Crossroads Conference 2017

Summary Report

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Executive Summary

The six presenters at the 2017 CTL Crossroads conference came from markedly various parts of MIT – studying business, economics, computer science, chemistry, and civil, mechanical, and electrical engineering – but their talks shared common themes connected to supply chains.

Dr. Jeanne Ross discussed the technologies that are disrupting companies – Social, Mobile, Analytics, Cloud and IoT – which she called SMACIT technologies. She then provided specific suggestions for how companies can harness these technologies to gain advantage over their competitors, and she described six companies' digital strategies.

Next, Prof. John Hart explored the potential of additive manufacturing – often referred to as 3D printing -- from both technological and economic perspectives to impact all stages of the product development process from conception to end of life. 3D printing has significant potential for on-demand manufacturing of spare parts, which could greatly improve the economics of service and maintenance operations by eliminating the need for large inventories of spares.

CTL's Dr. Matthias Winkenbach highlighted the potential role of advanced computer interfaces and augmented reality displays to more intuitively visualize and interact with complex data. CTL is building a lab for developing and demonstrating these new technologies and their potential use to address supply chain issues. Using intuitive tactile interfaces (such as moving small blocks on a map to signify warehouses and automatically recalculate the supply chain redesign consequences) could bridge the technical gap between data scientists and executives or other stakeholders in companies, government or partners.

Next, Dr. Anuradha Agarwal described how the ubiquity and low cost of sensors make them deployable along the supply chain, such as to enable a smart food supply chain. She outlined the development of a new chemical sensor platform that may be useful across industries, including oil & gas and healthcare.

Prof. Christian Catalini revealed how computers' cryptographic and networking capabilities can create a more robust means of securing and verifying global business activities. Once a transaction record becomes encrypted into a blockchain, it becomes virtually impossible to repudiate or modify that record. The blockchain concept can change the nature of supply chains and industries by enabling parties to trade with each other without knowing each other and without relying on centralized intermediaries like banks, thereby lowering transaction costs.

Finally, Prof. Markus Buelher showed how computers can successfully predict the properties of entirely new types of materials by simulating how atoms, molecules, composites, and macro scale structures behave. In his lab, Prof. Buelher and his team are creating new materials atom by atom at the nano-scale, and then producing them at macro scale using 3D printing. With these developments, supply chains could change because products could be lighter, stronger and more durable.

Turning Digital Disruption into Competitive Advantage

Dr. Jeanne Ross, Principal Research Scientist at the MIT Sloan School of Management, discussed the technologies that are changing the rules of the game in business. She then provided suggestions and examples of how companies can harness these technologies to gain advantage over their competitors.

Crafting a Great Business Strategy

Dr. Ross began by listing the five main technological forces that are disrupting companies: Social, Mobile, Analytics, Cloud and the Internet of Things – also known by the acronym SMACIT. Ross suggested that companies should respond to these forces with one integrated strategy that includes these technologies, rather than having separate strategies for each. The company's digital strategy is a business strategy, not a technology strategy, and it should build upon the company's business capabilities in ways that will improve customers' lives. As Dr. Ross put it, "Your digital strategy needs to be a business strategy inspired by the capabilities of powerful, readily accessible technologies (like SMACIT), intent on delivering unique, integrated business capabilities in ways that will improve your customers' lives."

Four Examples of Successful Digital Strategies

Good business strategies provide a grand vision for the company that guides it to the future. Dr. Ross described four examples of how companies are reinventing themselves for the digital age. In each case, the company developed an expanded vision of what it could provide its customers.

<u>Schindler: "Providing urban mobility solutions"</u>

Elevator manufacturer Schindler is in a cutthroat business in which essentially four global companies bid for all elevator installation contracts with razor-thin margins. The companies hope to make money on the service and support, but are often undercut by local technicians who offer to service the elevators at a lower cost.

To find a way to distinguish itself, Schindler first assessed its capabilities. The company noted that it moves a billion people a day in buildings and excels at doing this. So, the company decided to capitalize on this efficiency and expand it beyond just moving people inside a building. More broadly, the company could offer urban mobility solutions. But what did this strategy mean, and how did it tie to Schindler's elevator business? The company itself is not yet sure, Dr. Ross said, but it knows that it must move beyond simply providing efficient elevators. "Providing urban mobility solutions" points to a way forward. For example, the company analyzed the movement of people through the building to identify bottlenecks. One bottleneck occurs when visitors come to the building, queue at the security desk to register as a guest, and then queue for an elevator to their destination floor. Schindler could help handle this registration process, enable visitors to more easily register, swipe a code, and have an elevator that knows the visitor's destination and takes them only to that floor.

<u>USAA: "Ensuring the financial security of the U.S. military"</u>

USAA began as an insurance company serving military personnel and their families. The company then expanded to offering financial services like car loans. As USAA thought about its digital future, it saw the broader vision of "ensuring the financial security of the U.S. military." In this broader view, "financial security" could extend to helping its customers get the best price on a car, not just a loan for it. USAA now negotiates on behalf of its members to get the best deals. The next extension is not just to get customers the best deal, but to help them determine whether they can afford to buy a new car and how much they can spend on it. Like Schindler, the list of innovations expands as the company imagines how it can improve its customers' lives.

<u>Kaiser Permanente: "Patient-provider collaboration"</u>

Kaiser Permanente's health-maintenance organization business was originally designed around hospitals and the efficient delivery of healthcare. But its new digital services strategy focuses on the patient and health. The strategy emphasizes collaboration and the type of health care network that patients need to get healthy and stay healthy.

<u>Schneider Electric: "Intelligent energy management solutions"</u>

Finally, Schneider Electric is broadening from providing electrical distribution equipment to providing intelligent energy management solutions. The moves are high-risk and the way forward is not clear cut, but Ross suggests that companies must move serve their customers as old business models die. There is very little margin for Schneider Electric to simply sell circuit breakers. The company is aiming to help its customers run more energy-efficient buildings, tap into renewable energy, and utilize the Internet of Things to manage and use energy wisely and in more creative value-adding ways.

Digital Characteristics: What it Means to be Digital

Dr. Ross next described digital as encompassing two spheres increasingly personalized customer engagement and increasingly integrated digitized solutions. The customer engagement sphere is the marketing side of the business, and "increasingly personalized" means: seamless across all channels and consistent across sales and servicing; responsive to changes in customer expectations; engaging customers in a personalized relationship differentiated by customer segments; connecting customers with related communities when desired; and differentiated from the customer experience at competitors. The digitized solutions sphere reformulates the products and services that the company sells. "Increasingly integrated" means: integrated to provide a customer solution; responsive to emerging opportunities in the market; enriched with meaningful information and insights; seamlessly including partner products and service as appropriate; differentiated from competitor products. Dr. Ross stressed the importance of adding partners to the company's ecosystem so that the company can offer a greater diversity and personalization of products and services tailored to customer needs.

