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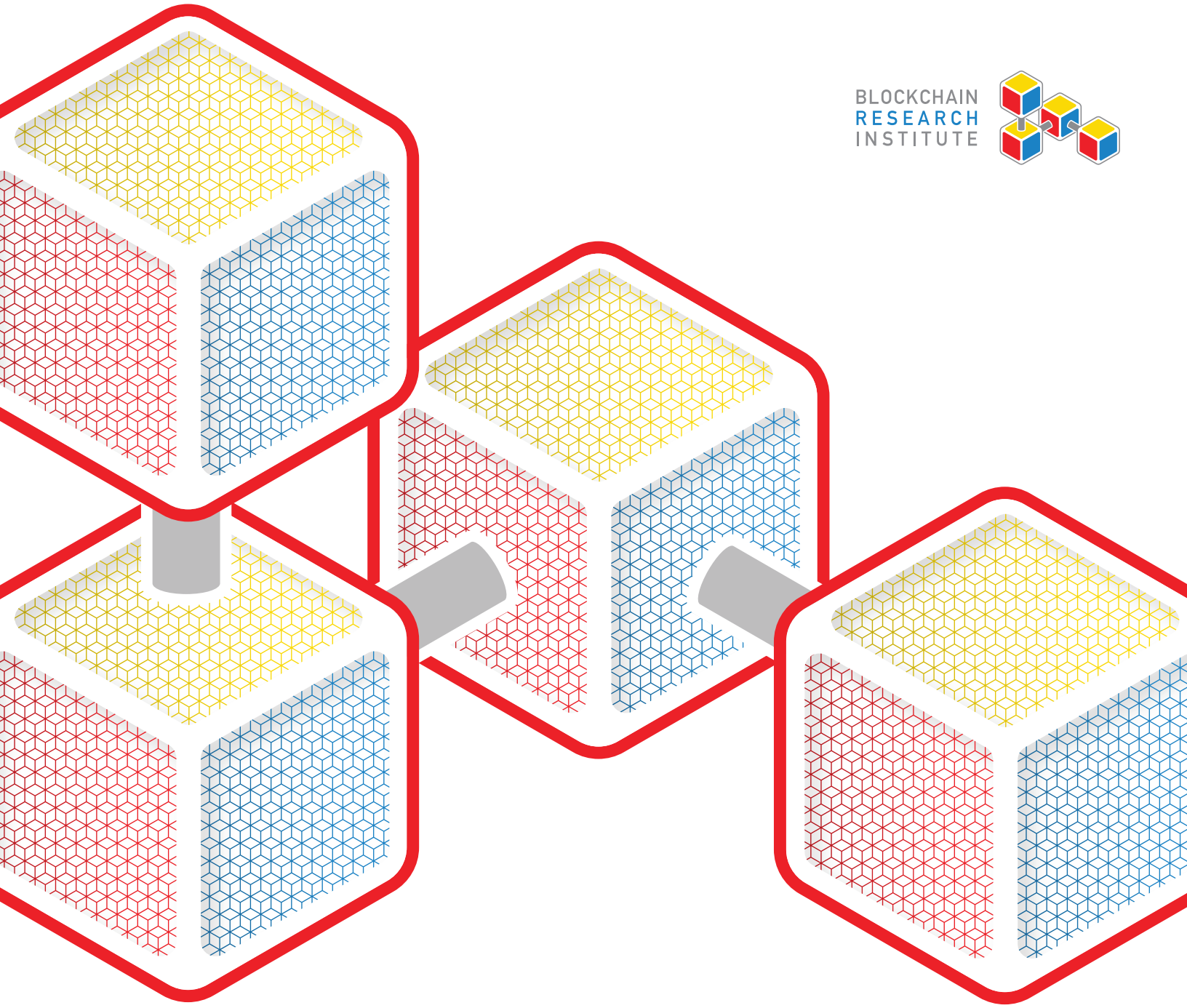


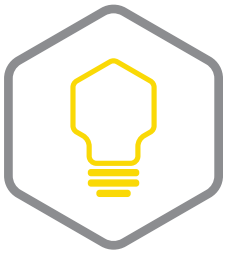
INTRODUCING ASSET CHAINS

The Cognitive, Friction-free, and Blockchain-enabled Future of Supply Chains

Tom Serres and Bettina Warburg
Animal Ventures

November 2017

A BLOCKCHAIN RESEARCH INSTITUTE BIG IDEA WHITEPAPER



Realizing the new promise of the digital economy

In 1994, Don Tapscott coined the phrase, "the digital economy," with his book of that title. It discussed how the Web and the Internet of information would bring important changes in business and society. Today the Internet of value creates profound new possibilities.

In 2017, Don and Alex Tapscott launched the Blockchain Research Institute to help realize the new promise of the digital economy. We research the strategic implications of blockchain technology and produce practical insights to contribute global blockchain knowledge and help our members navigate this revolution.

Our findings, conclusions, and recommendations are initially proprietary to our members and ultimately released to the public in support of our mission. To find out more, please visit www.blockchainresearchinstitute.org.

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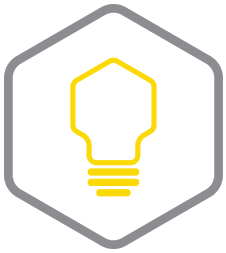


Foreword

I first met Bettina Warburg and Tom Serres in 2016 at the TED Summit in Banff, where Bettina and I both gave talks. Bettina was brilliant—her talk has well over two million views at this time of writing. In it, she quoted the work of Nobel Prize winning economist Douglass North on institutional economics and described blockchain as a new technological institution that would transform the economy and change how we exchanged value.

They got me thinking about the unprecedented volume of data that blockchains would be throwing off, enabling us to study large-scale economic systems as never before. Their research covers a major category of those systems—the global supply chains that manage most of our global trade, with an estimated value of $50 trillion. One of our conversations revved up my formulation engine and out popped the phrase, *asset chains*, in response to their description of the blockchains that would support the autonomous and distributed management of supply chains.

Their research is foundational and provocative for anyone who deals with assets of some kind—because *every asset has a supply chain*. More important, they explain what leaders should be doing now to prepare their organizations for an inevitable decentralized future.

First is to get comfortable with transparency, an integral component of corporate social responsibility and a source of competitive advantage. According to Bettina and Tom, the winners in the decentralized economy will be those who "drive supply chain transparency toward the most accurate network state possible." Second is to cultivate talent, not just lawyer-coders who can program smart contracts but also artist-engineers like Leonardo da Vinci who imbue their designs with humanity. Third is to form coalitions around common goals, one of which is the shared governance of asset chains and the development of standards and best practices. Now is the time to begin.

DON TAPSCOTT
Co-Founder and Executive Chairman
Blockchain Research Institute

Idea in brief

» Assets all over the world are extracted, designed, combined, transported, and sold every day through the supply chains that underpin global commerce. While technologies are increasingly disrupting traditional industries, this flow of goods has not been overhauled in years.

» Blockchain is decentralizing these traditional supply chains and combining with artificial intelligence, additive manufacturing, and the growing Internet of Things to bring about new value networks that scale to the demand of machines and human beings.

» These new supply chains are autonomous, distributed, and cognitive in the sense that they are learning and bundling what they learn into opportunities for systemic self-improvement in efficiency and responsiveness.

» Cognitive supply chains require a network state function that provides a singular universal truth as the basis for what we call *machine trust*.

» Integral to machine trust are *asset chains*, which provide a framework for machines to participate autonomously in supply chains and the markets they serve. They allow us to unlock the trading capability of machines without human intermediaries.

» This research project explores the business implications of asset chains and the leadership required to build coalitions and form alliances to achieve consensus on industry-wide protocols for asset chains.

Introduction to the decentralized economy

We've all been watching the news, reading articles, and following our friends posting on social media about the rise and fall of bitcoin's price or the latest company investing in a blockchain project. What's it all about?

Blockchain is a term discussed quietly as far back as 2008, when a mysterious figure named Satoshi Nakamoto and a band of freethinking crypto-enthusiasts began working on what would become one of the hottest and most interesting technologies of the twenty-first century.

Aside from its multi-hundred-million dollar market for initial coin or token offerings (ICOs) that are driving headlines in the Wild West of cryptofinance, blockchain is having a deeper and more penetrating effect on the underpinnings of the industrial economy.[1] The implications of blockchain are massive, and we're beginning to write a new economic chapter. The industrial economy will soon have to make way for this enormous transformation.

The industrial stepping stone

Steam engines, factories, steel magnates, railroads, and Western Union—these are relics of a past defined by the growth of consumerism, technology, and innovations in mass-production; the incredible legacy of the Industrial Revolution. Since the early nineteenth century, industrializing societies grew rapidly by building economic value and growth through corporations and firms. Societies also suffered from the seemingly endless economic cycle of boom and bust.

The decentralized economy is about scaling the one-to-one marketplace model, in which anyone can trade goods and services efficiently with anyone without intermediaries to support the buyers and sellers through a completed and trusted transaction.

Over time, markets expanded and trade with distant nations became easier. We began to optimize around these new global markets, and the firms serving them started to outsource production in new ways to compete in a globalized world. Over the last century, we have created new value by harnessing new markets and building global supply chain ecosystems—trading goods in increasingly larger volumes—all over the world. Trade of and within the industrial economy is defined by the exchange of goods and services, regardless of whether it is one to one or one to many. Supply chains are the coordination of that trade through intermediaries.

What's different today? In the industrial economy, economic equilibrium is nearly impossible to achieve. In this new decentralized economy—where, because of blockchain technology, artificial intelligence, and a world of connected devices, anyone can trade efficiently with anyone else without the need for firms or other intermediaries—economic equilibrium is fast becoming a reality.

It might sound as if we're laying out a utopian argument that promotes decentralized over intermediated architectures. We're not. The centralization that drove the last several hundred years of global economic expansion has achieved unbelievable scale in production and trade and unprecedented economic growth. Rather, we're saying that the decentralized economy is an evolution of the industrial economy due to rapidly changing technological forces that the industrial economy helped to unleash. We don't think of a decentralized economy as better; we think of it as inevitable. We believe it can continue many of the industrial economy's profit-maximizing goals.

The timeless story of trade

To return to our agrarian roots, we had a much easier time exchanging goods and services regularly with individuals in our communities because they were often small and we were trading with groups or individuals we knew quite well. On such a small scale, our one-to-one trading relationships were easier to manage and didn't require supply chains as we know them today.

As the distance and complexity of our trades grew beyond the boundaries of our own clans, uncertainty and fear grew around the enforcement and execution of these trades. To cope with this growing uncertainty, which we often refer to as *risk*, we built institutions such as banks, trading posts, governments, and corporations to create universal rules, verifiability, and order—in essence, the *protocols of business*. These institutions functioned as intermediaries, allowing us to grease the wheels of economic exchange by reducing risk in our trades.[2] They have come to define how we coordinate the activities of trade and commerce, representing the global supply chains we rely on today.

Fast-forward to our predominantly digital age. We have turned new protocol technologies such as TCP/IP and SMTP into tools for community and commerce—far beyond what their inventors initially imagined for sharing data from one side of the Earth to the other. Today, we call this confluence of technologies "the Internet," though younger generations refer specifically to their favorite brand of interface—YouTube, Amazon, Facebook, Snapchat, and Google. Running on top of a large and complex network of varying technologies, this set of applications and user experiences drives behavioral economics. It is this tool set that has changed how we communicate and do business with each other over the last fifty years, and we are embarking on change again with the invention and integration of blockchain technology (Figure 1).

Figure 1: Agrarian to digital era trade

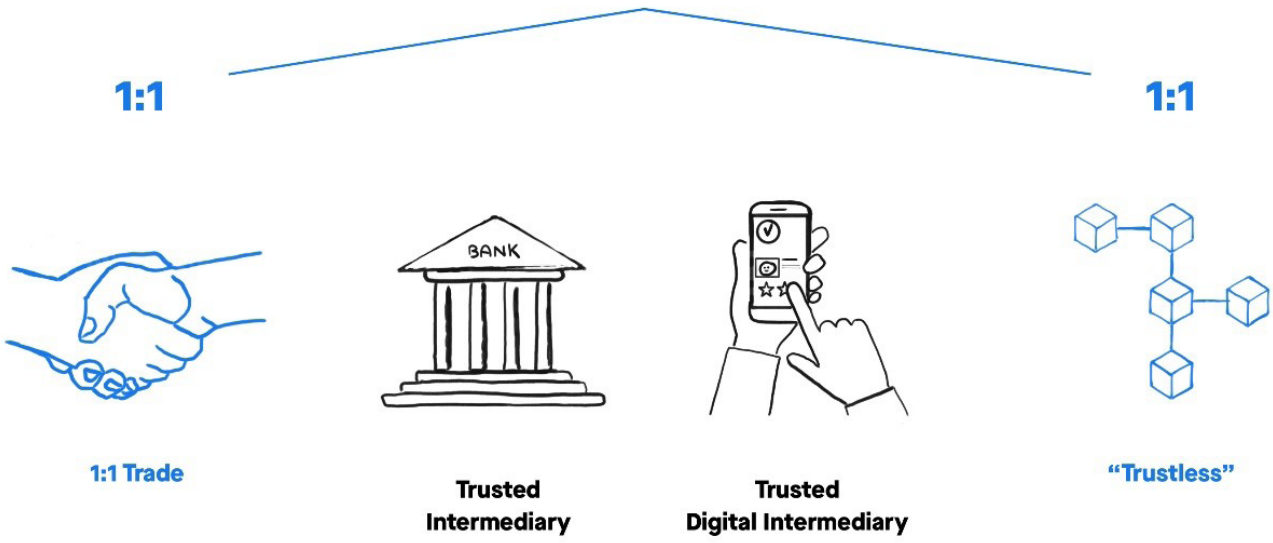
With new digital tools for communication and business, traditional institutions moved online: we created digital firms and marketplaces that scaled the trade for individuals and firms to new dimensions. We figured out how to leverage these new technologies to substantially increase speed and reduce risk associated with trading in marketplaces—not with just a few, or even millions, but with billions of transactions spanning across the globe. Now, without ever having met, buyers and sellers can execute transactions in seconds and receive goods on their doorsteps in a matter of hours or days. With global and digital trade, supply chain ecosystems and logistical networks have ballooned in size, and the complexity of these systems has reached entirely new levels. Today, 56 percent of global trade consists of intermediate goods and services—products that are part of another product's supply chain.[3]

Back to the future of trade

In the 1985 movie *Back to the Future*, Marty McFly travels back 30 years in Doc Brown's DeLorean to an oddly different but vaguely familiar world. That sense of familiar difference will be many people's experience of the decentralized economy. It will feel familiar in that trade will return to the era of peer-to-peer transactions, but foreign in its speed and scale.

The decentralized economy has roots in the early days of Napster, LimeWire, and BitTorrent—digital tools that opened up peer-to-peer networks for file-trading—but it's also an evolution of the agrarian one-to-one trade relationships from several thousand years ago (Figure 2). We can now make these transactions through blockchain technology—a technological trust layer that no single entity, institution, or firm controls.

