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Continuous interconnected supply chain
Using Blockchain & Internet-of-Things in
supply chain traceability

Contents

Introduction

Would you be able to cite a major supply chain scandal? You most probably could, and quickly, as many have been broadcast in the press, denting the reputation and costing millions to the involved firms.

While notions of transparency, fair trade, and sustainability are gaining importance in customers' purchasing decisions, most businesses must deal with complex and non-integrated supply chain networks. This prevents comprehensive and efficient end-to-end traceability and surveillance along the chain.

Nevertheless, development of new technologies will support industries in resolving parts of the challenges they face. Among others, Distributed Ledger Technologies (more commonly known as blockchain technology) and the Internet-of-Things (IoT) have the potential to solve important glitches in traceability and provenance challenges.

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A weak link

In Deloitte's 2013 Global Supply Chain Risk Survey, companies called attention to their difficulty in having to manage sudden demand changes and margin erosion, mostly because they lack the latest tools. One of their biggest concerns related to the risks inherent in their extended supply chain (i.e. their suppliers operations) are due to visibility shortages. Indeed, companies are often struggling when it comes to mastering procurement and information flows within their tiers, having no choice but to trust their stakeholders—both internal and external. While a majority of firms are using outsourcing as a business leverage, most companies fail when trying to find a way to have reliable visibility over their entire supply chains while limiting the dependence on one or several stakeholders.

Most straight-forward examples of traceability breaches or frauds are easily found in the food or the car manufacturing industries. Due to recalls or sales losses, their financial impacts can top US$100 million. Nevertheless, beyond preventing scandals and huge fines, making supply chain information more reliable is becoming a key challenge for the industry.

By its intrinsic properties, an IoT-enabled blockchain can address these visibility and traceability challenges. Breakthrough blockchain technology enables companies to record every event or transaction within a supply chain on a distributed ledger. This ledger is shared among all participants, not owned by any, and records events and transactions in a secure, immutable, and irrevocable way.
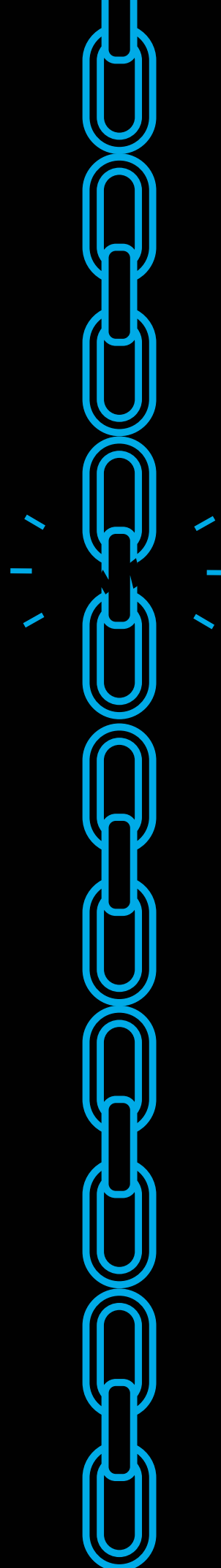
Blockchain to the rescue

Blockchain technology grabbed the public's attention when its cryptocurrency shook the financial services industry. Now we hear the technology expanding to new territories such as art, healthcare, energy, telecommunications, and supply chain. Today, blockchain also stands as gatekeeper in the emerging "trust economy," in which supply chain plays a central role. The efficiency of a supply chain relies on trust between the different stakeholders and the interaction between blockchain and IoT technologies can assist in increasing the traceability and reliability of information along the chain.

Globally, blockchain technology offers a way to record transactions or any digital interaction that is designed to be secure, transparent, highly resistant to outages, auditable, and efficient.

Technically, a blockchain is a digital, distributed transaction ledger that is stored and maintained on multiple systems belonging to multiple entities sharing identical information. This creates a web that shares the responsibility of storing, maintaining, and, more importantly, validating the information present on the blockchain. Any authorized participant can review entries and users can update information stored on the blockchain only if the network consensus algorithm validates it. Information stored in a blockchain can never be deleted and serves as a verifiable and accurate record of every transaction made within the ledger.