Although strategy in the past emphasized one of these spheres, the fact is that for digital business, companies need to have both. Dr. Ross has found that companies tend to have either both or none of these sets of outcomes. The two spheres need to be linked with an operational backbone that integrates them. This "backbone" (ERP, CRM, etc.) is a requirement, not an option, she said.

Nordstrom's Digital Strategy and Supply Chain Tie-in

Dr. Ross illustrated how retailer Nordstrom, Inc. is enhancing its renowned customer service by incorporating digital capabilities to provide a seamless, empowered customer experience whether the customer is in-person or online. Nordstrom has long been known for its outstanding customer service but was being disrupted by the increasing popularity of online shopping options and discount retailers. In its digital strategy, the company gives its in-store agents access to every item in Nordstrom's inventory in every location, so that the agent can bring the most relevant items to the customer in the dressing room, or offer to home delivery to them from a warehouse or other store if the inventory is not held locally.

Nordstrom first launched Nordstrom.com in 2004, adding omnichannel options in 2009. The years 2011-2015 saw the introduction of mobile apps, e-receipts, alerts if a customer was near a Nordstrom store, opportunities to buy clothing through Instagram, offering "buy it" pins online for immediate purchase, a "text to buy" app, and other innovations to make it easy for customers to buy apparel in the ways most convenient to them.

LEGOs' Digital Strategy and New Product Development

LEGOs nearly went bankrupt in 2004 due to supply chain problems created by a huge increase in the number and variety of LEGO bricks. The company lost $250 million on sales of $1 billion after focusing on new product innovation when its iconic brick went off patent in 1988. The company's SKU count quadrupled but many variations were so slight that they did not contribute to revenue but added significantly to costs. For example, the company sold 17 different policemen pieces, each with a slightly different shade of blue uniform -- requiring huge inventories of paint but not improving sales. The company had 11,000 suppliers in 2004, twice the number that aircraft manufacturer Boeing had.

LEGOs' biggest obstacle to creating a digital strategy was that the company did not think of itself as digital at all -- it made simple plastic bricks that snapped together -- in an era of computer games. The breakthrough came from a supplier's insight that a customer could build something in the real-life physical world and then absorb it into a computer game. LEGO implemented the idea and by 2015, company profit was $1.4 billion on revenues of $5.3 billion, with 60% of revenue coming from products introduced in the previous three months. The company partnered with Disney and created tie-ins to Star Wars characters, and introduced digitized products such as LEGO DIMENSIONS that featured characters from movies such as Ghostbusters, Back to the Future and The Simpsons. Players build figures to use in the video game.

LEGO is also using its digital services platform for innovation, to enable its customers to create new product ideas. Specifically, the company introduced the LEGO ideas platform (an expansion of its original internal product development platform) for use by customers. Using Open IT (the cloud), any customer can propose new products, such as the customer that suggested LEGO Minecraft and got 10,000 other customers applauding the idea within 48 hours. This fast response eliminated the need for market research and accelerated new product development. To encourage customers to share their good ideas, LEGO offers customers a small share of revenues for any customer-submitted idea that LEGO takes to market.

The Digital Services Platform

The Nordstrom and LEGO examples highlight the key role for a new kind of IT corporate system -- a digital services platform -- that operates alongside the traditional IT operational backbone to support all these new apps and customer-specific services. Dr. Ross likened a digital services platform to a growing, organic coral reef.

The digital services platform differs from a traditional IT operational backbone environment in that its objective focuses on innovation and agility rather than the traditional backbone's focus on efficiency, scale, security, and reliability. Funding also differs: rather than major project/program investments in infrastructure and large-scale systems, the digital services platform utilizes localized funding by product/capability owners who swiftly develop new service offerings in response to customer needs and trends. The backbone's usual thorough quality control process is replaced by a faster, looser "test, learn and then enhance-or-discard" approach for small experiments. The digital services platform draws data from various sources such as sensors and social media channels. Process owners and data owners play the key roles in the operational backbone, whereas in the digital services platform the key roles are held by the product and service owners. Finally, whereas the key processes of the operational backbone were road mapping and architectural reviews, in the digital services platform environment the key processes are cross-functional development and user-centered iterative design.

Five Steps to Competitive Advantage

In summary, Dr. Ross suggested four steps for companies to follow as they move to a digital strategy:

1. Commit to a digital vision
2. Create operational capabilities
3. Experiment with digital services
4. Adopt and continuously improve agile methodologies.

Q&A Discussion

A conference participant asked about the talent required for these spheres: could an operational backbone person also be working on the digital innovation platform? Dr. Ross replied that it was two distinct roles requiring different sensibilities and priorities. Rule-oriented operations people might be less comfortable is the more fluid environment of the digital services side, and innovation people shouldn't be subject to distractions of firefighting daily issues. Over time, however, the two functions could merge. USAA doesn't separate the two functions, but organizations new to digitization may feel nervous to have the same people doing both functions.

Another attendee asked how to convince CFOs to sanction the funding needed for such transformation projects, given the quarterly shareholder focus. Dr. Ross agreed that the transformation requires huge investments and the returns may be delayed if customers aren't quite ready for the changes. It requires an act of faith, but if management is not ready to make

In response to a question about BMW's strategy of "enabling individual mobility," (which Dr. Ross had briefly mentioned but not discussed in detail), Ross concurred that most car companies (not just BMW) are envisioning ways to support individual mobility and that this strategy is the most abstract of the strategies mentioned in her presentation. Both BMW and Toyota are considering "Uber-like" options, which would put them in competition with existing large on-demand ride-sharing services. Toyota is also contemplating offering a workday car that's driven five days a week and a fun car that's used on the weekends. Toyota is experimenting and trying to think of solutions that consumers may want.

A participant asked how to tackle the challenge of a digital disruption that interrupts the company's IT service. Dr. Ross commented that many companies could be hobbled if Amazon Web Services suffers a service disruption, but that every company faces these disruptions and thus they don't change the playing field. She also saw these problems as decreasing over time.

