workplace, and companies will need to invest in training to help their workers to quickly master the new technologies and, in some cases, to retool them for new positions. At the same time, management strategies will need to evolve and adapt to reshape corporate organizations and incentives in a way that fully leverages the potential of these new innovations.

All this will be enabled by a new digital software platform providing a standard way of connecting workers, machines and data. Deployed on premise or in the cloud, this platform will support a new wave of compatible, interconnected applications for data gathering, storage and sharing, ensuring mobility, scalability, customization and security. It will be part of an open ecosystem encompassing industrial and technology companies, academic and government institutions, and third-party developers; open-source collaboration will accelerate its development and adoption.

Thus the Industrial Internet presents attractive new possibilities for both enterprises and their employees. Work of the future has the opportunity to race with the new, intelligent machines of the Industrial Internet, not against them.



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Appendix A: Information

Information plays a crucial role in the efficiency, productivity, and profitability of nearly every complex economic process. Prices, for example, are an essential vehicle to distribute information. Traditional neoclassical economic models were built on the assumption of perfect information—an essential component of a benchmark efficient system, but patently unrealistic in many contexts. Half a century ago, the Nobel Prize winning economist George Stigler bemoaned the fact that "…knowledge is power. And yet it occupies a slum dwelling in the town of economics."[5] Stigler essentially argued that, with the assumption of perfect information, ignorance was ignored. Since then, a substantial and growing body of academic research has been devoted to analyzing the implications of different forms of imperfect information and information asymmetries.

At the same time, an increasing amount of attention has been devoted to the crucial role that information, and its efficient diffusion, plays within organizations, and in particular within corporations. For example, Patrick Bolton and Mathias Dewatripont (1994) defined and analyzed the "firm as a communication network," in an early effort to determine how a firm should be organized in order to process the flow of available information in the most efficient manner.

Information is a powerful and precious resource. It is therefore unsurprising that more recent studies are finding evidence that the way in which information is managed and distributed within a firm has a powerful effect on the performance of individual workers and of the firm as a whole.

Information is also a very special commodity because its accumulation in part depends on the individual worker's experience and domain expertise. In other words, in many contexts, information is a highly personalized resource, and its availability and diffusion today depend very often on voluntary interaction. Some individuals have to proactively seek information from others, and some individuals have to willingly share their information with colleagues. A substantial body of academic literature has been devoted to studying the way in which knowledge, both internal and externally acquired, is shared within a team or an organization, and the impact that this has on the team's performance. Some of these studies highlight the importance of network structures, and in particular of factors that can bolster social cohesion within a network, thereby improving the chances of information transmission.[6] One recent study shows that the way in which certain types of information are diffused within an organization often depends on organizational hierarchies and functional relationships, or on demographic and network factors, in a way that is not necessarily optimal.[7] All this further underscores the fact that information sharing in today's work environment depends heavily on proactive interpersonal relationships. These studies also find that timely access to information is a key determinant of worker productivity and that information sharing and better access to information is found to have a positive impact on performance.

Combined with the basic fact that "knowledge is power", that is, information is a very valuable commodity—this opens up a complex dimension of strategic interactions within the workplace. A worker who possesses information has to decide whether it is in her best interest to share this information with other colleagues or to keep it to herself. In some cases, jealously guarding the information might be regarded as a strategic advantage with career-enhancing benefits. Alternatively, sharing information could be perceived as a better strategy both because it can boost the overall performance of the team or firm,

and because it can in turn engender a cooperative response on the part of the colleagues, who will then also be more willing to share valuable information.

Moreover, if the way in which information is sought and provided is visible to other individuals within the firm, there is another important set of considerations that come into play: perceptions, or signaling, in the terminology of game theory.[8] Asking for information signals ignorance. A worker asking for information is revealing how much he does not know and could fear that this will have negative career repercussions. Conversely, a worker who publicly provides answers will be perceived as more knowledgeable and could hope to benefit from this perception in terms of career opportunities. These motivations then have to be weighed against the respective costs and benefits. Obtaining the information you need from a coworker will enable you to do a better job more quickly than otherwise; conversely, providing information to colleagues implies taking time away from performing other tasks.

A recent study finds that sharing information within a firm does indeed have a marked positive impact on performance, and that while lower-skill workers (in the sense of workers exhibiting weaker performance) benefit the most from the information sharing, there does not appear to be a significant negative impact on the performance of higher skill workers.[9] Information sharing can be a win-win strategy.

The basic result of this recent analysis conforms to intuition: sharing information within a firm improves performance by raising the average level of knowledge across the workforce. It also confirms two important caveats, however. First, the net impact on performance depends on the efficiency of the information-sharing mechanism: if it takes a substantial amount of time and energy for a worker to seek out the information, or for a colleague to provide it, the corresponding efficiency costs could mute the positive effect of information sharing. The second is that the degree to which information is shared will, in many current work contexts, heavily depend on individual choices, and these will in turn depend on individuals' perceptions of what best serves their interests. In other words, even in a context where information sharing would be beneficial across the board, there is no guarantee that this information sharing will happen, or that it will happen at the scale needed to boost the company's performance.

5. Stigler (1961)

6. Cummings (2004); Reagans and Zuckerman (2001); and Reagans and McEvily (2003)

7. Aral, Brynjiolfsson and Van Alstyne (2007)

8. On the role of signaling in the workplace see for example Spence (1973)

9. Di Maggio and Van Alstyne (2012); while the study is carried out in a specific context, namely a major Japanese bank, the effect estimated by the authors is substantial: a one-standard deviation increase in information leads to a ten percent increase in performance.

Author Bios

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