Figure 2: Evolution of one-to-one trade



Kelly's Law of Inevitability

"There is a bias in the nature of technology that tilts it in certain directions and not others. All things being equal, the physics and mathematics that rule the dynamics of technology tend to favor certain behaviors."

KEVIN KELLY
Author
The Inevitable

Blockchain technology, combined with artificial intelligence (AI), the industrial Internet of Things (IIoT), and additive manufacturing, is enabling the decentralized economy, and it's evolving at an exponential rate. While its inevitability can seem foreboding, the future is not predestined. In his recent book, *The Inevitable*, Kevin Kelly describes inevitability as a "bias in the nature of technology that tilts it in certain directions and not others."[4] For instance, the existence of a communications network like the Internet was inevitable, but the particular version we use today was not. We lean on this framing of inevitability when we describe the emergence of greater decentralization in our economy: our technological forces are biased toward decentralization, and this bias is pushing production and trade toward greater decentralization.

Facing the inevitable: A completely decentralized marketplace

If the decentralized economy is underway because new technologies are combining to reform our businesses and communication, then the supply chains that make up our economy will inevitably decentralize as well. To identify opportunities for value creation (and methods to protect against value elimination) and to define broader supply chain implications later on, we need to agree on some basic marketplace principles.

Marketplaces rest on three basic pillars:[5]

1. *Liquidity:* The most critical "win" or key performance indicator (KPI), liquidity is the user's (the buyer's or seller's) reasonable expectation that he or she can execute or complete a desired outcome (a trade) within a reasonable time period for conversion.

2. *Discovery*: To achieve liquidity, buyers and sellers must be able to find each other easily.

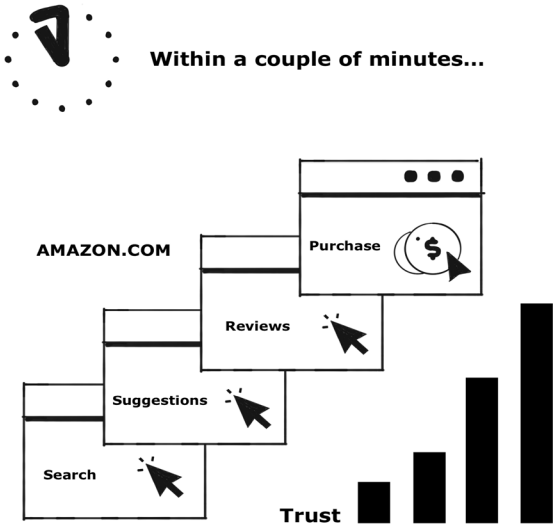
3. *Trust*: Trust is the belief, based on a shared understanding of various trade or business protocols and norms, that a transaction will occur.

If the decentralized economy is underway because new technologies are combining to reform our businesses and communication, then the supply chains that make up our economy will inevitably decentralize as well.

These pillars are highly optimized, scrutinized, and managed by today's institutions and firms. Institutions spend large amounts of capital to reduce friction caused by risk or uncertainty in trade. They are constantly seeking that elusive economic equilibrium.

Let's look at a very simple user experience on Amazon to understand how one of today's premier marketplaces goes about optimizing liquidity, discovery, and trust (Figure 3).

Figure 3: The optimization of liquidity, discovery, and trust in digital marketplaces



The optimization of liquidity, discovery, and trust in digital marketplaces © 2017 Animal Ventures. Reprinted courtesy of copyright holder. All rights reserved.

Our transaction is but one among millions of others every day, across Amazon's two-plus billion monthly visits. In a world where Google controls over 80 percent of all global search traffic, 55 percent of users are going to Amazon.com *first* to search for a desired product.[7] Amazon is winning the game of liquidity, discovery, and trust.[8]

- Amazon.com e-mails well-timed and highly curated notifications about what we desire most.
- We navigate to Amazon.com.
- Amazon leverages our profile and cookied history to customize its landing page so that we can more easily find a product.
- We begin typing what we're seeking in search bar.
- Amazon begins suggesting search terms and phrases.
- Our desired item pops up before we're finished typing.
- We click on the item from Amazon's suggestions.
- Amazon runs its "anticipatory delivery" system, which predicts what we're going to buy before we buy it—and ships products in our general direction before we decide to buy.
- We read buyer comments and ratings, which give us a five-star bird's-eye view of the seller's trustworthiness.
- We view photos, videos, product specs, user manual access, shipping times, and fees.
- We click the one-click payment button.
- Our Amazon Prime settings provide the remaining information.

We are not arguing that the evolving decentralized economy is better than the world of digital marketplaces we already know—in fact, the need to optimize liquidity, discovery, and trust in a marketplace, whether centralized or decentralized, will remain true.

What we are arguing is that the evolution toward a world with completely decentralized marketplaces (ones void of central authorities or intermediaries) is already taking place. See OpenBazaar, for example—an open-source marketplace that leverages blockchain technology to offer a system of transfer without a traditional institutional intermediary. Its tagline is "A free online marketplace. No fees. No restrictions. Earn bitcoin."[9]

What we are arguing is that the evolution toward a world with completely decentralized marketplaces (ones void of central authorities or intermediaries) is already taking place.

This evolution is inevitable. Not only will we be able to discover, execute, and trust transactions one to one, but we will also continue to optimize and scale those transactions just as Amazon does today—we just won't need Amazon's help. This is the promise of the blockchain: optimizing liquidity, discovery, and trust through technology instead of companies or governments.

As with any economic shift, a decentralized marketplace—and the inevitable decentralization of supply chains within it—will bring new opportunities and challenges. Those who engage with this decentralizing economy will be those who open up and shape new forms of value.

How can we maximize our opportunities? By reexamining the process by which we make, design, deliver, and use the products or services we trade in our marketplaces: our supply chains.[10] We could argue that supply chains come in many shapes and sizes and are ruled by diverging policy, technological, and operational factors, which make them hard to categorize as a whole. But all this variety plays much less of a role in the face of exponential change in our shifting economy. As our supply chains decentralize, they will continue to aim for economic equilibrium (and profit maximization) and to take shape in ways that leverage blockchain, AI, IoT, and additive manufacturing. They will become *cognitive supply chains*.

Moog Inc.

Moog is creating on-demand supply chains via additive manufacturing and blockchain.

Moog is a worldwide designer, manufacturer, and systems integrator of high-performance precision motion and fluid controls and controls systems for a broad range of applications in aerospace, defense, and industrial markets. Since its beginning in the 1950s, Moog has built machined metallic-piece parts, frequently used in sub-systems and controls for larger machinery, and has grown that business into $2.6 billion annual profits across 11,000 companies.[11]

In 2016, Moog acquired a controlling interest in Linear Mold and Engineering ("Linear"), a Michigan-based company specializing in

metal-additive manufacturing (3D printing). The promise of additive manufacturing is its ability to fabricate complex parts with precision, including features that traditional methods cannot manufacture, such as parts without joints.[12] The ability to print components and parts on demand replaces much of the manufacturing value that companies like Moog have offered—and 3D printing is getting better every day.

Because of the challenge additive manufacturing poses to Moog's traditional business model, Moog started to develop VeriPart, a self-funded service that leverages blockchain technology to certify and trace Moog's 3D-printed products and design files over their lifecycles. Moog is building VeriPart with external partners, and has three proof-of-concept projects underway, working toward a minimum viable product (MVP).[13]

Moog's evolution from traditional parts manufacturer to additive manufacturer to blockchain integrator epitomizes the ongoing changes in designing, making and delivering products across supply chains. Although there will still be demand for innovation and design of critical aircraft components, the entire supply chain for the actual production of these specialized parts can be collapsed as a result of production-ready 3D printing.

The promise of additive manufacturing is its ability to fabricate complex parts with precision, including features that traditional methods cannot manufacture, such as parts without joints.

The problems Moog is addressing with VeriPart

Moog's VeriPart project is addressing the following:

Supply chain challenges

- How to evolve traditional manufacturing into "time-of-need, point-of-use" production for specialized components
- How to certify and authenticate design files associated with 3D-printed products
- How to track and validate Moog 3D-printed products along their lifecycles

Business challenges

- How to develop a value-add business model in the face of an on-demand supply chain, where Moog products are 3D-printed instead of manufactured and delivered by Moog
- How to retain Moog IP value of design innovation for specialized parts in a market based on web-delivery of digital files rather than in physical products
- How to create a decentralized marketplace for regulated parts

New value through VeriPart stems from combining additive manufacturing with blockchain technology to pass the quality and regulatory authentication requirements of specialized components onto their 3D-printed versions. The 3D printing of components has

"Data integrity is that your data isn't corrupted as it moves."

JIM REGENOR
Business Director of Transformative Technologies Moog Inc.

obvious risks, namely validation and verification of authentic CAD files purchased from the future Moogs of the world. For instance, how will contractors that build or service advanced jets be able to trust that replacement parts 3D-printed in the heat of battle are the same parts represented in the CAD service purchased from one of its component designers? How will they know whether a part has been compromised? The security of such products is no small feat. The Semiconductor Industry Association estimates that up to 15 percent of replacement or spare semiconductor parts purchased by the Pentagon are counterfeit.[14] In addition, obsolescence and discontinuation of production of certain parts affect many supply chains where acquisition processes are long. For instance, the Defense Science Board suggested that "approximately 70 percent of electronics in a weapons system are obsolete or no longer in production prior to system fielding."[15]

VeriPart project leaders are leveraging blockchain as a technical solution for the certification of Moog CADs used in future supply chains using additive manufacturing of end-use products. Certifications would be tokenized on the blockchain to help ensure safety, improve security, reduce costs, reduce risk, track usage, and provide real-time asset provenance. The aerospace and pharmaceutical industries have stringent requirements for product certification, quality, and traceability for the critical parts Moog provides to be suitable for service.[16]

This certification relies on data integrity, process integrity, and build integrity. According to Jim Regenor, Moog's business director of transformative technologies, "Data integrity is that your data isn't corrupted as it moves. Process integrity and inside the *build chamber*, we are collecting data and checking it against the data of how it is supposed to be built."[17] Moog accomplishes these certification requirements through these blockchain features:

- **Provenance and traceability.** Because blockchain technology allows for the tamper-proof tracking of unique digital and physical assets, we often refer to it as a tool for collecting traceability data (e.g., history, location, point of origin, etc.). VeriPart uses two layers of authentication: a scannable identifier on the product (a hash, QR code, or microdot, depending on product size) as well as the grain structure of each product. Grain structures naturally vary enough for each 3D-printed item that they can act like a fingerprint that can be photographed and compared to the product's registered grain.[18] These two forms of authentication provide the end user with untampered data to trace the provenance of a particular Moog product.

- **Validation of digital files.** VeriPart wants to guarantee the integrity of any CAD file used to build end-use products designed by Moog. To do this, it relies on blockchain technology to control access to the encrypted data files and to validate the current state of the data file as authentic. When the state of the CAD file changes (e.g., when it is accessed

or altered), the users of that file can check whether they are accessing the valid state. If the file state has changed, then it is no longer the original file, and blockchain technology allows users to see this. Integrating state validation into the user experience and notifying users of a state change in the file they're looking to use reduce the risk of using a compromised or counterfeit file.[19]

As Moog sells products, blockchain can regulate user-licensing agreements similar to keys used by software companies to limit user access to the number of users licensed. Moog can therefore tackle the challenges of both transitioning to an on-demand supply chain and maintaining value creation and revenue from the sale and authentication of its intellectual property. This use of blockchain kicks off a significant transition for companies like Moog from an original equipment manufacturer (OEM) to something that more closely resembles a software-as-a-service (SaaS) provider.

Moog's opportunities and challenges

For years, supply chain organizations have attempted to streamline product flow and to perfect the relationship of supply to demand for a given product. Supply chain organizations have traditionally tried to optimize their flow toward either responsiveness or efficiency. For instance, the development and maintenance of military aircraft parts—a major revenue source for a company like Moog—relies heavily on measures of responsiveness for its supply chains. Responsive supply chains optimize for the ability to respond quickly to changing conditions such as customer demand, to meet service-level agreements required by the customer. For military aircraft development, the industry looks at KPIs such as "military readiness," the ability of equipment and technology to perform under combat circumstances, rather than at efficiency and cost-cutting measures. To *be truly responsive* to unpredictable demands of a particular customer segment, these responsive supply chains often bear more expensive products and carry greater inventory risk.

3D printing brings supply chains closer to time-of-need, point-of-use production, a long-time goal for many industries requiring special parts.

For companies like Moog that design and build highly complex aircraft components, maintaining responsiveness—and shifting to on-demand supply chains—presents a problem and an opportunity. The decreased inventory and transportation costs from on-demand manufacturing of production-ready parts and components will streamline military aircraft supply chains and drive both efficiency and responsiveness. 3D-printing parts reduces balance-sheet requirements for reserve inventory both for the military customer and for companies like Moog to match customer demand. It brings supply chains closer to time-of-need, point-of-use production, a long-time goal for many industries requiring special parts.[20] As Regenor put it, "What you are doing is pushing the conversion of bits to atoms right to the customer."[21]

While on-demand supply chain innovation streamlines many functions, it also presents a challenge to companies like Moog, which has traditionally created value in meeting and satisfying production

needs. If customers can simply print specialized components directly, then companies like Moog will see their multi-decade value creation evaporate. However, through VeriPart, Moog has identified opportunities to streamline an on-demand supply chain for customers and to create value in component design and sale. Through subscription models, individuals can copy and print across the network, and Moog can extend the liability and warranty of products according to a set of standards around the type of environment for printing a part.

Opportunities: More markets, less complexity, less waste, less risk

- **New markets.** The aerospace and pharmaceutical industries that VeriPart serves are under increasing pressure from existing and recent US federal regulations such as the Federal Acquisition Regulations, which already require provenance data for parts used in federal projects or contracts. These regulations are helping drive the technological integration that is opening up market spaces.
- **Collapsing traditional supply chains.** Projects like VeriPart remove the traditional supply chain costs associated with production, inventory, and transportation of products. By collapsing the supply chain management into fewer steps, companies that use VeriPart products will be able to divert funds elsewhere. As VeriPart ramps up, Moog has the opportunity to deliver subscription-model services to customers.
- **Tokens shrink paper trail.** Today, Moog may take two days to 3D-print a metal part, but two weeks to do the paperwork.[22] Critical real-world components can be tracked from origin through usage digitally via blockchain technology, which will cut down both timeline and paperwork associated with additive manufacturing.
- **Risk reduction.** Parts are not warehoused; instead, the prime contractor can build parts on demand to fulfill its service requirements. Therefore, on-demand printing removes traditional inventory needs, simplifies already-complex supply chains, reduces lead time, and thus reduces financial risk considerably for companies like Moog and their prime contracting counterparts. They can meet the financial requirements generally negotiated as fixed-contract fees (i.e., aircrafts can be expensive to build, and cost overruns are frequent because of the need to guess costs into the future).