The final question in this session concerned the tug-of-war that can occur inside organizations, such as the mainstream IT people seeing the digital services platform as a competitor to what they themselves provide. Ross agreed that such internal infighting can be a killer, and that the digital strategy vision needs to be embraced by the whole company if it is to get past this infighting. Achieving that unity requires enormous organizational change, with empowered cross-functional teams making continuous improvements. Hierarchy was the enemy of integration, which is why cross-functional teams were needed. LEGO utilized cross-functional teams in which members learned each other's jobs. This approach can also improve innovation, in that cross-functionally trained product people are less likely to create products that service people couldn't service.

Additive Manufacturing: Current Status and Future Potential

John Hart, Associate Professor of Mechanical Engineering at MIT, spoke about the status of additive manufacturing (AM). The technology is often referred to as 3D printing – even though 3D printing is only one form of AM – so the terms were used interchangeably in the conference.

Hart described the enormous potential of this technology from both technological and economic perspectives, and how it impacts all stages of the product development process from conception to end of life. His talk paralleled Dr. Ross's in that the essence of additive manufacturing is to merge the digital and physical, and to engage the customer in the manufacturing process in responsive ways.

Rethinking Manufacturing

Manufacturing is the realization of value at scale, and yet manufacturing techniques often have constraints in the quantity needed (e.g. minimum order quantities) to produce products at profit. Additive manufacturing techniques such as 3D printing let us think about value and scale in diverse ways, Prof. Hart said. The technology won't replace traditional manufacturing, but it will likely complement factories and make them look and behave differently.

3D printing is a process by which a digital design is used to build up a component or other item layer by layer by depositing material.

A factory could become a combination of 3D printers working with robotics and digitized automation. For example, for LEGO to manufacture a new brick shape, the company has to bet on that shape being successful because it has to invest in the tooling and be confident that it can sell enough of the bricks to recoup its investment. But with 3D printing (additive manufacturing), LEGO can build a new brick shape without buying the tooling for that shape. 3D printing does not require investment in tooling, and it does not require sticking with one fixed form for the brick.

Background on Additive Manufacturing

Many of the core elements that have subsequently defined additive manufacturing or 3D printing were invented at MIT. Emanuel Sachs and Michael Cima patented these elements in 1993, and sold them to Z Corp. in 1995. Sachs and Cima invented a way to inject liquid binder into powder using an inkjet-like printing head, thereby building up 3D shapes originated from a digital design.

As mentioned earlier, the terms "additive manufacturing" (AM) and "3D printing" are used interchangeably. In reality, "additive manufacturing" is the more accurate term to distinguish this type of manufacturing from the traditional subtractive manufacturing, in which a block of material is milled or machined in some way to remove material and create the needed part. With AM, material is added layer by layer, creating exactly the needed part with no extraneous material.

There are several AM technologies, including selective laser melting (SLM). SLM melts a powdered material (usually metal) that solidifies into parts such as a lightweight brake pedal for a race car. The cost would currently be too high to manufacture these brake pedals for mainstream cars but SLM can be used for high-performance results when cost is secondary. Another technique, stereolithography (SLA) uses photo sensitive liquid polymers that harden when exposed to certain frequencies of light. SLA is used by Invisalign, a company that makes invisible braces (aligners) for teeth. The company uses 3D printing to make each unique aligner. Another AM technique, Directed Energy Deposition, heats metal powder or wire with an electron beam to build big parts with 3D, such as a large piece of an excavator. A company called Sciaky uses AM to build fighter jet components for Lockheed Martin's F-35 aircraft program.

AM Industry Today: Market Size and Industry Applications

According to industry analysts Wohlers Associates, the size of the market for 3D printing machines and services was $5.2 billion in 2015. The number of printers sold has been growing 26% for 27 years, but it is still a minute part of the $15 trillion market for traditional manufacturing goods and services. Over half of the $5.2 billion is industrial 3D printing for end use -- not just for prototypes -- meaning that 3D printing machines will need to include robustness and performance characteristics at some scale.

The aircraft industry has seen some of the biggest benefits, using metal-based 3D printing to manufacture high performance parts for jet engines where weight reductions and performance improvements in fuel consumption have extremely high value. In the shoe industry, Nike is printing polymers to make custom shoes, and Google planned to use it for making a modular smart phone in which the consumer could snap on desired features such as a better camera. In the entertainment industry, Hollywood films production companies use 3D printing to print realistic models, such as very detailed miniatures of James Bond's Aston Martin car, which can be filmed exploding rather than exploding the real thing. The healthcare industry could also be a great beneficiary of this technology, because implants could be printed as needed in emergency situations.

In the food industry, Frito Lay, maker of Ruffles brand potato chips, tested how customers would respond to new ridges in its potato chips by quickly prototyping different ridge shapes and letting customers physically touch them to identify their favorites.

Supply Chain Implications

3D printing can influence the lifecycle of products from conception through to end of life. For example, at the concept stage, 3D printing provides fast and inexpensive prototypes of potential designs. At end of life, when legacy products are still in the field and must be maintained even though they are no longer being manufactured -- such as certain kinds of farm equipment or aircraft -- 3D printing could produce spare parts on demand. Thus, a company could maintain a digital warehouse rather than a physical one of spare parts inventory.

Advantages of 3D Printing

In contrast to many mass-manufacturing techniques, additive manufacturing requires no product-specific tooling which implies that very small quantities can be made cost-effectively -- even down to units of one. In fact, each unit can be completely customized using digital data and computer design techniques for each individual without significant custom tooling costs.

The 3D printing process can make some parts that are impossible to produce as a single item using other methods. These include hollow lightweight parts, parts with complex passageways, or parts inside other parts. Making these kinds of complex features using traditional manufacturing typically requires assemblies of many simpler parts, which adds to the total cost and supply chain complexity. Some additive manufacturing systems can even incorporate more than one material simultaneously to create monolithic parts with unusual combinations of soft or hard, rigid or flexible, or multicolored features.

The main advantage of 3D printing occurs as the geometric complexity of the part increases. As Prof. Hart showed, "complexity is free" in that the cost to print a complex, intricate product is the same as the cost to print a simple product. In traditional manufacturing, the cost of intricacy increases because more material must be removed, more tooling may be needed, and more machining set-up may be required. AM costs are almost invariant to complexity, and indeed a complex part can take less time if it requires less material, because the time to build it decreases. Most important, 3D can allow shapes that would be impossible to produce via material subtraction.

Prof. Hart described some use cases, such as Wiivv Wearables, a company that makes custom insoles for shoes based on customers taking five photos of their feet and sending them to the company. Another use case is last mile packaging that is tailored to specific retailers or to seasonal variations.