Blockchain technology can be summarized into four key characteristics on which it builds its reputation:

Fast transaction settlement

- Transactions are processed directly from peer to peer with fewer intermediaries

- Ledgers are automatically updated

- Both sides of the transaction are executed simultaneously

Low cost

- Resources used to validate transactions are mainly computing power that cost less than traditional man power

- Less use of intermediaries

- No reconciliation work is required

Transparent and auditable

- Blockchain is an open-source technology

- All transactions are visible to authorized participants and traceable within the ledger

- All accounts are identifiable on a pseudo-anonymous basis

Reliable

- Blockchain technology is resilient and does not have any single point of failure

- Transactions processed in the blockchain are immutable and irrevocable

These functions serve as an introduction to increasing the potential for innovation in every major industry. In supply chain, these characteristics help to reduce the number of intermediaries, including the former keepers of trust along the chain. This will increase efficiency and reduce overall costs.

Digital fusion

Along with blockchain technology, IoT is one of today's most hyped themes and stands as a preeminent topic of the beginning of this century. It represents a myriad of technologies and devices that can be associated with almost any aspect of life or business, from entertainment to government-level security. Linking it back to supply chain, it can and will be a formidable transformative force to address the bottom line by improved efficiency and traceability, as well as introducing greater differentiation and innovation.

Along with blockchain technology, IoT is one of today's most hyped themes and stands as a preeminent topic of the beginning of this century.

The main purpose of IoT is to link the physical world with the digital world. The process is quite simple:

1. Collect data from real-world objects

2. Communicate and aggregate those data into information

3. Present clear results to systems or users so that decisions can be made or object behavior adapted

Two main families of IoT devices exist:

- **Things** – These are devices attached to an object, or independent devices that can behave autonomously. They are connected to a network, permanently or temporarily, and collect and communicate intrinsic information about their identity, their behavior, their geolocation, and more. Some of them are able to receive instructions to adapt their behavior.

- **Sensors or beacons** – These are devices that take extrinsic measurements of behavioral or environmental conditions, such as speed, acceleration, temperature, humidity, lights, sounds, etc. They can be attached to moving objects or fixed in place.

Things and sensors work together in various ways, depending on the application. For instance, an RFID chip can be attached to a parcel to identify it. Together they are the "Thing." When it goes out of a warehouse, a sensor positioned at the gate detects the parcel and sends a signal over the network that the parcel has left the building.

IoT is not just the devices. For the concept to work, an entire infrastructure is deployed:

- **Sensors and Things**
  Sensors create the data that is sent downstream to subsequent layers of the architecture, enabling the "Things" in IoT.

- **Networks**
  The network is the connectivity layer that communicates data from the sensors and connects it to the internet. It can be broken down into the hardware, software, and protocols that enable this transfer of information from the sensor layer to the integration layer. This layer includes network gateways that help communicate data from devices to the cloud, and perform data formatting and protocol translation.

- **Integration**
  The integration layer is the linchpin of the architecture, managing the sensor and network elements, aggregating the sensor data from the first two layers, integrating it with other external data sources, and accumulating it for the analysis that occurs in the augmented intelligence layer.