On-demand printing removes traditional inventory needs, simplifies already-complex supply chains, reduces lead time, and thus reduces financial risk considerably.

Challenges: Third party involvement, continued investment, and standards

- **Third-party transactions or repairs.** What happens when a third-party vendor services or repairs a VeriPart product? Do we repair a part or just redesign and reprint? How do non-

chain vendors interact with the VeriPart chain? How do we validate a third-party alteration and maintain verification?

- **Building a marketplace of verified artisans and printers.** To make full use of blockchain, Moog will need to invest in a platform marketplace and bring both artisans and machines onto that platform.
- **Developing standards in physical to digital transfer integrity.** How will we incorporate regulatory standards that differ across jurisdictions? How will we manage the data and accuracy of materials, specifications, or warranties for a product with a variety of standards around the world as customers push toward product customization? What about the regulation of products 3D-printed in real-time to fit custom conditions and fight obsolescence? For management approaches that leverage blockchain for product-integrity, when and how will regulators get involved?

For Regenor, no single technology will boost growth; rather, the convergence of artificial intelligence, additive manufacturing, and blockchain technology is "where the exponential growth vector will be."[23] The future of Moog is geared toward leveraging the convergence of additive manufacturing, blockchain, and artificial intelligence for precision hardware processes of the future.

Broader considerations for on-demand supply chains

Moog is not alone in the pursuit to combine additive manufacturing with blockchain technology. PROSTEP AG is leading the development of the secure additive manufacturing platform (SAMPL), funded in part by the German Federal Ministry for Economic Affairs and Energy. SAMPL is working to develop a consortium that brings the copyright and licensing models of the publishing industry to the blockchain.[24] SAMPL provides the license to print. Its efforts cross the design, manufacturing, and in-field life cycle of products, and its leaders have a vision for moving into the extended ecosystem supply chain (Figure 4).[25]

Cognitive supply chains are more than smart supply chains; they are intelligent and autonomous supply chains that learn.

Enabling cognitive supply chains

Before the Moog case, we introduced a term that describes a vision of the future; one that we have researched and lectured on for some time. That term was *cognitive supply chains,* intelligent and autonomous supply chains *that learn*.

We could argue that intelligence *is* learning, but preeminent AI architect Luke Hutchison told us,

> If you go to Wikipedia and you look up definitions for *intelligence,* there's a page that lists all of the definitions… dozens and dozens…and not a single one of them…explains how to build something that's intelligent. I don't think that anybody in the world, including people who are working on the so-called AI, actually understand what intelligence is.[26]

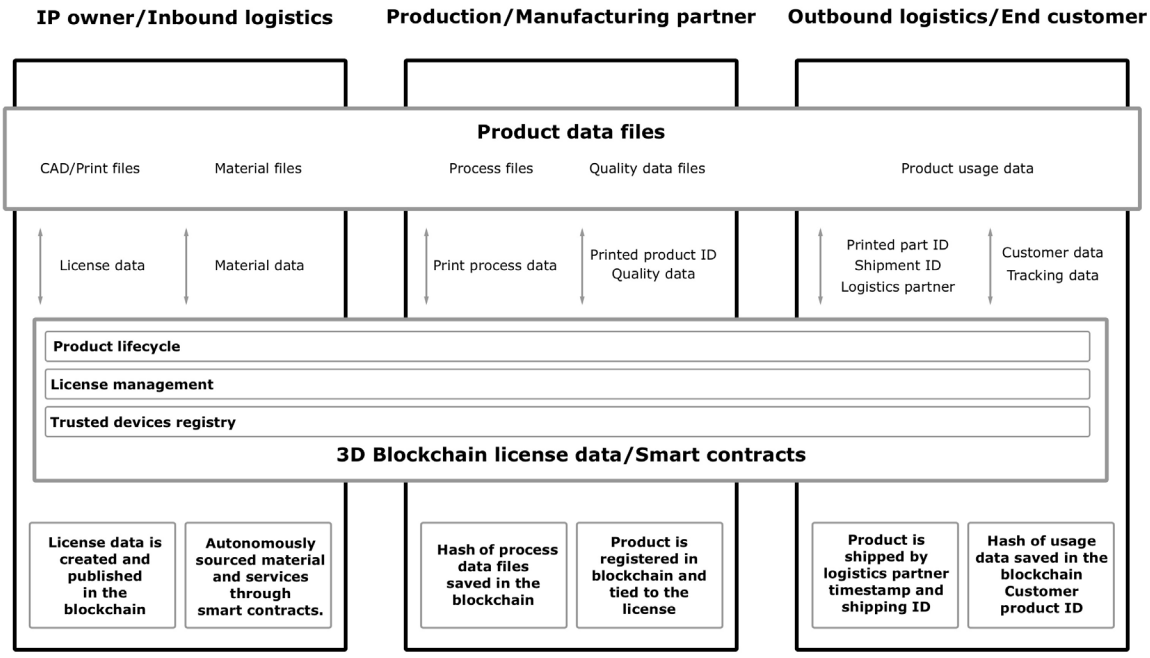
Supply chains may seem unsexy, but they are the core of commerce, and, some would argue, the core of all global finance operations.

In most cases, companies are making supply chains *smarter* with "smart algorithms," transportation management systems (TMS), and enterprise resource planning (ERP) solutions to augment human intelligence. Some are leveraging algorithms, machine learning, and computational tools for automation in amazing ways. Groups such as TransVoyant or One Network's Real-time Value Network are working to develop sentient and demand-driven supply chains that incorporate predictive analytics in enterprise solutions.[27]

But today's smarter supply chains are not necessarily *learning* or packaging new learnings into opportunities for systemic and autonomous improvement of supply chain efficiency and responsiveness. Our supply chains are not yet cognitive because no actor can see them in their global entirety.

Creating intelligent and autonomous supply chains that learn is still a goal, and achieving it will rely heavily on our ability to integrate lessons into organizational processes. As General David Petraeus, former commander of the US Armed Forces in Afghanistan, chairman of KKR, and former head of the Central Intelligence Agency, told us, "Organizations have to be learning organizations. We used to say that

Figure 4: SAMPL's extended ecosystem



Source: Animal Ventures, simplification of Dr. Martin Holland, "IP-Protection and Licensing of 3D-Printing Processes," PROSTEP AG, 2017. Used with permission.

"Organizations have to be learning organizations. We used to say that the side that learns the fastest in combat is the one that typically prevails, and we tried to learn faster than the enemy."

GENERAL DAVID PETRAEUS
Chairman
KKR

the side that learns the fastest in combat is the one that typically prevails, and we tried to learn faster than the enemy." Learning organizations can be large or small; but, according to Petraeus, lessons aren't learned "until they're adopted as big ideas, or refinements to the big ideas, and they're actually in a campaign plan, or in a policy, or in a directive, or a standing operating procedure."[28]

An organization's ability to learn will matter greatly, particularly its ability to build learning into the processes that coordinate activities for designing, making, and delivering end-use goods and products. To become a learning organization, we must rapidly implement our knowledge across our supply chains because supply chains that *learn* will be the competitive survival and success metric of future businesses. The faster we learn, and the faster we process our lessons into real impact, the more likely we will survive in the future.

Designing, making, and delivering value

While we have yet to see businesses transition to fully cognitive supply chains, the significant change underway across supply chain functions will help. Supply chains may seem unsexy to most casual observers, but they are the core of commerce, and, some would argue, the core of all global finance operations. Most people don't realize that supply chains manage the majority of global trade—as much as $50 trillion by some estimates (i.e., the bulk of gross world product, which hovers around $75.6 trillion).[29] However, the forces decentralizing our industrial economy will affect these, too.

The idea that anyone can trade efficiently (at scale) with anyone without the need for firms or intermediaries will fundamentally change how we coordinate and produce goods. These changes will decipher where the new value-creation opportunities are.

Let's review the Moog case. On one hand, intermediary manufacturing companies will become obsolete as additive manufacturing advances. Parts once made in-house will be printed on demand by an end-consumer. On the other hand, Moog is creating new value by leveraging blockchain technology to certify and track its digital IP and by building new licensing and subscription models.

The faster we learn, and the faster we process our lessons into real impact, the more likely we will survive in the future.

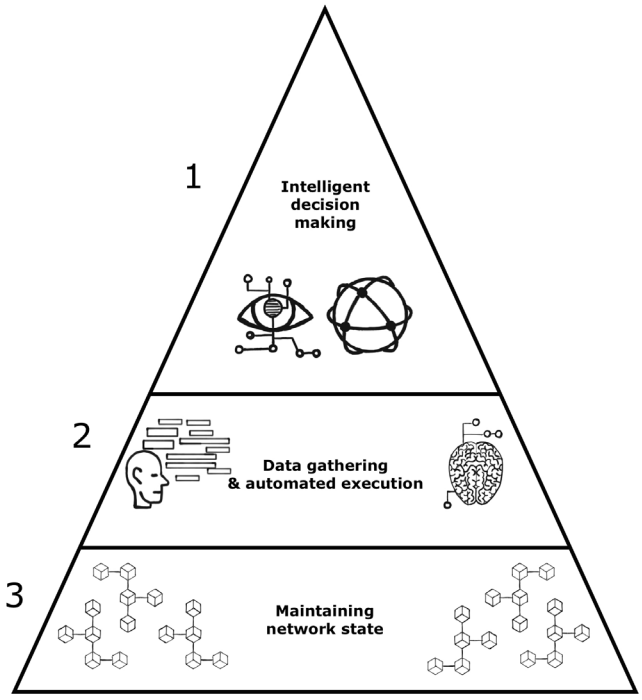
The making of a product is not the only supply chain function that will change because of blockchain and other technologies; how we design, deliver, use, and coordinate these activities will also change. While supply chain management has advanced over the years, the technologies bringing about the decentralized economy affect it significantly.

The core functions of cognitive supply chains

How we coordinate activities related to designing, making, and delivering end-use products will rely entirely on the core functions of cognitive supply chains (Figure 5).[30] These functions are already optimized using blockchain, IoT, additive manufacturing, and AI across supply chain processes.

The act of making a product is not the only supply chain function that will change because of the affordances of blockchain and other technologies; how we design, deliver, use, and ultimately coordinate these activities will change, too.

Figure 5: Core functions of a cognitive supply chain



Cognitive Supply Chain Core Functions © 2017 Animal Ventures. Reprinted courtesy of copyright holder. All rights reserved.

The core functions of cognitive supply chains are:

1. *Intelligent decision-making:* The analysis of all activities, data, and network state that allows a machine-based intelligence to learn autonomously and make decisions on how best to improve the overall supply chain entity.

2. *Data gathering and automated execution:* Human- and machine-based data gathering for machine intelligence to execute activities autonomously in collaboration with other humans, AI, and machines.

3. *The maintenance of network state:* A blockchain-based ledger of activities that provides a historical and current network state in order to help machine intelligence to manage autonomously business functions associated with procurement, contracting, research and development, finance, sales, manufacturing, and distribution.

Traditionally, most of these core functions are managed through enterprise resource planning systems, smart algorithms (dumb AIs), and industrial and non-industrial machines. Humans are at the top and scattered throughout to make more intelligent decisions that drive core business KPIs.

By giving life to more autonomous and intelligent AIs, cognitive supply chain entities will eventually replace humans in terms of who holds the responsibility of intelligent decision-making. This has meaningful implications on how we design, make, and deliver end-use goods.

As Dr. Ravi Prakash Mathur, senior director of supply chain management at Dr. Reddy's Laboratories, wrote, "Common wisdom tells us that organizations compete on the strength of their supply chain ecosystems. Future organizations would compete on the strength of intelligence embedded in their systems. Ultimately, the winner will be the supply chain that learns most quickly with greatest precision."[31]

"Common wisdom tells us that organizations compete on the strength of their supply chain ecosystems."

DR. RAVI PRAKASH MATHUR
Senior Director of Supply Chain Management
Dr. Reddy's Laboratories

How AI is driving value across designing, making, and delivering

People have been hard at work making supply chains smarter across functions. Consider Amelia, an AI platform developed by IPsoft: Amelia handles business-process queries like a human. She not only reads (at 10 pages per second) all the manuals that humans read, but she increases her knowledge by observing humans answering questions that she cannot and codifying those answers for later use. Amelia acts as not only a living FAQ but an improving one. "Amelia helped engineers fix equipment in remote locations," read one oil company report. "Because the system has read the manuals, the engineer can ask Amelia to send information about the problem, diagnose the cause, and suggest a fix."[32]

We are also seeing technology combinations bring to life the "smart" or lights-out factories of the future, such as the partnership among FANUC (a robotics and factory automation company), Cisco (a leader in digitization), Rockwell Automation (an industrial automation company), and Preferred Networks (an AI solution company) to develop a FANUC Intelligent Edge Link and Drive (FIELD) system. This system aims to connect machines and robots with the IoT to enable manufacturing optimization.[33] Rowan Trollope, senior vice president of IoT and applications at Cisco, described the collaboration as "a historic shift in the industry, with the IoT, industrial automation, and machine learning coming together to make the factory of the future a reality. It's been talked about for years, but now it is really happening."[34]

Factory and warehouse activity is increasingly automated using a combination of robots, 3D depth-sensors, lasers, and smart algorithms to perform challenging tasks. For instance, Changying Precision Technology Company replaced 600 human jobs with 60 robots along its assembly lines, "resulting in a fivefold reduction in manufacturing errors and an increase in production of over 250 percent."[35] These unmanned factories will only increase as robots integrate more human skills and move supply chains from smart to intelligent via better AI.

How the IoT is driving value across designing, making, and delivering

Efforts to enable real-time access to both unstructured and structured data from sensors and connected machinery across a supply chain are ramping up. In a survey by SCM World and Cisco, plant managers and business-line executives were asked which "things" were already being connected. Production equipment ranked very high. As Bryan Tantzen from Cisco reported, 62 percent of survey respondents planned on connecting such resources by 2020.[36]

Delivery is also affected by IoT implementation in a supply chain, from inventory and warehousing to logistics and transportation operations, and overall supply chain management. DHL and Cisco estimated that IoT will put $8 trillion in value worldwide at stake over the next decade. As the International Data Corporation (IDC) explains, consumer product manufacturers will require a year-round model for fulfillment, logistics, and general supply chain management. According to IDC,

> *If manufacturers are going to respond to shrinking order and delivery timelines, greater numbers of delivery points (as a result of omnichannel commerce), or even direct-to-consumer shipments, it is hard to see how to effectively do this without moving to the reality of 24 x 7 x 52 continuous logistics. Manufacturers that fail to adapt will fall behind the industry.*[37]

We can see increased pressure on delivery times by looking at Amazon's recent proposal via patent applications to 3D-print customer orders from inside delivery trucks as they travel to a customer.