Current Challenges of AM

Along with the advantages of 3D printing, Prof. Hart listed some of the disadvantages. First, the process does not offer the economies of scale of other mass production methods. Traditional manufacturing is often less costly if production volumes reach high-enough levels. Prof. Hart showed that the cost of manufacturing a part, such as for a cellphone, via injection molding or via 3D printing reached a cross-over point at about 5,000 units.

Second, 3D printing has a more restricted set of possible materials, and the processes may not produce parts with comparable strength as parts machined from solid blocks (this is changing with time as more materials are being added as well as additional AM processes). The latter issue may affect regulatory approval, especially in scenarios where additive manufacturing might be used to create replacement parts that serve in life-critical applications. Third, the surface textures of printed parts may not be as smooth, controlled, or attractive, which doesn't matter if the part is hidden or is for industrial applications, but is a problem for exterior parts in consumer end products. Secondary machining or processing might be needed to create an acceptance surface. Finally, how to qualify printed parts from a regulatory perspective is an issue that has yet to be resolved.

Q&A Discussion

A personal care company asked whether it was possible to manufacture not just durable goods but a mix of liquids. Prof. Hart replied that the principle was the same and that it was possible to 3D print both solids and a liquid, such as a liquid inside a shell.

An electronics company asked how it can tackle the problem of substandard surface finish appearance. Prof. Hart replied that the solution doesn't have to be from 3D printing itself but in the production process. For example, perhaps after being printed, the products could be directed to a further processing stage. Or, there may be novel coating materials that smooth out a surface. He encouraged companies to think about 3D printing as one step and then using other processes to finish the surfaces afterward.

A manufacturer asked about qualification of spare parts used in passenger transportation vehicles such as cars or airplanes. Prof. Hart replied that he is working on computationally qualifying the parts, such that they would come with a machine bill of health. Understanding the underlying physics lets one know that the right microstructure was produced, he said.

In response to a question about how to increase the speed of the 3D printing process, Prof. Hart said that one solution uses more force to push the material faster through the print head.

A handful of people at the conference were from companies that are already using 3D printing. One of these companies was using the process for prototyping new products and was considering the validation issue. For that company, the biggest nut to crack was how to transition to a validated manufacturing process. Another company uses the technology for prototyping but noted that there is a learning curve for chief engineers to accept the new kinds of products that can be created. The company echoed that the jump from prototyping to production was a big one. Some of the critical success factors mentioned for using 3D was hiring talent and being able to invest in the process, because industrial 3D printers are still expensive.

Visual Analytics: The Answer to Data Overload?

As Nobel Prize winner Herbert Simon put it, a wealth of information creates a poverty of attention. "Our ability to collect data outpaces our ability to process it and turn it into insight," explained Dr. Matthias Winkenbach, Director of the MIT Megacity Logistics Lab at CTL.

Although a few years ago Dr. Winkenbach's work on megacities was held back by the need to find the right data, the current struggles aren't with finding sources of data but being able to separate the noise from the signal.

Why Visualization is Needed

The core problem is that humans think differently than the way machines process data -- "few of us think in terms of data tables, but that is how the information is currently presented," Dr. Winkenbach said. What's needed is a means to combine data analytics with visualization in a way that lets humans use human intelligence and context awareness to process the information in an intuitive way.

Interactive Logistics

CTL has developed an interactive visualization tool for logistics. The table-top display uses "capacitive-touch" sensors that let users interact with supply chain maps by physically moving LEGO-like bricks on a table. The bricks represent warehouses or other nodes in a supply chain. Any user can physically move the bricks on the table, putting warehouses in different physical locations on the displayed map. Then, sensors measure the location of the brick and a computer reruns an analysis and redisplays key analytics such as the cost of serving the market with this revised network.

This visual tool's intuitive interface allows each user to talk about the same problem in the same way -- even if their respective languages and fields may differ. For example, executives from a grocery delivery service can use the table to understand how a change in network design might impact the company's service levels or the number of consumers reachable within some delivery window. Everyone can see the map, interact with the network design by moving the blocks, and see direct feedback on how repositioning a facility has tangible effects on performance.

Although advanced optimization models could directly compute the optimal network design, the complexity of those models makes them inscrutable to non-specialists. It's often valuable for people to explore the various levels of information themselves -- such as customer data and traffic patterns -- to see the network and the effects of different changes.

Three Levels of Interactive Visualization

The first level of interactive visualization is seamless data visibility and analysis. This can show historical transactions and operations data, real-time supply chain data, and flexible disaggregation of information that enables "drill down" to find the root cause of a disruption or bottleneck.

The second level is intuitive data analytics and decision support, which includes descriptive and predictive analytics, prescriptive models, and optimization and simulation modeling. This level uses data to make an impact assessment or scenario analysis that can be discussed. For example, users could do a simulation or quantitative analysis to see the financial impact of a disruption, and then evaluate and rank the top three solutions.. CTL can add the analytical tools to do the scenario analysis and help people communicate their actions.

The third level is immersive collaboration and experience in which users can collaboratively explore data about the supply chain as well as contextual information such as weather, traffic, politics and economics. Augmented reality (AR) and virtual reality (VR) tools will bring this next level, taking visibility out of specialized environments and letting anyone anywhere put on an AR headset to pull up supply chain information. In AR, digital content (numbers, words, as well as hologram-like images) are superimposed on a user's view of the real world. Displaying content in this way will make it more accessible and enable more people to contribute innovative ideas. For example, people could experience a redesigned warehouse virtually. They would be able to simulate how the new warehouse might impact work performance and understand the tradeoffs.

AR and VR may be able to revolutionize the way city planning is done. With tactile interfaces and immediate visual feedback, stakeholders of all types could possibly view historical and new layouts overlaid with traffic patterns. They could see how the use of smart traffic management would impact movement and congestion. Similarly, retail stores and warehouses may be able to visualize how to optimization backroom space.

CTL's Visual Analytics Lab

CTL is building a Visual Analytics Lab in its renovated headquarters. The lab will have a touch-enabled video wall that supports interactive multi-user applications for supply chain analytics. It will use real-time operational data as well as contextual information about suppliers, sites, transport vessels, inventories, sales channels, markets and so forth, along with customized alerts and risk assessments. There will be visual interfaces for advanced data analytics tools such as network design, inventory optimization, demand forecasting, and process optimization, and AR headsets that depict operational environments. For example, holograms can be used to show information on housing structures so that users can think about different delivery solutions. It will be possible to superimpose social or economic data without overburdening the executives making the decisions. Although complex mathematical tools help produce solutions, the struggle that often takes place is how to get that information across to decision makers.