- **Augmented intelligence**
  The augmented intelligence layer takes raw data from sensors and external data sources and processes it into actionable insights based on analysis. Two variants of this information flow are data in motion (for real-time, perishable insights) and data at rest (for insights that need large volumes of data over time).
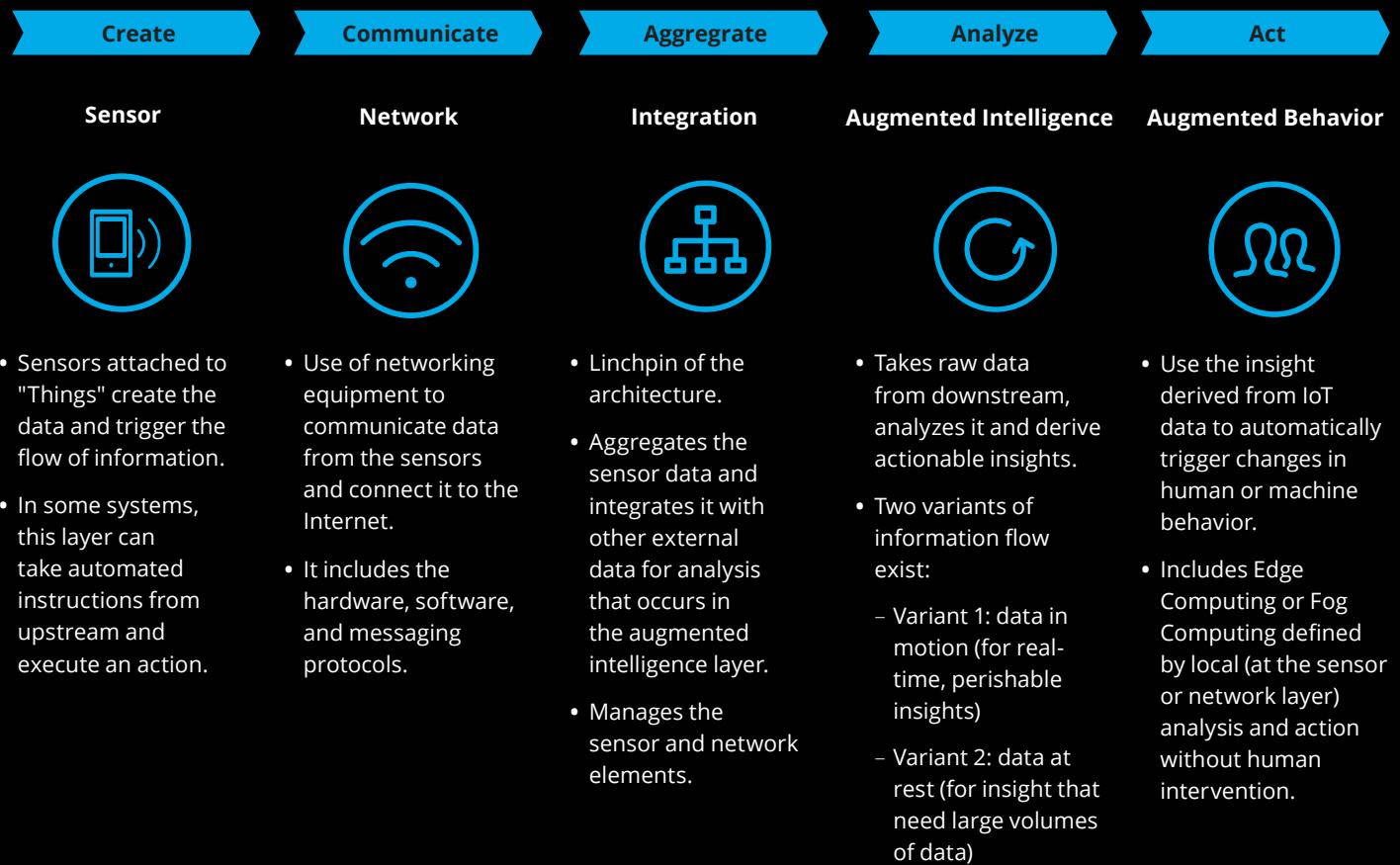
- **Augmented behavior**
  The augmented behavior layer encapsulates the actions or changes in human or machine behavior resulting from insights generated by applications using IoT data. This includes Edge Computing or Fog Computing, defined by local analysis (at the sensor or network layer) and action without