Additionally, *Business Insider*'s research estimates that about 90 percent of the North American market (180 million commercial vehicles) will use connected fleet management to integrate IoT into delivery.[38] We can even see increased pressure on delivery times by looking at Amazon's recent proposal via patent applications to 3D-print customer orders from inside delivery trucks as they travel to a customer—combining additive manufacturing with delivery for reduced friction. According to the *Wall Street Journal*,

> *Customers could order, say, replacement parts for their car through the Amazon website and have them delivered in time for a road trip that day. Another plus: Amazon could guarantee to have the products available, without having to stock the inventory.*[39]

Active and passive IoT sensors, microchips, and nanotechnology are enabling companies to tag products with unique digital identifiers and track them across their lifecycle, and this too is pushing the kinds of things that are getting connected in supply chains. To track and trace more effectively across supply chains, products are increasingly being tagged and connected to digital networks through microscopic electronic devices, next-generation RFID tags, and embedded markers. Steve New, associate professor in operations management at Oxford University's Said Business School, suggested that,

> *New generations of tags—such as Hitachi's sand-grain-size mu-chip—can be used, for instance, to label jewelry inconspicuously. It can even be embedded in paper and*

plastic, making the product's provenance data part of the material itself. And smaller-scale tags—labeled exotically as "radio dust"—are in development.[40]

We can even tag humans to allow greater interaction with things and environments. For example, Three Squares Market in Wisconsin embedded microchip trackers in its employees.[41] VivoKey, enabled human-to-machine transactions for increased security.[42]

In terms of supply chain coordination, other predictions, such as IDC's, expect that "IoT technologies will be materially affecting the way that all companies manage their supply chains by 2020, and that 25 percent of their supply chain IT-spend will be for the IoT or IoT-related technologies" (Table 1).[43]

Data gathering throughout a supply chain offers opportunities such as "reduced late deliveries, improved warehouse labor productivity, improved planning, and optimized routing. In addition, IoT creates the potential to leverage such information in non-logistics elements of supply chain planning such as inventory positioning, inventory

Table 1: Future use cases for the Internet of Things by industry

Industry	Use cases	KPI/Metric impact
Supply chain (function rather than industry)	▪ Real-time track and trace ▪ Inventory visibility ▪ Alignment of planning with execution ▪ Predictive estimated time of arrival (ETA)	▪ Working capital, safety stock, and productivity ▪ Inventory turns and return on asset (ROA) ▪ Forecast error, perfect order fulfilment, and production plan adherence ▪ Customer service level, on-time delivery, and productivity
Transportation and logistics	▪ Optimized routing ▪ Predictive maintenance ▪ Improved scheduling	▪ Customer service level, productivity, and on-time delivery ▪ ROA and asset utilization ▪ Labor costs and productivity
Manufacturing	▪ Predictive maintenance ▪ Modern vendor-managed inventory (VMI) ▪ Alignment of inventory with production ▪ Reduced energy consumption	▪ ROA, asset utilization, and uptime ▪ Cost of goods sold (COGS), inventory turns, and reduced downtime ▪ ROA, inventory turns, and working capital ▪ Carbon footprint
Retail	▪ Real-time inventory optimization ▪ Demand sensing and shaping	▪ ROA, inventory turns, and working capital ▪ Sales, ontime in full (OTIF), and perfect order fulfilment
Oil and gas	▪ Predictive maintenance ▪ Connected components ▪ Well monitoring	▪ ROA, asset utilization, and downtime ▪ Operating costs and ROA ▪ Throughput and ROA

Source: IDC, 2015.

levels, and safety stock calculations, which have a direct relationship to profitability."[44]

Progress on liquidity and discovery, but not trust

We've made massive leaps in leveraging both basic AI and IoT to change how we design, make, and deliver using *intelligent decision-making* and *data gathering and automated execution*. The adoption of these changes will continue, and many industry practitioners can barely keep up with the rate of technological advancements. Ten percent of Amazon's workforce already consists of robots![45]

Ten percent of Amazon's workforce already consists of robots!

The one area of our core-functions pyramid that hasn't improved is the base: the *maintenance of network state*. That's not to say that SAP, Oracle, and other brand-name ERP and supply chain software systems haven't been evolving; if anything, they've had to evolve a lot to keep up with the ever-growing web of supply chain networks. But, as Lora Cecere, a supply chain and enterprise strategist, argued,

> *The product road maps of conventional technology providers are not closing the dark holes. Instead, the focus is on refining today's enterprise applications. It is unrealistic to think that vendors like Infor, Microsoft, Oracle, and SAP will ever work together to erase the dark holes of information in the supply chain. Likewise, it is very clear that ERP will be the backbone or system of record for transactions within the enterprise, but it is insufficient as the backbone or system of record for a value network. It is also clear that through globalization, value networks aren't linear. Instead, they are a set of complex interactions which are increasing in speed and depth of the interaction.*[46]

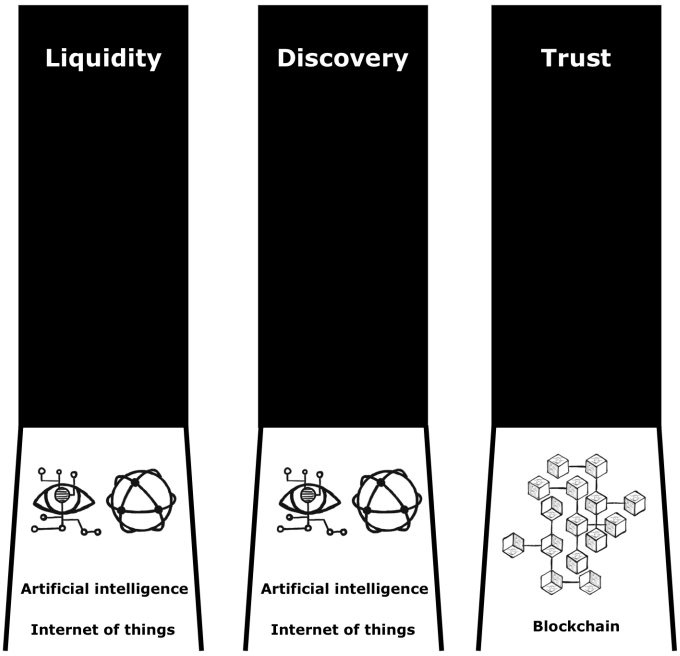
In a decentralized economy increasingly managed by intelligent data-gathering, decision-making, and automated execution, companies will need a radical step forward in innovation to transform standard supply chains into cognitive ones.

In a world defined by the decentralized economy and increasingly managed by intelligent decision-making, data-gathering, and automated execution, companies will need a radical step forward in innovation to transform standard supply chains into cognitive supply chains. This step will require more than a system tweak or a feature upgrade to the latest ERP.

Cognitive supply chains will thus require a network state function that provides a singular universal truth as the basis for something we call machine trust.

Let's return to our marketplace pillars of liquidity, discovery, and trust (Figure 6). The first two are accelerating rapidly through AI and IoT innovations. The third, trust, is managed largely by people or firms, even in this digital age. Blockchain approaches trust through technology that unlocks the potential of machines to interact at scale. Which means that future cognitive supply chain entities will need to support the ability of machines to conduct business autonomously, either with each other or with any other type of identity that exists now or might in the future. Cognitive supply chains will thus require a network state function that provides a singular universal truth as the basis for something we call *machine trust*.

Figure 6: Pillars of liquidity, discovery, and trust in a marketplace



Pillars of Liquidity, Discovery, and Trust in a Marketplace © 2017 Animal Ventures. Reprinted courtesy of copyright holder. All rights reserved.

The missing link: A solution for latency in cognitive supply chain networks

The network state that will support cognitive supply chains will replace *human trust networks* with *machine trust networks* for managing activities, contracting, procurement, governance, compliance, and updating the network state to its most current version. Today, with augmented intelligence, human beings acting as intermediaries manage supply chain network states. In their intermediary role, humans create significant network latency that machines will struggle with, slowing down the learning and cognitive capabilities meant to optimize supply chain activities. We all know what it feels like to have slow Internet. Imagine what it's like for a machine on a network where human latency is generated by activities best served by machines.

Asset chains, the direct evolution of the 2008 invention of bitcoin, allow us to unlock the trade capability of machines without human intermediaries.

In the decentralized economy, machines will have the ability to do business with each other without human intervention. Much in the same way that we use robots to build cars and act as drivers now, machines will be continuously supplied with capacity and will require a means of transacting their data and decisions. The basis of these cognitive supply chains—the missing link—is something we call asset chains.

Asset chains, the direct evolution of the 2008 invention of bitcoin, allow us to unlock the trade capability of machines without human

intermediaries. They are blockchain-based networks that provide the technological infrastructure for tracking, contracting, procurement, and payments associated with assets across autonomous and intelligent supply chains. Supply chains will reconstitute using blockchain as the basis of a value network that scales to machines and humans.

Human latency and information gaps hamper the ability of a supply chain to learn, and learning is the key to survival in a decentralized economy.

The major hurdle to achieving fully decentralized marketplaces and supply chains is the lack of autonomous network state across the design, production, and delivery of goods. We need more autonomous management of network state. Human latency and information gaps hamper the ability of a supply chain to learn, and *learning is the key to survival in a decentralized economy*.

Sweetbridge Inc.

Founded in 2016, Sweetbridge Inc. is a for-profit company based in Scottsdale, Arizona, owned by the Sweetbridge Foundation in Zug, Switzerland. Sweetbridge leverages blockchain technology in the logistics and supply chain space, and is building a decentralized autonomous value network, the Sweetbridge Alliance, to drive greater collaboration across supply chains while unlocking working capital. Through its non-profit foundation, Sweetbridge will fund the development of "protocols and applications that accelerate trade by freeing money, assets, and talent in supply chains."[47] Sweetbridge's founder and CEO, Scott Nelson, has a background in supply chain and logistics performance management via his previous start-up, Trax Technologies Inc., which offers data and optimization tools for global supply chains.[48]

Sweetbridge is approaching the global supply chain market as a whole, including the $8.6 trillion logistics market and the $16.6 trillion export-merchandise market.[49] It will focus on the processes and logistics management that pervade supply chains, regardless of industry; an enormous opportunity to unlock stagnant working capital and leverage new technology to synchronize siloed digital data-flows tied to physical assets. With the future Sweetbridge is building, Nelson noted, "You can literally trade things like toilet paper and pencils and exchange them for a timeslot in factories. Or in the future with 3D printers."[50]

Sweetbridge is building the global network state (the singular universal truth) for its supply chain.

The problems Sweetbridge is addressing with blockchain

» Supply chain-heavy industries lack a single, decentralized, inter-enterprise database to manage their interwoven supply chains. This means there are "dark holes" of lost or unsynchronized data.[51]

- The current technology solutions (such as ERPs) are enterprise-centric and do not offer a state-view of interrelated networks.[52]
- Stranded capital assets, such as idle trucks or container capacity, are underutilized across supply chains (the US Federal Reserve estimates only 75 percent utilization).[53]
- Working capital liquidity can be streamlined to shrink lead times in supply chains.
- The process of procurement in supply chains does not have a technology infrastructure that combines contracting, payment, and enforcement of contracts.

The Holy Grail has been a product developed to define the single source of truth for the state of supply chains—a universal digital platform for supply chain management utilized by all companies.

The number of companies and processes involved in making a single product is increasing, which means that the number of touchpoints for a single product is going up too.[54] While technology has tried to innovate alongside the growing needs of supply chains, there are still many unmet needs. The Holy Grail for many companies offering technology solutions in the supply chain space has been to develop a product that defines the single source of truth for the state of supply chains—a universal digital platform for supply chain management utilized by all companies. While companies like SAP, Ariba, E2open, i2/JDA, Oracle, GT Nexus, and others have significantly improved on the efficiencies of enterprise supply chains, the simple reason none has built the killer app is distrust.[55] It is very hard to imagine a business arrangement where a single company acts as the source of supply chain management truth for an entire industry: no customer would want to give up their data or be forced into a one-size-fits-all solution. Customers may want the efficiencies of a monopoly—where interdependent enterprise supply chains can act as one fluid end-to-end supply chain rather than siloed product flows—but most industries are unwilling to create one by handing over their power.

Supply chains have been dominated by company thinking rather than network thinking and are optimized by each enterprise to address the processes and inefficiencies that come from opaque transactions.

To date, the most advanced mechanism for industry coordination of supply chains has been through federations or alliances (in the auto industry, for example). However, these are not paired with advanced technologies, and they offer governance without innovation. As Nelson said, "In the past, the supply chain's incentives have been misaligned with supply chain collaboration."[56] Without a non-monopolistic approach or the technology that synchronizes governance, we are left with the inefficient status quo.

Currently, supply chains are optimized by each individual enterprise to address the processes and inefficiencies that come from their interdependent but opaque transactions. Supply chains have been dominated by company thinking rather than network thinking. As Nelson explained, "A digital-supply chain vision is common to many industry thought-leaders. What may not be obvious is that the lack of information about trading-partner behavior (transparency) and the automatic ways to reach consensus (settlement) are primary drivers of inefficiency in the flow of goods and money. The perceived risk of trade is much higher than reality, because of trading-partner

opacity, bad data, and outdated banking practices."[57] Executives from a 2013 study conducted by Rob Handfield at North Carolina State University concurred that "strategic frameworks and tools are needed for engaging the entire network in the management of risk and disruptions," across supply chains.[58] The potential is not just to drive down coordination inefficiencies across increasingly interdependent supply chains, but also to unleash the capital these inefficiencies keep trapped.

Beyond this single-state coordination challenge, we need technology that pairs a digital state with an asset's physical state. If assets can be controlled via smart contracts that enforce procurement terms, supply chains can begin to embed incentives in assets along the chain at a much more granular level.[59] Issues of data latency, accuracy, and consistency occur across the systems that currently report on supply chain assets.

Sweetbridge wants to integrate blockchain technology by reimagining supply chains as decentralized autonomous value networks (DAVNs): "networks of individuals, organizations, and companies that add value through processes to supply products that meet customer demand."[60] At the core of this transformation is the missing link of a single-truth digital state for products across global supply chains—and the digital state relies on blockchain technology.

Using the Sweetbridge settlement protocol and blockchain-based smart-contract templates that arrange compensation, participants can enforce transactions across supply chains in the Sweetbridge Alliance. As its blog described, Sweetbridge will support "two new forms of value exchange natively. First, the payment for the use of assets based on a share of the value generated. Second, the payment of talent based on the outcome being produced. Using blockchain technology, the Sweetbridge protocols will be able to support these structures and will also be able to facilitate the payment for value received."[61]

Using the Sweetbridge settlement protocol and blockchain-based smart-contract templates that arrange compensation, participants can enforce transactions across supply chains in the Sweetbridge Alliance.

Sweetbridge will launch with a dual token design initially (Table 2): one for assets (that acts like gold and appreciates) and one for liquidity (that's used for trade and depreciates slightly, to be spent). But Nelson described 11 tokens in the works, which will have varying

Table 2: Sweetbridge dual token design

Sweetbridge supports two forms of value exchange: payment for asset usage based on share of value generated and payment of talent based on outcome produced.