It is expected that AR technology will become more mature, reliable and affordable, coming down in price in the next few years. Goldman Sachs sees price declines for head-mounted displays coming down 5-10 percent annually.

Q&A Discussion

A participant asked what kind of applications AR had beyond data visualization. Dr. Winkenbach replied that AR, like Google Glass, could be used to improve operational efficiency at a warehouse, or that lightweight AR equipment could help drivers with last-mile delivery navigation. AR is a mixed reality environment in which users augment their real environment with critical information that is tied to the physical environment.

Another conference attendee asked about applications of AR in transportation, such as simulating equipment delays. Dr. Winkenbach elaborated that in urban environments, when a company sees a truck behind schedule, it could use visualization to see which customers are at risk and where other trucks are nearby that could be rerouted, or simply to have more visibility into the prevailing traffic patterns. He cautioned that events such as accidents are unexpected and require quick reaction, whereas seasonal traffic patterns or systemic risks can be identified ahead of time.

A few companies in the room were using AR. One company uses the technology for maintenance of pipes and electrical equipment. Maintenance personnel are given glasses and iPads to detect where they had to do a repair. The system is being piloted but the company faced some scaling challenges because some of its production plants have flammable gases that restricted the use of electrical devices. Another company envisages using AR to reduce the surface area that has to be drilled when searching for oil.

Finally, Dr. Winkenbach pointed out that AR technology could be used for remote collaboration between suppliers and companies -- such as to visually see a disruption rather than just exchanging spreadsheets -- so that the two partners can work together to solve the problem.

Industry Applications of a New Silicon Photonics Sensor Platform

Sensors are everywhere said Dr. Anuradha Agarwal, Principal Research Scientist at the MIT Microphotonics Center. For example, the typical smartphone has 14 sensors, such as an accelerometer, barometer, proximity sensor, magnetometer, gyroscope, thermometer, light sensor, and of course a touchscreen. Similarly, homes have sensors for heat, motion, light and smoke.

Ubiquity and Low Cost of Sensors Enables Supply Chain Applications

The ubiquity and low cost of sensors makes them deployable for applications along the supply chain. Take, for example, applications in food supply chains. An enterprise called Analog Devices is monitoring crop growth of tomatoes remotely, tracking the glucose and salt levels as well as pesticides around the tomato. After the tomato has been grown and harvested, sensors track handling along the supply to assure that it has been maintained at the right temperature. Sensors can identify the location of the cargo, whether it is in stock in a location, and whether the tomato is still fresh. The entire food chain from farm to table can be made smarter, Dr. Agarwal said.

Sensors could tell consumers if there are pollutants such as carbon monoxide or sulfur oxides in the area, whether their drinking water is clean, and so forth, enabling better health and safety. There are promising industrial applications of sensors in oil and gas, automotive manufacturing, process control, healthcare and for the military.

Global Photonics Sensor Market

Photonics sensors are sensors that use light to measure a range of physical properties. The global photonics sensor market is forecast to be $15.2 billion in 2020, growing at a 16.9 CAGR; fiber optic sensors lead the growth. Applications are seen for the military, homeland security, industrial processing, and faculty automation. Europe is expected to be the highest revenue-generating region for sensors in 2020.

Creating a Lab-on-a-Chip

Dr. Agarwal described the process of developing a sensitive "lab on a chip" photonics sensor for detecting and measuring important trace chemicals from their infrared fingerprint. Air, gases, or liquids move through a sensing chamber and interact with a channeled beam of light. Measuring changes in the light lets the chip detect and measure relevant trace chemicals. Design challenges included: creating optical circuits that amplify subtle interactions between light and trace chemicals; developing ultra-sensitive detectors; connecting the lab part to the chip part of the system; making everything with standard semiconductor manufacturing techniques; and choosing the right materials. Unlike traditional chips that are sealed inside the body of the chip, these sensors must be open to the world to detect chemicals in the environment, which poses special challenges to the design of the system. More importantly, the design is intended to be a platform that can be tailored to a wide range of use cases.

Dr. Agarwal then described three use cases of these sensors. First, in the oil and gas industry, a sensor network could be set up along the 1,000 miles of pipeline that runs across the country, to detect leaks quickly and precisely -- much more effectively than workers walking the pipelines. The sensors would need to have high sensitivity, high selectivity, low false positives and low power consumption. Dr. Agarwal showed that the $3 billion in cost to install sensors along the entire length of the pipeline would be recovered in three years. Furthermore, in 10 years, the deployment would save $5 billion.

Another application is to monitor the quality of water, such as on an airplane, to ensure no contamination. Currently, monitoring water quality requires taking a sample and sending it to a lab, but with the "lab on a chip" results would be known immediately.

Sensors could also be used in medical applications, such as a PSA test for prostate cancer that doctors could have in their offices and know the results immediately. The total market for PSA tests was $1.73 billion in 2017.

Q&A Discussion

When the audience was asked for ideas for applications for these sensors, they suggested using them in the food chain to deliver the right flavor profiles to customers. Also, the sensors could be used in high pressure oil drilling environments, inside nuclear reactors and on the battlefield.

In response to a question about applications of sensors in the food manufacturing industry, Dr. Agarwal said that sensors could alert shippers that a refrigeration system had failed and that corrective action was needed. Dr. Agarwal explained that photonics sensors could detect the gasses coming out of meat and fish and could alert a consumer if the product was spoiling. Sensors could even be used to detect the presence of food pathogens.

Dr. Agarwal encouraged companies to come to the MIT Microphotonics Center with a problem, the way Analog Devices did, and the lab could help build the solution, test it, and then fine-tine it. The lab/industry partnership would be a win/win to get the technology tested and tailored for real-life applications.

Blockchain: How Transformative is the Technology?

Christian Catalini, Assistant Professor at the MIT Sloan School of Management, talked about blockchain -- the algorithmic technologies behind Bitcoin and other rising cryptocurrencies -- with the goal of pinpointing what is possible and where the breakthroughs and opportunities lie in different verticals. Overall, the opportunities lie in the convergence of three fields: computer science, economics & market design, and law & contracting.