	Tokens for assets	Tokens for liquidity
Purpose	Held like gold and appreciating	Used for trade and depreciating
Example	Sweetcoin, a collateralizing token to store value and license use of Sweetbridge protocol	Bridgecoin, a stable token pegged to fiat currencies

economic roles and create different alignments across their network. For instance, the Sweetbridge blockchain will include a stable token (Bridgecoin), which will be pegged to different fiat currencies (e.g., BridgecoinUSD, BridgecoinEURO) and used to create liquidity. Additionally, SweetCoin will act as a collateralizing token—a store of value and a license to use the Sweetbridge protocol.[62] A separate token is planned to protect and represent intellectual property on the blockchain. Said Nelson, "Once you can tokenize IP, you can tokenize talent and leverage your future revenue." Asset tokens can be wrapped in compliance tokens to "obey the tax laws and trade compliance of your government jurisdiction, so you get real-time trade-value based on the legal regime."[63]

While Sweetbridge's work hinges on a larger vision for the global economy, its blockchain-based alliance relies on the development of a decentralized network that logs and represents a single state of supply chain.

"Once you can tokenize IP, you can tokenize talent and leverage your future revenue."

SCOTT NELSON
Founder and CEO
Sweetbridge

A snapshot of possibilities for Sweetbridge

Opportunities

- Creating a single source of truth for the global supply chain market
- Leveraging data across an industry to improve demand forecasting
- Eliminating costly inefficiencies from previously opaque partner data
- Creating a payment infrastructure that tracks results and fulfillment of purchase orders against payment per asset in real-time

Challenges

- Designing a governance structure for the technology and powers of the Sweetbridge Alliance that incentivizes member participation
- Ensuring enterprise-level confidentiality of company data in the network. Gaining the efficiencies of data sharing and transparency without foregoing the competitive advantages and proprietary data of participating companies is possible. For instance, one could integrate zero knowledge proofs
- Competing with the large-enterprise software solution providers (e.g., SAP, Oracle)

Broader considerations for global network state

Enabling global network state for supply chains is hefty. It may take the decentralized form of one large, open-source network

with no controlling entity (a Sweetbridge-like platform), or as many localized or specialized decentralized networks that interoperate. Regardless, such a network state will rely on several key factors: identity of objects, machines, and people through an evolving IoT; tokenization of traditional and cryptographic assets; and the ability to transact quickly across these assets. Projects like UniqeID, VivoKey, Chronicled, and uPort are already working on technology that combines identification with blockchains to track and trace object, human, and bot identities across various transactions.[64] Additional platforms and tools, such as IOTA and the Raiden network, are pushing forward new methods of micro-transactions to handle the volume that will emerge as the IoT trades across our supply chains.

Asset chains

Evolving state management through asset chains

The optimal supply chain requires large volumes of information and data to determine the exact state of the entire supply chain network, and to make the most effective decisions possible at the precise moment in time decisions are needed.

State is often defined as "a condition or way of being that exists at a particular time."[65] We use *state* in conjunction with *supply chain* here to make clear the particular condition of the entire supply chain at any moment in time: the flow of product to location, the temperature, the conditions, the inventory levels, or the price of a finished or unfinished asset.

For machines to do business autonomously with each other, we must first have a new method of state management—one void of human intermediaries (latency)—to deliver on the promises of such advanced technologies as AI, industrial IoT, and additive manufacturing.

Today, the state of existing supply chain networks is derived by leveraging both human and machine intelligence. In some of the largest supply chain entities in the world, humans maintain network state with the support of large, complex enterprise solutions, analytical systems, and data-management systems. But for machines to do business *autonomously* with each other, there must first exist a new method of state management—one void of human intermediaries (latency)—to deliver on the promises of advanced technologies like AI, industrial IoT, and additive manufacturing.

When Satoshi Nakamoto and crypto-enthusiasts created a solution to the infamous *double-spend problem* with bitcoin, they may not have fully understood where the technology would go. It's unlikely that they expected to solve the double-spend problem for *any* asset by creating and transferring identity, ownership, and custodianship across a distributed network of exchange. While we have been able to identify products and their containers of transfer for some time (and are improving these techniques with trace DNA, nanotechnology, and other innovations), we have not yet had the mechanism for verifiable transfer of physical goods, document flows, or financial flows associated with our supply chains.

Enter asset chains: the missing piece of the cognitive supply chain puzzle. Today's blockchain networks have become more like large-scale global computing platforms untethered from the concept of a central system administrator. System administration can be decentralized and executed through programmable consensus algorithms that rely on a single source of truth as it relates to the state of the entire blockchain network. *Consensus* is the mechanism by which we all come to agree on state, and state is derived from blockchain-based data-management methods. Blockchain is the technology framework that provides a universal truth through an unalterable and distributed ledger of activities.

Today's blockchain networks have become more like large-scale global computing platforms untethered from the concept of a central system administrator.

Asset chains—blockchains that will power cognitive supply chains—are what allow for *autonomous* and *decentralized* management of supply chains. They create a framework for machine trust, a way for machines to participate autonomously in supply chains and, ultimately, the marketplaces they serve. They are the mechanism by which we eliminate human latency in supply chains so that equilibrium can finally be achieved and profits can be maximized. If today's firms are built to optimize the relationships between liquidity, discovery, and trust, then asset chains unlock the autonomous machine-based optimization of these relationships.

Asset chains—blockchains that will power cognitive supply chains—allow for autonomous and decentralized management of supply chains.

Cognitive supply chains will require the scaled one-to-one trade infrastructure that the decentralized economy promises to deliver. Future marketplaces and cognitive supply chain networks will allow machines to transact with humans, objects, AIs, and other identities based on business protocols. It's human talent matched with armies of lawyer-coders (smart contract developers) who will ultimately serve as the magistrates that define what those business protocols are.

A decentralized Amazon marketplace requires an accurate, transparent, and reliable version of network state that is reported on and updated without management by intermediaries to give everyone (machine, human, and enterprise) the same trusted information. It is Amazon without Amazon (Figure 7).

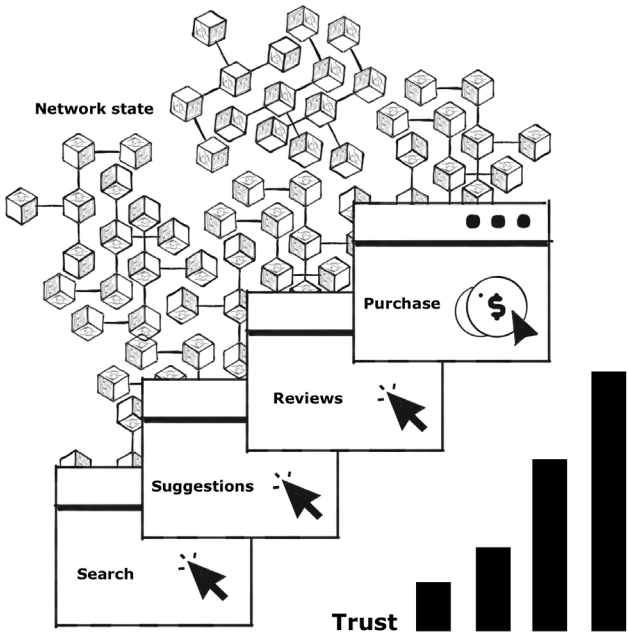
With trillions of dollars flowing through sprawling supply chain networks that span all corners of the globe, the impact on global financial systems and their marketplace participants is currently unimaginable.

How asset chains impact design and make and deliver value

Autonomous and cognitive supply chain entities are going to reshape global commerce. With trillions of dollars flowing through sprawling supply chain networks that span all corners of the globe, the impact on global financial systems and their marketplace participants is currently unimaginable.

We should prepare for a future in which robots (machines) become the next big consumer class. Asset chains will give rise to a new type of supply chain agent and marketplace participant—an autonomous agent with a wallet and purchasing power who will, at any point in time, know the exact condition of the entire network state, be able to quickly and easily analyze large volumes of data, and (because of asset chains) *autonomously* execute transactions.

Figure 7: Amazon marketplace without Amazon.com



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To achieve state maintenance asset chains rely on several features of blockchain technology that exist beyond the systems in use today (Figure 8). The first is smart contracts, which enable rules or tasks to be written as code, and executed when terms are triggered; a combination of business logic and enforcement. The second is the matching of a physical and digital identity and its permissioning. The third is the censorship-resistant truth across non-trusting parties that blockchains can create without forming a monopoly, which enables the transition of custodianship and contracts across entities. These features allow asset chains to reconfigure tasks that traditionally have been held separate in our supply chains.

Binding procurement and contracting via asset chains

Binding procurement with contract execution is possible across a supply chain's design, make, deliver, and use functions. Previously, a procurement department or an individual would source a material or product necessary for their business and establish a contract for sourcing it. But the process for measuring outcome and ensuring execution of that contract was its own undertaking. With asset chains, procurement contracts are smart contracts and self-executed on a blockchain, which means that they are tied to the outcome of contract fulfilment. The sourcing, contracting, and payment-upon-delivery is bundled into one smart process. Procurement and contracting can even take on new meanings, wherein the credit of a prime contractor can be cited all the way through to the financing of component pieces made by subcontractors. Projects that integrate blockchains into trade finance to bind procurement and contracting

are currently underway at Foxconn (via its subsidiary, Chained Finance), CGI Trade360, Mizuho, and more.

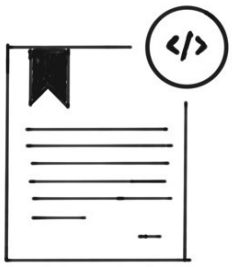
Binding governance and compliance via asset chains

Binding governance tasks with compliance is also possible via asset chains. Smart contracting allows us to devise the rules of enterprise interactions on a supply chain network, which can include the differences in regulatory terms across jurisdictions as a product moves in the real world, and the service terms particular to a company or product. For example, start-ups like Chronicled, BlockRx, and Ambrosus are working on governing objects for pharmaceutical and other supply chains, and Walmart, IBM, and Zest Labs are among the groups that are working on food supply chains.[66] Zest Labs even has a Zest Fresh tool that leverages the IoT in monitoring a product from harvest to retail. The tool's overall purpose is to extend "best by" dates, which contribute to 33 percent of the $165 billion worth of food wasted in the United States annually.[67] Everledger and Provenance are projects that are bringing sustainability and regulatory conditions to the sourcing and sale of diamonds and artisan objects.[68]

We can also view projects that bind governance terms with compliance as *compliance innovation*, a new way to ensure that rules are not only stated but also followed across supply chains.

Figure 8: Asset chains rely on blockchain for state maintenance

These three features of blockchain technology enable asset chains to reconfigure tasks that separate entities have traditionally performed in supply chains.

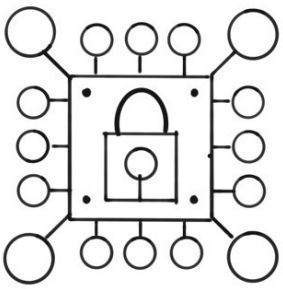


Smart contract

- Rules can be written as code
- Tasks can be executed when terms are triggered (a combinaton of business logic and enforcement)

Identity verification

- A physical and a digital identity can be matched and permissioned



Data immutability

- Non-trusting parties share censorship-resistant truth without forming a monopoly
- Parties can transfer custodianship and contracts across entities

Binding functions across supply chains will change how we design, make, deliver, and coordinate our products. The autonomous execution of these functions through asset chains will change both their form and their value-capture opportunities.

However, as IBM stated in its early work on the ADEPT project in 2015, "While each approach has its merits and demerits, we are yet to see consensus on a common approach across the board. A blockchain to cater to hundreds of billions of devices needs to be scalable."[69]

Blockchain scalability for asset chains requires innovation such as

- Leveraging advances like sharding
- Splitting the volume of trade between on- and off-chain technologies, which could include structures like the Raiden network for Ethereum
- Using light clients to alleviate the need to run a full node[70]
- Leveraging older ideas around nanobartering between machines[71]
- Applying alternate approaches using *directed acyclic graphs* (DAGs) to allow microtransfers for IoT devices.[72]

However, scalability is generally an innovation in functionality driven by adoption, and the corporate interest in adopting the forces of the decentralized economy will necessitate this scalability sooner than later.

Binding so many core supply chain functions through asset chains doesn't necessarily eliminate the need for human involvement in supply chains; it mostly challenges the role of humans as intermediary functions and in the coordination of enterprise resourcing and planning. Human value will shift to the edges of the network, which will provide opportunities to expand creative cognition, root the future value of humans in *design,* and reduce the role of humans in the *making* and *delivering* functions of cognitive supply chains.

Human value will shift to the edges of the network, which will provide opportunities to expand creative cognition, root the future value of humans in design, and reduce the role of humans in the making and delivering functions of cognitive supply chains.

As Luke Hutchison said,

> *The way to think about AI is actually as a prosthesis for the human brain. [It's like] when you're driving: the car … is a prosthesis for your brain. It's like a metal body that can move faster than you can move; it's more powerful than you are. You can carry many more goods, but your brain is ultimately at the helm. When you see a plane in the sky, it's the same thing: a giant prosthetic body, with one brain that's at the helm (assuming it's not on autopilot). But … autopilot is a good example: we can automate some of these things. But, the reality is, always, machines are driven by our intelligence.*[73]

Once machine-driven supply chains function in a decentralized, autonomous way, we'll be able to extend this idea of prosthesis to the entire supply chain. Human intelligence in design and generative tasks will further improve supply chains, so firms that invest in tools and programs to unlock human design talent will be those that reap the benefits. Supply chain talent is already scarce. As Linda Topping, VP and chief procurement officer with Colgate-Palmolive Co. explained to *Industry Week*, "Supply chain management is getting exponentially more complex, so supply chain talent is the price of admission for the next decade."[74] Design input into cognitive supply chains in particular will be extraordinarily valuable, as will the emphasis on acquiring, maintaining, and harnessing human talent.

Merck & Co. Inc.

Merck is an innovative global healthcare leader that, in addition to studying some of today's most significant health challenges (cancer, hepatitis C, cardio-metabolic disease, antibiotic-resistant infection, and Alzheimer's), works to advance the complex supply chains of the pharmaceutical industry.

At the start of 2017, Merck's supply chain group partnered with our firm on a pilot project using blockchain technology. According to Craig Kennedy, senior vice president of global supply chain management, and sponsor of the project,

> *If you look at a lot of the healthcare supply chain, the exchange of information in the silos we have created … have not only negatively impacted each company but also the ecosystem as a whole. [We all struggle with] serialization mandates, anti-counterfeit strategies, or the ability to transition transactional information to our customers in an easier fashion. After understanding the core affordances of blockchain technology and more distributed environments, we wanted to begin experimenting rather than be skeptical.*[75]

"Rather than trying to imagine a 'solve it all' blockchain solution, our team began dissecting many of the supply chain inefficiencies to imagine micro-solutions we could pilot and continue to build on top of."

PAUL COCUZZO
Director of Supply Chain IT
Merck & Co. Inc.

Paul Cocuzzo, director of supply chain IT, and an IT lead for the blockchain project, said that rather than imagining a "solve it all" blockchain solution, "our team began dissecting many of the supply chain inefficiencies to imagine micro-solutions we could pilot and continue to build on."[76]

Merck and the supply chain

Merck manufactures and packages products distributed to more than 163 markets around the world. Its facilities, along with those of external contractors, suppliers, and partners, make up an integrated, interdependent, global manufacturing network. Kennedy elaborated,

Our supply chain group gets the products to patients through customs. This involves coordinating across many industries, external partners, and checkpoints, all with incredibly diligent safety requirements. In addition to our planning hubs and private manufacturing facilities, we also operate 148 external manufacturing plants and produce 10,300 different product-size finishes. Each facility has to coordinate with many pharmaceutical ingredient suppliers, packaging companies, and product distributors.[77]

This 125-year-old pharmaceutical company is initiating a blockchain pilot in its supply chain department.

A study by McKinsey revealed that 20 percent of the pharmaceutical industry's profit can be attributed to introducing supply chain best practices, compared to the six percent rate in the consumer packaged goods industry.[78] Aside from economic differences, the flow of goods differs markedly in Merck's industry. A typical computer manufacturer can receive an order for a pallet of customized computers and deliver it the following week. A typical pharmaceutical manufacturer, however, needs two months to deliver to distribution centers out of a formulation and packaging plant.

Healthcare supply chain is thirsty for innovation and improvement. It is hard to ignore the increasing demand for affordable products from hundreds of millions of people living in emerging economies. Quality standards, compliance issues, and serialization mandates are on the rise, which creates further risk. Merck's challenge is to minimize storage, lead times, and other logistics costs, and this is where its supply chain leadership is focusing its initial blockchain experiments.

Jacob Lustig, executive director of manufacturing IT—supply chain, external manufacturing, and analytics, said,

We are in an industry that has many partnerships that rely on trust, yet there is very little trust. Deploying information technology and new database solutions that create a more trustless environment is something that opens up a world of possibilities for our company and the industry as a whole. So we initiated a plan to use a blockchain-enabled product internally for our manufacturing division to share sensitive information related to our safety and good manufacturing practices in a more trustless way.[79]

"Our industry's current supply chain models will not be able to meet tomorrow's rapid challenges. This is going to require companies in the sector to develop new capabilities of working together."

PAUL COCUZZO
Director of Supply Chain IT
Merck & Co. Inc.

Cocuzzo is proactively thinking through the industry's serialization improvements:

Our industry's current supply chain models will not be able to meet tomorrow's rapid challenges. This is going to require companies in the sector to develop new capabilities of working together. Without a global standard, tackling the challenges of product complexity, global reach, and improved supply chain safety will be significantly more costly and arduous for our industry. By learning from our initial blockchain pilot experience, I believe the governance structures within blockchain is promising, for finding that global standard.[80]

To reap the full potential benefits, Merck's blockchain pilot team is now eager to work with different players on the improvement of this emerging technology.

The problems Merck is addressing with its blockchain pilot

Supply chain challenges

- Creating trustless access to relevant supply chain transaction data with internal and external stakeholders for systems to interoperate, which would result in better supply and demand planning, and preemptively remediate negative events
- Identifying and sharing safety events more transparently to reduce their occurence and repetition
- Leveraging IoT device networks within the supply chain that's communicating key, sensitive information in a scalable and cost-effective manner
- Improving supply chain efficiency by reducing human latency
- Proactively leading sample projects that exhibit how blockchain could be a component of global serialization standards

Business challenges

- Ensuring that industry stakeholders understand, embrace, and collaborate on the advantages of decentralized technology
- Involving other industry partners (government, suppliers, and even competitors) in the direction of trustless supply chain collaboration
- Forming consortium efforts with industry partners
- Building internal knowledge of decentralized applications and blockchain development within Merck's manufacturing IT teams

The primary use case for this foundational system was to securely encrypt, delegate, store, and retrieve highly sensitive documents.

The pilot blockchain project focused on a communication layer that enabled Merck employees to share sensitive safety information within the company in a more secure and trustless manner than that of traditional applications. The primary use case for this foundational system was to securely encrypt, delegate, store, and retrieve highly sensitive documents.

The project was also an opportunity to validate the use case among employees, explore a new technology stack, and provide a partial training exercise for the entities involved and their participating personnel.

John Fitch, of Animal Ventures, who led the project's product development, said,

> *We worked with Merck to choose a small use case that we could build in three months. This was important to not only get a blockchain-enabled product into users' hands quickly; it was also so that the leadership within Merck could gain real experience in designing, building, testing, and integrating decentralized applications. There is a lot of stigma around blockchain, and quickly building a lean product showcased to Merck's leadership the tremendous opportunities connected to smart contracts, machine trust, and automating business logic. After tackling a small, successful pilot that addressed an immediate need of the company, the entire team now has increased confidence in pursuing larger supply chain use cases.*[81]

In just three months, Merck's IT leadership had a clear understanding of decentralized applications. Cocuzzo, who managed the integration implications of the experiment, maintained that

> *The practitioner level is where real innovation is happening. By building out a pilot like ours, you realize this is not vaporware powered by imagination. This is real technology where we can start to solve a specific business problem that we have agreed on. In the course of solving a specific problem, you also get a real opportunity to learn and reflect on what are the opportunities you have not even thought about. These small experiments are an ongoing source of clarity.*[82]

"There is a lot of stigma around blockchain, and quickly building a lean product showcased to Merck's leadership the tremendous opportunities connected to smart contracts, machine trust, and automating business logic."

JOHN FITCH
Researcher
Animal Ventures

The completed product gave Craig Kennedy's leadership team something to show others how Merck could expand into other practical pilot programs. This influence is part of innovation. Kennedy said, "It is easy to prove two computers or Ethereum wallets operating in a trustless form, but first you have to show the people you work with that trustless is OK to operate in. Experimenting in that way allowed us to prove internally that we could maintain control, privacy, and confidence without having to trust."[83]

The solution's high-level architecture was designed to be generic enough for multiple kinds of users, and this was for good reason. The initial use case is the first hurdle in Merck's larger vision. Kennedy compared the process to lining up dominoes (Figure 9):

> *Our first domino … was building a communication layer that we could leverage internally, and increase the frequency of sensitive information being shared. The second domino is to build off of our internal trust and allow us to partner [with] a government or a key player in our supply chain and collaborate on supply chain improvement. After connecting external partners, the third domino is to extend the user base of the solution to smart devices within our supply chain. Once we have those components contributing to a collaborative supply chain network, we can extend into huge opportunities that are connected to cognitive asset chains.*[84]

"Breaking down smart contracts to both business and IT professionals usually leads to a breakthrough moment: suddenly they both understand the potential of business automation and how this changes all aspects of IT management."

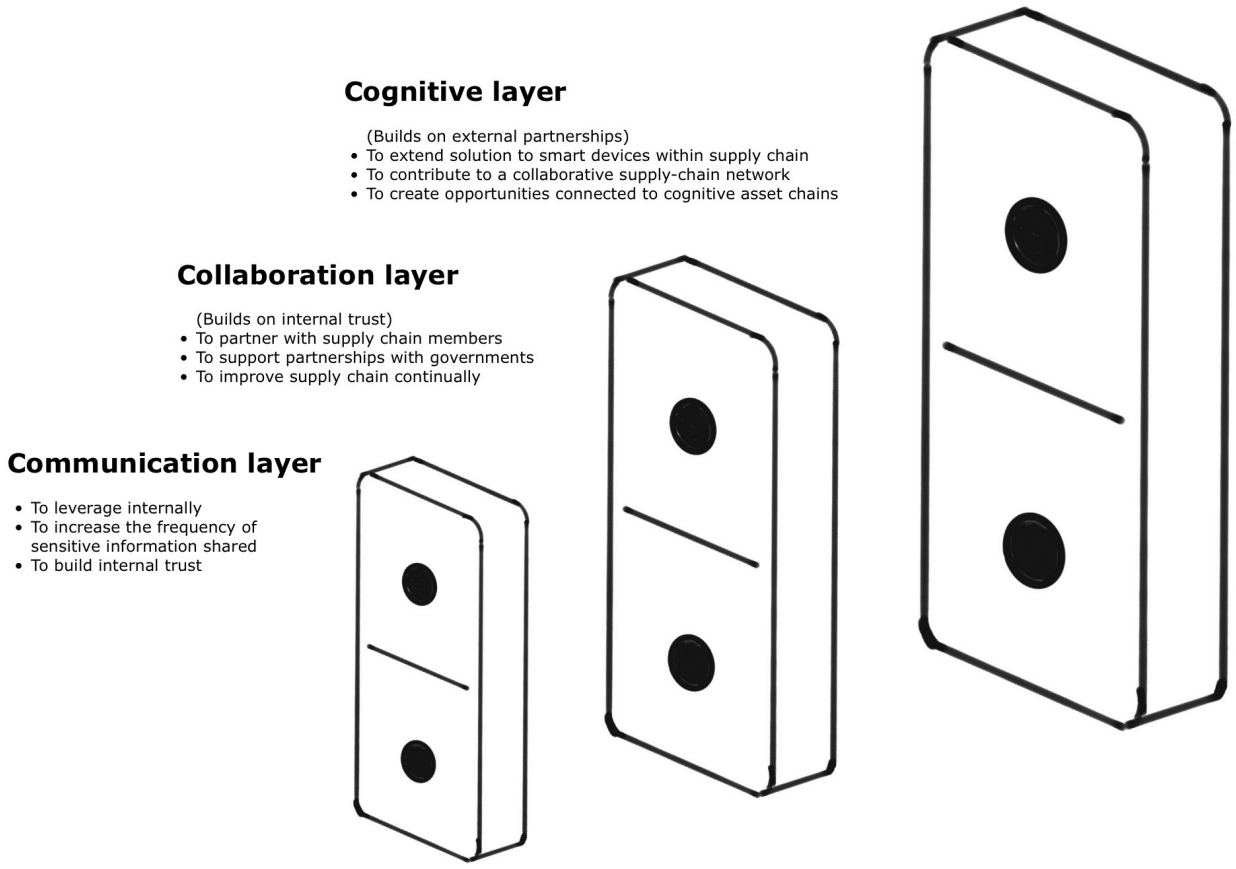
JOHN FITCH
Researcher
Animal Ventures

How is blockchain involved?

The pilot was an Ethereum-based decentralized application. The team built a Merck user interface on top of emerging secret-store components, access control smart contracts, and other middleware libraries provided by Parity Technologies. Although the project's technology stack served well, Merck will be blockchain agnostic and work with various technology partners as the industry evolves. Fitch noted,

> *Building our pilot gave everyone involved exposure to smart contracts and new architecture paradigms that would be hard to grasp without getting your hands dirty in a product build. We also utilized IPFS [InterPlanetary File System] and other decentralized solutions that quickly exposed the team to cutting-edge technical opportunities in the market. Breaking down smart contracts to both business and IT professionals usually leads to a breakthrough moment: suddenly they both understand the potential of business automation and how this changes all aspects of IT management.*[85]

Figure 9: Merck's pilot: Lining up the dominoes toward its long-term goal



Though the project was based in blockchain, the team is considering how that foundation supports the potential for consortium networks and AI-powered machines.

A snapshot of possibilities for Merck

Opportunities: Connection, continuity, and standardization

» **Supply chains that are proactive.** Kennedy believes that the flow of goods without interruption, interference, and disruption can be increased in an asset chain-enabled environment: "It is powerful to imagine when we can deploy asset chains which are all capable of making decisions and notifications on the fly—faster, safer, and smarter than we can."[86] He also believes they can connect otherwise disconnected chains of processes (payment, access, information sharing, etc.), which currently have no means of connecting, through a more trustless environment. Elaborating on future use, Kennedy said,

You can take these solutions beyond human users, and then join with intelligent assets like refrigerators that can dispense product, shipping containers that know what is happening to them and their belongings, and drones that can deliver based on demands found on the asset chain's network state.[87]

» **Supply chains that rapidly adapt.** In the summer of 2016, Merck experienced a severe ransomware attack that illuminated their need for smarter supply chain components that decrease product-flow interruption when something unexpected occurs. Kennedy noted,

The importance of supply chain … has been heightened by the cyber-attack. It has become strongly recognized that a robust, fully functioning, lean, agile, and intelligent supply chain is required to ensure that the company maintains its value-promise even in a cyber-attack. If anything, supply chain innovation has become more important to our company. Our job is not only pushing the boundaries of efficiency, but also the innovation to respond to external circumstances.[88]

Our job is not only pushing the boundaries of efficiency, but also the innovation to respond to external circumstances.

» **A path toward a serialization standard.** Cocuzzo is hopeful that we can improve the current pharmaceutical industry serialization models:

The two predominant models for serialization are the bookend model and full track-and-trace. … Each government that has introduced serialization is investing into one of those two models. Europe is bookend, and other countries have moved toward track-and-trace. Regardless of what happens, the reason I believe in a blockchain-based serialization model is that two existing models are not sustainable, given the complexities ahead and added costs we haven't even considered yet.[89]

Cocuzzo believes in a shared global infrastructure and operating practice for serialization because entities could learn from each other via technologies that contribute in a trustless and secure way. He said,

> *It will allow the industry to understand how products move from manufacturer to patient, and how to improve the supply chain itself. If the rate of product movement through the supply chain is not what we hoped for, we can analyze many factors given a collaborative network state. Each company can now individually do this kind of analysis within parts of their supply chains, but having a global source where we can all assess and create new opportunities affords the ability to interrogate a global supply chain with new questions.*[90]

Merck introduces more than one billion products each year, which means that with those products come a massive volume of robust active data. The knowledge gained from this data is critical to supply chain innovation but it is difficult to fully leverage if the data doesn't flow seamlessly from country to country

Challenges: Convincing skeptics and thinking big

» **Industry buy-in and skepticism.** Merck's supply chain leadership believes that the main hurdle is inviting partners to participate in their ongoing developments, since many will wonder, "What's in it for me?" The business outcome must be compelling. Kennedy accepts the challenge:

> *What I will talk to them about is that transparency between the partners (without trust) and how the transparency will have a positive impact on our businesses. If you join us, we will be even easier to work with. I can share things with you now that I couldn't before. We will discover things that would make our business move faster and add to more material flow.*[91]

Merck's supply chain leadership believes that the main hurdle is inviting partners to participate in their ongoing developments, since many will wonder, "What's in it for me?"