What Is Blockchain

A blockchain is a digital data structure holding an encrypted chain of data blocks that represent important data records such as financial transactions, digital goods, authenticated users, or any type of data that people, companies, or governments might wish to record in a secure but verifiable way. It's the technology that underpins Bitcoin and other competing cryptocurrencies that allow anonymous parties to pay each other in a secure fashion without revealing their identities. In the case of Bitcoin, the blockchain records the owner of the coins by way of a ledger of transactions between coded addresses representing the owners. Blockchain uses distributed computers, encryption algorithms, and the chaining of the blocks to make the chain more secure over time, such that it becomes computationally impossible to subvert the blockchain, repudiate recorded transactions, or fraudulently change the transactions later.

This ability to create and manage trustworthy data records among parties that don't necessarily know and trust each other makes blockchain a promising technology beyond cryptocurrencies. Many companies are looking at how the technology might be adapted to other areas of finance, business, healthcare, and the sharing or management of resources. To date, $1.5 billion of venture capital investment has been made, primarily in cryptocurrencies, though some ventures like Ripple are about applying blockchain to regular banking to reduce cost. The state of the field is about where Internet was in the mid-1990s. Entrepreneurs are experimenting with pilots like using blockchain for micropayment.

Reducing the Cost (and Risks) of Verification

The cost of verification is expected to be reduced by blockchain technologies. Every time something moves, verification of the people involved, the events that happen, the money that changes hands, etc., must occur. Currently, verification relies on costly auditing processes that check the integrity of the records to ensure they have not been falsified.

With blockchain, integrity is assured by the cryptographic properties of the chain and the practical impossibility of modifying the data once it's been recorded in the chain. Verifying the data is almost cost free. Attributes of a transaction such as its existence, timestamp, parties involved, conflict resolution rules, collateral, etc., are all recorded and can be verified.

Current verification systems also create risks by forcing participants to leak information. For example, to open a bank account, an individual must disclose his or her Social Security Number, which creates risks of identity theft. Going into a bar to buy a drink, a person must show an ID card that reveals their name and address, when all that is really needed is to prove that they are of drinking age. This over-disclosure potentially has a big cost in terms of security as well as in employee verification time.

In a blockchain system, coded information can verify a crucial attribute of a person or company without revealing any other information. Instead of revealing everything, a small amount of cryptographic data serves as proof through an easily-computed check of that coded data against the blockchain. Imagine verifying attributes without disclosing identity or proprietary data. A company could audit a bank or a supplier without those parties having to reveal their accounts. Or, companies or people could disclose to a merchant that they are worthy of getting a loan without needing to disclose their identity.

Reducing the Costs of Trusted Networks

The second cost that could be changed is that of creating and operating economic networks between far-flung entities. Currently, sending a wire transfer of money requires trustworthy intermediaries (such as SWIFT) and relies on the integrity of banks, insurance companies, government institutions, transfer accounts, and so on. These intermediaries act as trusted gatekeepers that verify the participants and transactions; but, they also incur significant costs, can become abusive monopolies, or can create fragile single-points-of-failure in the network.

In contrast, Bitcoin and the blockchain concept replaces these centralized managers of the economic network with a decentralized network of agents. The decentralized nodes use consensus to collectively secure the common ledger using computation. Clever design of the control algorithms gives participants incentives to act honestly and support the smooth functioning of the network. No single node (or minority voting block of nodes) can disrupt the broader functioning of the network.

This change from centralized intermediaries to blockchain systems will be potentially disruptive because it may eliminate the current intermediaries that create these economic networks. But it may take 10-20 years before it is fully realized. Moreover, blockchain will not eliminate all intermediaries, but it may change the nature of what they do and reduce the power they wield. Intermediaries can still operate by facilitating use of the blockchain network or providing value-added services derived from blockchain data.

Applications

Blockchain has many potential applications in finance beyond today's cryptocurrencies. It could be used for global settlement, peer-to-peer money transfer, retail transactions, and micropayments either by consumers or for crowdsourced labor. Central banks could use blockchain to create digital currencies.

Blockchain could be used to transfer other digital resources such as data storage and computer time. Current cloud computing services such as Amazon or Dropbox are centralized, which puts them at risk for censorship and disruption. But variants of the blockchain could let people barter (and provide) spare computer resources such as the available space on their hard drives. It could be used to manage other digital assets such as copyrighted content. More generally, with the Interet of Things, a self-driving car would be able to barter with other cars to get lane space during heavy traffic if, for example, its owner was late for work.

One key feature of the design of blockchain is the prevention of double-spending -- a Bitcoin's owner cannot spend the same coin twice. That feature and the immutability offered by blockchain can be used to track and ensure provenance. The buyers of an item can trace its source and confirm that someone hasn't counterfeited the item. Of course, tracking provenance is easier with unique items such as diamonds than it would be with commodity items such as pork chops unless those items can be coded, too. A key prerequisite to the design of blockchain systems is in ensuring the validity of the initial data.

At a more abstract level, blockchains encode contracts and contractual actions. In theory, blockchains could store any kind of contract and data related the performance and satisfaction of the contract. Parties could easily verify contract terms and status while the distributed blockchain process created consensus around the satisfaction of the contract. Similarly, an organization could be considered a meshwork of contracts involving suppliers, employees, investors, customers, and so on.

Q&A Dicussion

A conference attendee asked whether blockchain technology could be used with current currencies – not just cryptocurrencies – to set up something like conventional payment schemes. Prof. Catalini replied that some applications do use both blockchain and cryptocurrency but many do not, especially in the supply chain domain.

When asked by an attendee if anything prevented governments from regulating blockchain, Prof. Catalini replied that this issue applies to a range of technologies. Regulation can create obstacles to entry unless consumers get something of value and demand deregulation. Government can add regulation and slow things down, but there will be pushback if value is being provided.

Asked what applications they could think of for blockchain in their organizations, one audience member noted the possibility of using the technology to identify counterfeit aircraft parts and pharmaceuticals. Prof. Catalini agreed that this is a good use case. Others include tracking nuclear waste moving through a system. The challenge is how to capture the information that is critical to identifying an original part. The plane part may have tiny variations (as diamonds do) that could be used to uniquely identify it, which enable a robust identity system for tracking the item. But the item does have to be verified by a human at some point.

An audience member said that his company has inspectors but wants to empower self-inspection by quality control teams at factories. Could the company use blockchain to record all the inspection reports? Prof. Catalini advised that if a system already has a central player, then blockchain is just an added cost to that system. But if the company wants to be able to prove that even the company itself is unable to alter given data, then yes, blockchain technology could make a value-added contribution to accomplish that.

How Advances in Materials Science Could Reshape Products

Markus Buehler, McAfee Professor of Engineering and Head of MIT's Department of Civil & Environmental Engineering, discussed how he and his team are using multi-scale modeling and synthesis to create materials atom by atom at the nano-scale and then producing them at macro scale using 3D printing.