» **Small-scale thinking.** Lustig is concerned that in the case of these emerging technologies industry partners are assessing incremental value, not long-term. Instead of putting blockchain and other technologies in a box, pharmaceutical supply chain companies should re-engineer how they operate. He said,

> *By having all of us critical partners collaborating early in the experiments, we can transition into a new world rather than trying to define exactly how it works before the technology actually reaches its full potential. We will need to approach our collaboration with a long-term perspective and be prepared to overcome initial hurdles to lay the groundwork for supply chain improvement.*[92]

Broader considerations for industry coalition building

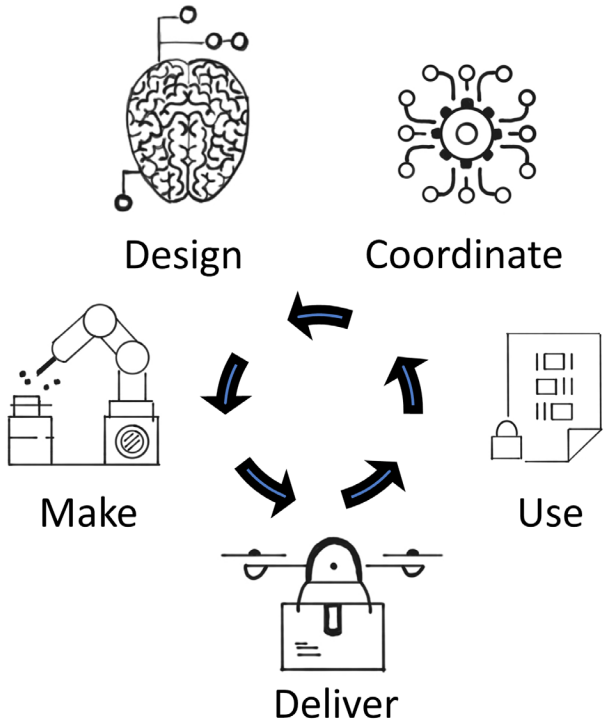
Large companies with sprawling supply chains are facing significant regulatory pressure to move toward transparent networks. This move requires greater industry collaboration and coalition-building beyond the pharmaceutical industry; it includes food and agriculture, extractive industries, and even luxury goods.

Asset chains and the longer-term outcomes derived from their implementation and integration into global cognitive supply chain networks further reinforces the importance of acquiring talent.

Business implications of asset chains: Value creation at every stage

Asset chains and the longer-term outcomes derived from their implementation and integration into global cognitive supply chain networks further reinforces the importance of acquiring talent. Let's evaluate the challenges and value-creation opportunities of asset chains within the design, make, deliver, use, and coordinate functions (Figure 10).

Figure 10: Five stages of the supply chain



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Design: Learning to learn and unlearn

The World Trade Organization defines intellectual property as creations of the mind.[93] We believe that *design is the act of creation or innovation*, and that, as humans move from intermediary roles in supply chain management and marketplace optimization to the edges of the network where design becomes the competitive cornerstone of value creation, creation and innovation will drive the future.

The companies of the future will need to transform into highly optimized learning machines to produce creations of the mind, primarily a derivative of human cognition.

Kevin Kelly told us,

> *We're all very proud that we've mastered the smartphone, but in five years there's going to be a whole 'nother thing that we're going to have to learn: new gestures, new shortcuts, new framings, new metaphors, new languages, … and that's going to keep going on, and on, and on. If you're very young, you're going to be constantly having to learn, and, more importantly, unlearn what you already knew. I think that the primary skill education should be imparting is the ability to learn how to learn something, because that's what you're going to be doing, and that's what your livelihood and happiness will depend on, in some cases: your ability to keep learning all your life.*[94]

The companies of the future will need to transform into highly optimized learning machines to *produce* creations of the mind, primarily a derivative of *human* cognition.

If intellectual property is the bellwether of value creation in the decentralized economy, we must consider how asset chains can help harness and extract that value as inputs into our new cognitive supply chains.

Protecting intellectual property is difficult, especially in the dark web of pirated software and with the copy-and-paste structure of the Internet.

Blockchain is different. It allows us to create *truly unique* digital things that *cannot* be copied because they have an immutable record, like a fingerprint, etched into a digital token that travels with them from the moment of their birth.

The blockchain hashing system and its integration with cryptography allow for the traceability of a product's provenance. This hash is similar to a hyperlink address that points back to a thing's birth. Unlike a hyperlink address (which is just an address for a location that can change), a blockchain hash points to a thing's *original* context. If the *current* context has been altered in even the slightest way, the hash will no longer reference the original context and not be the same thing.

We can now apply this same affordance to physical things. We can already make unique physical things based on unique physical

differences, such as a fingerprint, or, in the case of something manufactured, identifiers on a product that make it original. We can reference these unique characteristics of a physical thing and pair them with unique tokens on a blockchain. Multiple technology providers are pursuing this digital twinning to provide provenance records.

How do we protect intellectual property, certify authenticity, and provide provenance traceability in the future of additive manufacturing?

As we print products through additive manufacturing, we can give them unique characteristics during the process, and pair them with digital tokens to validate the authenticity of what was printed. We can use the same technology to validate the provenance and authenticity of a digital file.

Finally, through smart contracts, we can turn both physical and digital things into smart assets—assets that have their own digital rules. For example, if a manufacturer had a license to print only 100 physical copies of a design, the associated digital token would prohibit the printing of more units unless the manufacturer pays for an upgrade to the next purchase tier or switches to a more expensive cost-per-print model. Asset chains will provide these kinds of affordances in the future of supply chain.

In the definition of intellectual property—*creations of the mind*—the key phrase is "of the mind," meaning, "of the *human* mind." Super-human intelligence (or truly *conscious* artificial intelligence) is much further off than some believe. Today's headlines that refer to artificial intelligence are actually referring to the smart algorithms that already exist to *augment* human intelligence.

If highly optimized cognitive supply chains are able to manage the making and delivering of products, then we could be entering a period in which the human ability to create and innovate accelerates creative output. We could test theories and ideas faster, and the design-thinking process and our ability to learn could develop together.

We need design thinking that leverages augmented intelligence and lawyer–coders who will drive the future of compliance innovation.

Design will need to cover not just new IP, but also customized products that match differing regulatory standards across jurisdictions, cultures, and values. As the volume of intellectual property increases, we'll need lawyer–coders to manage the use and implementation of smart contracts, and the licensing arrangements necessary to govern the usage and value of these new smart assets. These lawyer–coders will also be intimately involved with the creation and management of business protocols that govern the overall supply chain entity.

Make: What we need, where and when we need it

The production process for most finished goods is changing faster every day, no matter the industry, because of technological advances in additive manufacturing, robotics, and connected devices. We need to overhaul how we manage making things.

While businesses have been using 3D printers to support the prototyping process for some time, most industries are moving toward 3D printing for "on-demand" *finished* goods. The healthcare industry is already starting to use the technology to print pharmaceuticals and prosthetics; it also dreams of printing human tissue.

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New tech-centric food-start-ups such as Hampton Creek are experimenting with different kinds of plant products to create a multitude of food options, such as using a plant to make something that looks, tastes, and feels like eggs.[95] In the future, we will need mass quantities of printable-food formulas. Companies such as Natural Machines are working on the on-demand 3D printing of food.[96]

Sweetbridge's Scott Nelson said, "You can now anchor a supply chain with the ultimate producer and the ultimate consumer. Frankly, that's where all the assets are. All the stuff in between is either going to be simplified or eliminated altogether."[97] Additive manufacturing is eliminating entire supply chains, shipping and logistical systems, and manufacturing centers that provide support for these more traditional *make* supply chains.

Prime contractors will soon divest themselves from many of the traditional supply chain complications and costs, thereby reducing many of the financial risks that come from maintaining highly responsive or efficient supply chains. Lead times will fall dramatically, giving companies an opportunity to innovate faster, cheaper, and more frequently, and bring experimental products to market sooner. Supply chains will balance responsiveness and efficiency simultaneously.

"You can now anchor a supply chain with the ultimate producer and the ultimate consumer. Frankly, that's where all the assets are. All the stuff in between is either going to be simplified or eliminated altogether."

SCOTT NELSON
Founder and CEO
Sweetbridge Inc.

Eventually, point-of-need or point-of-use products will dominate the marketplace. Without so many intermediaries, many supply chains will be less complex. We'll be able to print what we need when we need it, and use AI and robotics to assemble most of our end-use products.

Deliver: With speed, at scale, and using robots

Once we have designed and made a product, we need to move it from point A to point B quickly and securely to maintain good supplier-contractor partnerships. In the decentralized economy, suppliers will need to deliver products at scale and with speed—not just on demand but more localized. To cite Kevin Kelly, the cost of production has often been about labor, but it is increasingly about transportation.[98] To drive efficiency and low cost, our horizontal supply chains have been outsourcing work to diverse nations. As labor shifts to robots, competitive advantage will come from delivering better products faster. Through connected devices and AI, companies will get better at knowing their customers.

For example, Walmart has tightened its shipping window from four days to two, and penalized suppliers for repeat delays.[99] Amazon is

According to Kevin Kelly, the cost of production has often been about labor, but it is increasingly about transportation. In the decentralized economy, suppliers will need to deliver products at scale, with speed, on demand, and localized.

exploring such innovations as floating-drone hive-warehouses and 3D printing-capable delivery trucks. Postmates is leveraging human gig workers to carry items from one location to another. Trucking companies are exploring autonomous vehicles. Zume Pizza is experimenting with autonomous pizza-delivery trucks, where robots make and heat pizza while en route to their delivery location.[100] Transportation and logistics companies are investing in blockchain methods to increase utilization and logistics efficiencies across their systems. International shipping giant Maersk and the ports of Antwerp and Rotterdam are working on logistics projects using blockchain to address container capacity, custodianship, storage, and transfer of goods. As transportation and logistics improve delivery, asset chains will connect these systems into a shared value network.

Use: Self-policing, self-compliance from origin to end use

Historically, vendors have been hard-pressed to guarantee authenticity of product to their customers. Legislation and collective action—for instance, by the US Bureau of Consumer Protection—have worked to ensure recalls or remuneration for fraudulent company practices, but these initiatives focus on damage control, not prevention. Today, individual and enterprise consumers want not only authenticity of product; they want complete transparency of provenance. Asset chains can make these assurances possible.

Supply chains will become self-policing as they will comply with various laws, rules, and objectives—often referred to as "compliance"—and based on provenance traceability. Many highly regulated, supply chain dependent industries (e.g., aerospace, pharmaceuticals, and food) will have an opportunity to drive compliance innovation. These industries are under increasing pressure from new and existing global regulations—such as the US Federal Acquisition Regulations and US Food and Drug Administration and EU serialization mandates—which already require provenance data for parts used in federal contracts, the tracking and tracing of drugs and food, and so forth. Global regulations are demanding innovation that helps to drive technological integration and open up otherwise closed market spaces. Perfect harmonization across borders is far away, but there is great benefit to leveraging asset chains as a technology implementation that could marry interoperability of global supply chains with regulatory and jurisdictional idiosyncrasies on products and their use.

Asset chains will also shrink the use of paper in a product's paper trail. Tracking the origin of a product typically requires heavy paperwork, and heavy auditing of that paperwork. Supply chains that involve additive manufacturing may take only two days to 3D-print a metal part, but two weeks to complete the paperwork.[101] Now, using tokens, they can store paper trails digitally, immutably, and verifiably. They can track critical, real-world components from origin to use by blockchain technology, which simultaneously certifies compliance to allow stronger cases for use of a product. Think *fair trade* or

organic labels, except the consumer would have visibility from "dirt to shirt," so to speak, and certainty of the product's authenticity. Consider companies such as L'Oréal and Lufthansa: L'Oréal is building internal blockchain projects that help certify its branded products, and Lufthansa's Blockchain 4 Aviation Initiative is getting close to tracking repaired assets.[102] Lufthansa's project involves moving commercial aircraft maintenance, repair, and overhaul (MRO) records to a blockchain, particularly for life-limited parts that involve multiple repair parties and require stringent documentation requirements.[103] In the future, technicians and suppliers will also certify installations or review faulty products via virtual or augmented reality-based "call desk" that offers assistance from afar.

L'Oréal is building internal blockchain projects that help certify its branded products, and Lufthansa's Blockchain 4 Aviation Initiative is getting close to tracking repaired assets.

Utilization of products across supply chains is another concern. For some time, the latent value of assets has been locked up or impossible to exchange. Today, we cannot easily barter non-equivalent items, and so we rely on money as an intermediary value. With tokenized assets, however, we will be able to unlock and trade valuable assets, from grain to warehouse space, in a supply chain. "Once you can quantify the values of assets [factory, etc.] and compare them," said Sweetbridge's Scott Nelson, "then you can actually turn the assets into something you can share. In high-change environments, that means you can optimize the asset way better."[104] Asset chains enable us to build entirely new marketplaces on top of supply chains, and create entirely new value out of the use of those assets, value that we can then leverage.

Coordinate: How best to manage supply chains

Managers have long coordinated supply chains in silos. Sophisticated and highly optimized enterprise solutions for tracking and managing supply chain systems do exist, but they remain enterprise-centric at best and optimized for a company's internal activities and return on assets.

Asset chains enable the formation of a new method of management that could finally create a single source of supply chain state, or a global universal truth for accounting and supply chain state. New inter-enterprise asset accounting systems. With this new method, firms could sit atop a global asset chain that would provide universal visibility into the state of all assets and parties in a supply chain—an inter-enterprise asset accounting system.

Coordination via asset chains is the potential gateway for the achievement of true economic equilibrium, where supply and demand are equal.

We don't use such a system because we simply don't trust one another. We exploit information asymmetries for competitiveness. In a decentralized economy, competitiveness will rely less upon optimization and more upon access to high-quality human capital. We can leverage the convergence of AI, the IoT, and blockchain technologies in asset chains to maximize efficiency and responsiveness at the same time. Coordination via asset chains is the potential gateway for the achievement of true economic equilibrium, where supply and demand are equal. This equilibrium is, in many ways, the perfect realization of the capitalist market model.

For example, a supply chain that handles high-value goods, such as military aircraft or vaccines, would optimize for a responsive supply chain to meet customer demand quickly. Faster responsiveness has required a greater level of transparency in a supply chain, to know how best to meet changing conditions and for better state-management. However, a supply chain that handles lower-value goods, such as grains, for which the demand cycle is relatively stable and predictable, would choose to optimize for efficiency, and find ways to smooth its supply chain and eliminate costs.

A company's tactic, whether it chooses responsiveness or efficiency, has traditionally defined its competitive advantage, and would therefore require confidentiality to protect that advantage. A supply chain that is simultaneously responsive and efficient for economic equilibrium and profit maximization currently does not exist, but the combination of additive manufacturing, blockchain technology, and artificial intelligence via asset chains makes it possible.

As we can see, there are critical combinations for unlocking new value across a supply chain's design, make, deliver, use, and coordinate functions. In each of these functions, asset chains give

Table 3: Ways to create value at every stage of the supply chain

Stage	Action items
Design	Cultivate design thinking Leverage artificial intelligence Reimagine IP rights management Reimagine role of supply-chain auditors Prepare for the need for lawyer–coders
Make	Overhaul management of manufacturing Deploy additive manufacturing, robotics, and connected devices Prototype both products *and* processes Anchor a supply chain with the ultimate producer and consumer
Deliver	Tighten shipping windows Explore warehouse management innovation (floating-drone hive) Explore delivery vehicle innovation (3D printing, autonomous) Leverage human gig workers Use blockchain for custodianship and transfer of goods
Use	Drive compliance innovation across jurisdictions Shrink use of paperwork in the mutable paper trail of products Track mission-critical components from origin through use via blockchain Deploy virtual or augmented reality-based customer service Tokenize assets to unlock and trade valuable assets in a supply chain
Coordinate	Form new inter-enterprise accounting systems for assets Leverage the convergence of AI, IoT, and blockchain technologies Coordinate via asset chains to maximize efficiency and responsiveness

us the ability to bind procurement with contracting, and governance with compliance, which will create not only new assets, but also new ways of managing our machines, people, and ideas.