Inspired by Nature, Perfected by Technology

Specifically, Prof. Buehler uses computers to design the materials and to simulate their behavior. He observes and studies natural materials such as spider silk or clam shells but then improves upon them. His goal is to understand the structure of these materials and understand how they break -- at the molecular level -- so that he can design materials that are stronger and better and can be put to human use. For example, he might create a structural model of a silk, simulate breaking a silk molecule and then consider ways that the protein could be made a bit smaller or bigger by changing the DNA sequence. One of the design insights that Prof. Buehler has gained through his simulations and mechanical analysis is that making the structure smaller makes it stronger and tougher.

From Lab to Computer and Back

His lab, the Laboratory for Atomistic and Molecular Mechanics (LAMM), both simulates and empirically analyzes materials at a many levels of scale from the molecular level to the bulk part level. The lab's researchers watch how materials like glass or graphene break and then simulate those properties from a chemistry perspective with the goal of bringing their ideas back to real life. For example, researchers simulate how to make protein-based silk stronger by changing the DNA sequence.

From Nano to Macro

The lab studies and manipulates materials at multiple scales. The toughness of the material in pearls, for example, arises not from a single special molecule but from combinations of different molecules and how sheets and grains of different materials are fitted together to absorb impact or prevent cracks from growing. Understanding this kind of interplay of structures and properties at multiple scales could give engineers unprecedented control over the properties of parts. For example, a molecular version of carbon known as graphene is the world's thinnest and strongest material, but it is flat. Prof. Buehler uses origami-type folding to turn sheets of graphene into a box, for example, with perfectly sealed edges.

Depending on exactly how these sheets are warped, folded, and bonded, they can create hard or soft, rigid or flexible, dense or light materials. Using multi-scale modeling and synthesis, Prof. Buehler can "dial in" strength and density into materials to, for example, build a car using one basic material -- such as carbon -- but creating different strengths from that same material. Thus, the car would be made entirely of one material, requiring no connections, bolts or other things because the structure would be "grown" atom by atom as one piece. The structure would be inherently stronger than existing materials and yet would be lighter weight because no connecting materials would be needed. The car would also be lighter weight because parts could be hollow except as needed for structural integrity. The supply chain implications are that parts and products could be moved with smaller vehicles because the products would be lighter weight than they are now.

From Nature to Lab to Nature

Prof. Buehler's lab can build structures using organic as well as inorganic materials. Using organic materials such as biocompatible proteins means that biomedical implants could be built out of materials that the human body would not reject. For example, Prof. Buehler bought silkworm cocoons -- which are very inexpensive and can be bought by the pound. He then carefully dissolved the macrostructure of the silk cocoons to create nanofibers that could be rebuilt into a membrane that could filter out molecules (such as to produce pure water) and that could be implanted in the body and be stretched up to 1300 percent without failure.

Design a Material and then Print It

Prof. Buehler initially predicted many ways of creating material structures back in 2000, but at that time there was no way to build those materials. Now, with 3D printers, the materials can be printed very inexpensively. The implications include building wearable yet ultra-protective clothing for the military or custom-tailored football helmets. Current helmets are made of foam with a hard shell, but they could be built from custom-designed microstructures that use different gradients of softness and hardness to more effectively absorb or redirect shock around the skull.

Another disruption that could evolve from Prof. Buehler's work is that, instead of manufacturing by using 3D printers, perhaps organisms could be harnessed to build the structures -- as spiders build webs or silkworms build cocoons -- making them autonomous 3D printers.

Q&A Discussion

To questions about using less raw material or reuse of material, Prof. Buehler replied that by using his approaches, material could be made stronger out of less material and with lower density. The key is to be able to scale production. Areas where adoption could be quick are in the biomedical field, such as brain implants -- where the value is high and mass production is not needed.

Themes

Although the six presenters came from markedly various parts of MIT - with research spanning business, economics, computer science, chemistry, and civil, mechanical, and electrical engineering -- the talks shared four common themes connected to supply chains. The first is the increasing use of information technologies to create qualitative changes in business strategy. The second is new materials and manufacturing techniques that could potentially change how supply chains are structured. The third is the convergence of greater disparate kinds of data, ideas, and technologies that can be combined into new levels of innovation. And cross-cutting these themes are the business uncertainties associated with all this innovation.

From Computer-Enabled to Digital-Inspired Businesses

The first cross-cutting theme was the pervasive role of computers in both operations and innovation. According to Dr. Ross, computers have become more than just enablers of incremental improvements in existing ways of doing business. They now underpin entirely new strategies and models for doing business. In particular, the ubiquitous availability of rich data and deepening toolset for converting that data into action enables new services and products.

For example, an elevator company is re-envisioning its business model from one that makes, installs, and maintains elevators to the more open-ended strategy of providing mobility services in urban environments. Greater connectivity to building occupants' smartphones and building security can improve the speed and efficiencies for the one billion people that the company moves each day. According to Dr. Ross, this kind of digital business model requires two very different sides of enterprise IT. First, the company must have an efficient and reliable backbone of enterprise IT to handle manufacturing, installation, and services of elevators. Second, the company needs a digital service platform for hosting customized solutions that meet the specific needs of specific customers.

Information technology has done much more than broaden the possibilities for what business might do. Prof. Buelher showed how computers can successfully predict the properties of entirely new types of materials by simulating how atoms, molecules, composites, and macro scale structures behave. Although physicist Richard Feynman predicted the advent of nanotechnology in 1959, only in the last few years have computers and laboratory techniques become powerful enough to realize that early vision.

Prof. Catalini revealed how computers' cryptographic and networking capabilities can create a more robust means of securing and verifying global business activities. Blockchain technology relies on a distributed network of computers to encrypt any kind of transactional data (Bitcoin financial transactions being the most popular example). Once a transaction record becomes encrypted into the blockchain, it becomes impossible to repudiate or modify that record without far more computational power than exists in the entire network. More generally, the ideas underlying blockchain can change the nature of supply chains and industries by replacing centralized, controlling intermediaries with distributed, consensus-managed networks.

Dr. Agarwal described new types of sensors built on the silicon substrates for measuring chemicals in air and water. As with the development of new materials, the researchers depend on computers to accurately simulate and design these new sensor chips and prove that they can perform as expected. Moreover, the sensors can include an embedded computer and wireless network for internet-of-things networks. These sensors can feed computers with ever more detailed data on conditions in factories, stores, homes, and the environment. Such sensors offer unprecedented levels of detail to support customized business services. But, in turn, the high volume of data creates a data overload problem.

Fortunately, computers can address the data overload issue, too. Dr. Winkenbach highlighted the potential role of advanced computer interfaces and augmented reality displays to more intuitively visualize and interact with complex data. CTL is building a lab for developing and demonstrating these new technologies and their potential use to address supply chain issues. Using intuitive tactile interfaces, (such as moving small blocks on a map to signify warehouses and automatically recalculate the supply chain redesign consequences) could bridge the technical gap between data scientists and executives or other stakeholders in companies, government or partners. Moreover, these virtual reality or augmented reality technologies can support telepresence, remote supply chain activities, and collaboration around the globe. In that regard, computers can help accelerate the conversion of data to information and to wisdom.

Additive Manufacturing Multiplies the Possibilities

Both Prof. Hart and Prof. Buelher spoke of revolutions in materials and manufacturing that leverage biological strategies. For example, additive manufacturing -- often called 3D printing -- synthesizes parts by steadily adding small amounts of material to build up the part. It's the same basic principle used when spiders build webs, snails build shells, and trees build leaves, twigs, branches, and trunks. Additive manufacturing can create much more complex parts with much less wasted material than can traditional subtractive manufacturing methods that rely on cutting, milling, or drilling material out of a larger block.

Early applications of additive manufacturing (AM) were in rapid prototyping because the technology enables low-cost fabrication of one-off parts. AM also has significant potential for on-demand manufacturing of spare parts, which could significantly improve the economics of service and maintenance operations by eliminating the need for huge inventories of spares. Although additive manufacturing can't beat the cost efficiencies of mass production of simple parts, it can manufacture very complex structural designs that were previously impossible or that required costly assemblies of many different parts. This advantage of offering nearly cost-free complexity has induced some companies to use 3D printing for high performance finished goods such as jet engine parts. In this regard, these new material technologies represent a step-change in the complexity of what is feasible, not unlike the step-change in the feasible complexity of organizational capabilities.

This may be more than just a revolution in materials -- it could change the nature of supply chains. Today's supply chains depend on hundreds of thousands of materials to make millions of distinct kinds of component parts that go into millions of SKUs of consumer products. But biology takes a different approach. Prof. Buehler noted that a spider needs only one raw material -- flies -- to make silk, spider legs, spider eyes, and every other spider-related structure or component including more spiders. Using a biological manufacturing strategy, a single feedstock material or perhaps a few types of materials could be processed and printed in ways that may create virtually any combination of stiffness, flexibility, hardness, or softness.

Thus, future supply chains might shift much of the differentiation that creates unique features in complex products from a broad base of traditional suppliers of different parts into downloadable digital files and additive manufacturing assets that could be placed anywhere – even the consumer's own home. In fact, an entire factory might fit in a standard shipping container and be deployed (and redeployed) anywhere. A steady supply of a few feedstock polymers, resins, or metal powders might be all that's needed to make anything, anywhere. The varieties of raw materials and supplier parts might plummet even as the variety of end-consumer goods skyrockets using end-user customization and the ability of additive manufacturing to create very low quantities of products at a viable price. These manufacturing technologies can underpin the kinds of personalization needed for Dr. Ross' vision of a digital service platform.

A Convergence of Data, Ideas, and Technologies

Companies are being bombarded by innovative technologies, which Dr. Ross dubbed SMACIT (Social, Mobile, Analytics, Cloud, and Internet of Things). But rather than cope with each technology independently -- a social media initiative, an analytics initiative, etc. -- Dr. Ross recommended integrating all these technologies into a digital business strategy. Many of the other presenters also illustrated a similar kind of convergence of multiple technologies to create something greater than the sum of the parts.

For example, Prof. Catalini showed how blockchain represents a convergence of computer science, law, and economics and market design ideas. All three disciplines affect how blockchain is designed to not only work technologically but also to align incentives and legal structures to ensure the overall system is robust. Similarly, Dr. Agarwal's sensor uses a convergence of knowledge of chemical spectroscopy, micro-optics, and semiconductor fabrication technologies. And Prof. Buehler's nanomaterials depend on a convergence of high-performance computing for detailed simulation, biological technologies that enable synthesis of new protein-based polymers encoded by engineered DNA, and powerful laboratory tools for studying, analyzing, and testing materials. Finally, CTL's new lab for visualization combines technologies in storage, computing, and display technologies in conjunction with ideas from psychology about human cognition.

Of Applications and Uncertainties

Comments by both the presenters and the audience highlighted an interesting gap on both sides. The presenters know what their technologies can do, but many admitted less familiarity with the supply chain environment and business needs. The audience members know their supply chains and business needs but did not know what the technologies could do. Part of the rationale for the Crossroads event is in the cross-exposure between academia and business, or theory and practice. To help close this gap, CTL and many of the presenters were seeking opportunities to co-develop their technology with corporate partners or offering special short courses on their technologies.

This gap also implied that the technologies faced uncertainties in business adoption and that the businesses faced uncertainties with respect to the effects of the technologies on their industries and competitive environments. Overall, the talks covered cutting edge research that shows much exciting promise, but no one could offer guarantees regarding commercial impact. Although some presenters cited market data showing exponential growth in the use of advanced technologies such as 3-D printing and blockchain, no one knew exactly how long this growth might continue or how the new technologies might metamorphose into other technologies. Products based on blockchain, 3D printing, internet-of-things sensors, augmented reality, and other technologies are in production, but all are early in their adoption curves and some may be over-hyped.

At the same time, companies are under increasing pressure to try new things. Dr. Ross cited examples of companies being forced to look beyond their core businesses because of the combined pressures of brutal price competition and changing consumer behavior. Moreover, the technologies themselves might disrupt incumbent players. For example, blockchain enables disintermediation; additive manufacturing may shift production from suppliers to retailers; new materials might supplant traditional suppliers of metals and polymers, and so on. Thus, companies are looking for much broader business models than just the manufacturing and distribution of their traditional mainstream products.

Although companies still need to deliver their bread-and-butter products with efficiency and reliability, they also need to develop new products and services that add extra value to each customer relationship. To do both, Dr. Ross noted that companies need a reliable operational IT backbone that strives for reliable efficiency, but they also need a digital service platform. That digital services platform can be geared to experiments in innovative technology, speculative products, and customized services. As companies operate more and more in the crossroads between business and technology, such approaches can help them explore the many forks in the road created by change, uncertainty, and innovation.

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