Ten observations about the decentralized economy

From our research on the technological forces catalyzing decentralization, cognitive supply chains, and smart assets, from the projects we have discussed to the people we have interviewed, we have distilled ten primary observations. Our goal in sharing them here is to help readers push past existing phenomena to start seeing the emerging realities. We recommend incorporating each of these into individual and organizational strategies for generating value in the decentralized economy.

1. **The decentralized economy will enable more cognitive supply chains, which will require asset chains to self-govern.**

   We are moving from a scaled one-to-many economic model with partially decentralized marketplaces to a scaled one-to-one economic model with completely decentralized marketplaces. This shift requires autonomous and intelligent supply chains that learn, and supply chains that learn require asset chains to translate autonomously learnings into marketplace optimizations.

   Today's leaders need to reimagine how they design, make, deliver, use, and coordinate their products in light of the decentralization underway. The inevitability of decentralization via AI, asset chains, IoT, and additive manufacturing makes preparation imperative. Leaders should understand why this transition is happening, what technologies are in play, and what the potential implications are to their organization, in terms of potential gains and losses in future value.

Today's leaders need to reimagine how they design, make, deliver, use, and coordinate their products in light of the decentralization underway.

2. **Cognitive supply chains will autonomously and iteratively seek economic equilibrium, perfect responsiveness, perfect efficiency, and profit maximization.**

   All businesses seek economic equilibrium and will invest significant amounts of capital to achieve it. As supply chains and the markets they serve become smarter and richer in data, achieving economic equilibrium will become much less difficult because machines are better and faster than humans at matchmaking, data crunching, and pattern recognition. Asset chains will allow machines to act more autonomously in terms of executing, gathering feedback, incorporating their learnings and re-executing. Until machines can do this, the system will continue

to be hindered by human intermediaries who function as a latency component in the supply chain entity's learning process. Supply chain leaders will need to understand the distinction between intelligence augmentation provided to humans by their current ERP systems and the future in which supply chains act and learn without human involvement.

The future supply chain leader will be surrounded by renewed competitive effort to drive supply chain transparency toward the most accurate network state possible.

3. **Instead of investing in corporate social responsibility programs, businesses will increase investment in human intervention and crisis management as core business functions.**

   Today's leaders see supply chain transparency as a necessary component of corporate social responsibility, and they are right to do so. Customers are increasingly adamant that their favorite brands be positive corporate citizens in the world, and regulation has pushed for greater accountability across supply chains. But as asset chains become more fully implemented into the emerging cognitive supply chain ecosystem, transparency will be necessary to provide a cognitive entity with the *network state* by which machines can make the most precise decisions possible, and execute new and potentially novel commands autonomously.

   As a result, the future supply chain leader will be surrounded by renewed competitive effort to drive supply chain transparency toward the most accurate network state possible. As competitive pressure increases the need for supply chain transparency, an increasing number of adverse supply chain events will likely come to light and need to be managed quickly, humanely, and professionally. As a result, intervention teams and crisis management efforts may also increase alongside these new events.

4. **Value generated by intermediaries will decline significantly as value shifts to the edges of the network.**

   Because of the technological advances in the four forces impacting global supply chain networks (asset chains, IIoT, additive manufacturing, and AI), many of the traditional supply chain businesses between raw material and finished goods will go extinct. Moog, for example, will begin to see its traditional "make" value decrease and its "design" value increase as more of its components move directly from design to point-of-need printing. The value previously generated from the traditional model will shift to other areas.

   Supply chain leaders need to understand where they currently generate value and how new frameworks such as asset chains can generate new value, once intellectual property becomes more valuable. Leaders could focus their "make" workforce on highly specialized design. Moog in particular could consider a "software as a service" business model and license its concepts to aircraft assembly companies.

We recommend this approach not just for aircraft manufacturers but also for leaders in the food, pharmaceutical, healthcare, and energy sectors. All should be asking themselves about the location of their customers and their raw materials in their overall asset chains.

Leaders will need to be extremely good at training, sourcing, and managing potential design talent.

5. Artisans who specialize in some form of design—think of Leonardo da Vinci—will be the most recruited free agents in the decentralized economy.

The decreased need for human intermediaries in supply chain management, and the effect of human latency on how we make, deliver, use, and coordinate the development and flow of products means that the importance of the design function (intellectual property generation) for value creation will increase.

Intellectual property is the direct result of *creations of the mind* and will be human generated, mostly (though potentially AI-assisted in the future). Designers of intellectual property will be highly sought after because of their ownership of the original asset. Talent could include multiple designers who collaborate, as we already see in crowd-generated work. Leaders will need to be extremely good at training, sourcing, and managing potential design talent.

6. The decentralized economy will face a talent shortage of lawyer–coders (smart-contract developers).

Assets, both digital and physical, will have individual governance models, such as a digital CAD file that restricts its own printability because of unique licensing deals; aircraft manufacturers that have accurate provenance and traceability to comply with FAA regulations; certain kinds of health, food, or pharmaceutical products that provide automated compliance management at the unit of sale in its municipal jurisdiction; or autonomous delivery trucks that maintain their own profit and loss statements (P&Ls) and respond to their individual shareholder demands. To properly manage these individual governance models means that supply chain leaders will need to activate, educate, and recruit a new class of employee that merges the lawyer with the programmer: the lawyer-coder.

Leaders will need to activate, educate, and recruit a new class of employee that merges the lawyer with the programmer: the lawyer-coder.

7. The ability to learn and unlearn quickly will be the most coveted skill for people, objects, and entities looking to thrive.

The idea that learning gives one a competitive advantage isn't new. Continuous learning has always been important for harnessing the opportunities of tomorrow. In the decentralized economy, however, we're going to have to learn how to learn—and how to unlearn.[105] The rate at which tools and processes are evolving means that we—people and organizations—must be agile and quick in how we learn. The ability to adjust to changing demands will be paramount to our success in a world in which

artisan IP output partners effectively with highly optimized cognitive supply chains to experiment and deliver product quickly. We need new methods of and investments in learning and unlearning.

8. The ability to build coalitions will become a highly prized leadership quality.

Managing our reputations in the decentralized economy will be imperative, if we are to scale autonomous one-to-one business operations.

Contrary to the concept of *trustlessness* inherent to the decentralized economy, the ability to form alliances and partner with groups to achieve a common purpose will become even more important than it is today. Quantitative metrics or reputation scores assigned to identities operating in a marketplace or supply chain will be a key factor in achieving autonomous one-to-one business operations at scale. They will also help build a consensus on industry-wide protocols for asset chains. As a study by Deloitte on supply chain talent described, the shift of supply chains is one in which "longstanding industries are blurring into ecosystems—dynamic and co-evolving communities of diverse actors who create new value through increasingly productive and sophisticated models of both collaboration and competition."[106] Additionally, managing our reputations in the decentralized economy will be imperative: bad actors in supply chains will be represented by unalterable unique digital tokens in perpetuity.

9. Cognitive supply chains and asset chains will give rise to the next biggest consumer class: robots and AI machines.

Supply chain leaders will need to understand the role of procurement, payment, and contracting in cognitive supply chains. These roles will be distributed to the level of each individual asset.

Procurement leaders will be the protocol managers and smart-contract developers who govern how assets move through supply chains.

As an asset moves, procurement, payment, and contracting will be managed on a machine-by-machine basis. These machines will source intermediary assets autonomously, execute/enforce their own contracts, and manage their own wallets and profits to pay for these activities. While there are machines that can perform some of these basic functions today (think Amazon Dash buttons), the introduction of asset chains will provide the base business protocols by which machines can execute these functions autonomously, without the need for human intermediaries or banks. This means that robots and AIs will become some of the largest purchasing agents in the world, with budgeting and purchasing power that far exceeds the capability of most of today's procurement specialists.

Procurement leaders will be the protocol managers and smart-contract developers who govern the ways in which assets move through cognitive supply chains. They will curate how we do business in an autonomous and cognitive ecosystem.

Liquidity will be the most important performance metric for determining the health and viability of a marketplace.

10. Liquidity, discovery, and trust will still define what makes the best marketplace.

While the tactics and technologies by which we optimize these basic principles might change at faster intervals, such as autonomous intervention by machines, the principles themselves will remain. Therefore, when supply chain leaders respond to these new marketplaces and new economic pressures, they should continue to solve for liquidity, discovery, and trust. Liquidity will be the most important performance metric for determining the health and viability of a marketplace.

Recommendations for leaders

How do we achieve a world filled with asset chains? The transition concerns many companies in terms of how it will affect business, and knowing at which stage to begin implementing any changes. Quentin Roach, chief procurement officer of Merck, said,

> *There are tremendous opportunities for companies to learn from the disrupters and innovators utilizing leading-edge technologies such as blockchain, IoT, AI, and machine learning. Companies have a responsibility to look at new technologies and find ways to improve the efficacy and efficiency of how they are working today, and how these new technologies can lead to better ways to serve customers or expand product offerings or solutions. We are seeing an impact not just in how we utilize these technology advancements, but also in how our people engage, collaborate, and inspire innovation in other areas.*[107]

Companies will likely begin to incorporate blockchain technology locally via private networks. These networks may be company or industry-specific, which would offer the benefits of a shared reality (a shared network state) without releasing much of the confidential or proprietary information that drives competition. Companies could eventually publish certain data-feeds to public networks or transition to a public network once technological advances solve for confidentiality concerns. Blockchain network developers are already charting new paths forward in cryptography (such as homomorphic encryption and zero knowledge proofs) and distributed-systems design, which will allow varying modules of on- and off-chain information to contribute to network state while protecting individual data.

For example, the Metropolis release of the Ethereum blockchain includes the ability to send private transactions over the main network using zero knowledge Succinct Non-interactive ARgument of Knowledge (zk-SNARK) encryption technology.[108] This will enable private transactions to occur in both public and private chains. In

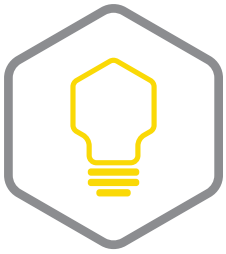
its future releases, outlined in the Plasma whitepaper co-authored by Vitalik Buterin and Joseph Poon, Ethereum will allow private chains to communicate with the root Ethereum network, and even allow for sub-chains.[109] This means we could implement a private proof-of-authority chain that only communicates encrypted data with authorized nodes using existing technologies, and hide the data through inter-chain sharing protocols.

Soon economic equilibrium will be an actual state achievable through decentralized and autonomous asset chains.

Private chains are an important stepping stone for companies willing to innovate and leverage emerging technology early in their supply chains. But we need the development of a universal network state for all global supply chain activities to eliminate the "dark holes" that exist across today's supply chains.

We opened this paper with the idea that decentralization of production and consumption will bring about economic equilibrium, where supply equals demand, and trade is one to one at scale.

Supply chains have been optimizing via emerging technologies such as AI and the IIoT. Blockchain takes optimization one step further. Soon economic equilibrium will no longer be a theory on a chalkboard, but an actual state achievable in the market through decentralized asset chains. It is already visible in almost every industry that constantly monitors the proper and accurate allocation of resources in managing a global supply chain—food, defense and aerospace, energy, pharmaceuticals, and more. Very soon, supply chains will no longer have vertical or horizontal structures for product actualization. They will be autonomous, decentralized webs that comprise the emerging decentralized and tokenized economy.



About the authors

Tom Serres and Bettina Warburg are co-founders of Animal Ventures, a prototyping studio and consultancy focused on building start-ups, educating executives, and designing detailed strategies to help large companies, governments, and small to medium enterprises take advantage of some of the most advanced technologies coming to market: blockchain, artificial and augmented intelligence, and the Internet of Things. Their premier online course, "The Basics of Blockchain," has grown to nearly 4,000 students across 101 countries since its launch in 2016. In 2017, Animal Ventures will launch an entirely new educational series for executives and software engineers. Animal Ventures also produces the show, "Tech on Politics," which features interviews with some of the world's top innovators, entrepreneurs, tech pioneers, luminaries, and political operatives at the intersection of politics, technology, and governance. Season 1 has over 250,000 downloads, and Season 2 will be released in the fall of 2017. Tom and Bettina are regular speakers and educators on blockchain, the decentralized economy, cognitive supply chains, and other emergent technologies.

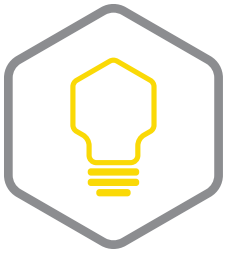
At TEDSummit 2016 in Banff, Bettina was one the first speakers to unpack the topic of blockchain to a global audience. Her talk, "How the blockchain will radically transform the economy," has over two million views.

Tom is a seasoned entrepreneur, public speaker, and technology executive. In June 2012, Tom made history by raising $7.9 million in Series A venture capital funding entirely online for Rally, his first company. In 2013, Tom was named one of America's Most Promising CEOs under 35 by *Forbes Magazine*. In a few short years, Rally has hosted 70,000 organizations and grown to nearly one billion dollars in fundraising volume.

Our research team included research leads Vangelis Andrikopoulos and Nicolas Walker, who managed additional research contributions and interviews by Collin Cusce, John Fitch, Travis Kupp, Lindsea Wilbur, Tate Ryan-Mosley, and Birgitte Krohn.

Disclosures

Animal Ventures is paid for its blockchain consulting and implementation work with Merck & Co. Team members have low-level holdings of various cryptocurrencies, remain agnostic in terms of blockchain technology implementations and partners, and choose to work across the emerging ecosystem.



About the Blockchain Research Institute

Co-founded in 2017 by Don and Alex Tapscott, the Blockchain Research Institute is a knowledge network organized to help realize the new promise of the digital economy. It builds on their yearlong investigation of distributed ledger technology, which culminated in the publication of their critically acclaimed book, *Blockchain Revolution* (Portfolio|Penguin).

Our syndicated research program, which is funded by major corporations and government agencies, aims to fill a large gap in the global understanding of blockchain technology and its strategic implications for business, government, and society.

Our global team of blockchain experts is dedicated to exploring, understanding, documenting, and informing leaders of the market opportunities and implementation challenges of this nascent technology.

Research areas include financial services, manufacturing, retail, energy and resources, technology, media, telecommunications, healthcare, and government as well as the management of organizations, the transformation of the corporation, and the regulation of innovation. We also explore blockchain's potential role in the Internet of Things, robotics and autonomous machines, artificial intelligence, and other emerging technologies.

Our findings are initially proprietary to our members and are ultimately released under a Creative Commons license to help achieve our mission. To find out more, please visit www.blockchainresearchinstitute.org.

Leadership team

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Notes

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