human intervention. This may be facilitated by Edge Computing gateways that process data and generate insights in the local loop.
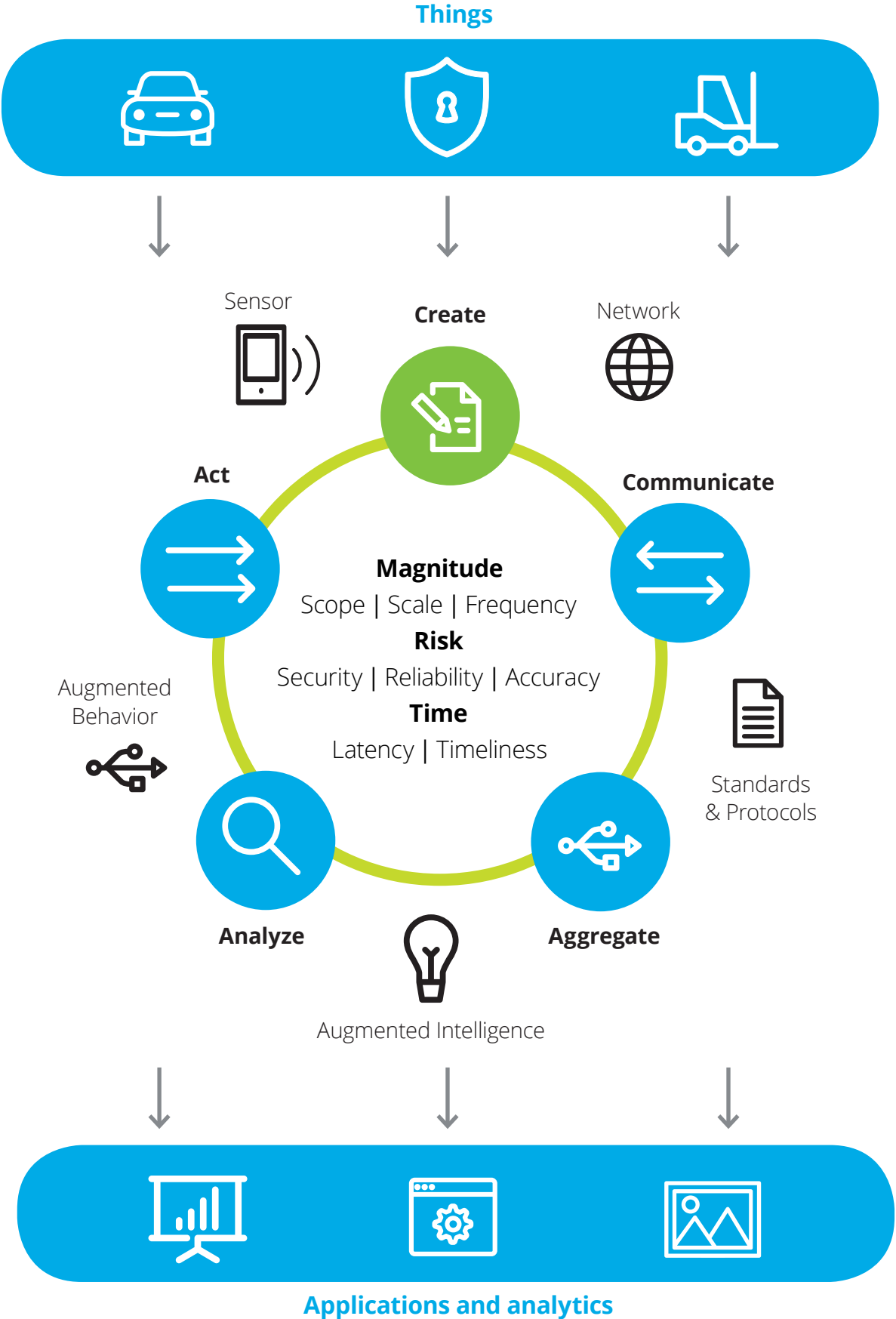
Definition of the different layers in an IoT Architecture

Create	Communicate	Aggregrate	Analyze	Act
Sensor	**Network**	**Integration**	**Augmented Intelligence**	**Augmented Behavior**

Sensor

- Sensors attached to "Things" create the data and trigger the flow of information.
- In some systems, this layer can take automated instructions from upstream and execute an action.

Network

- Use of networking equipment to communicate data from the sensors and connect it to the Internet.
- It includes the hardware, software, and messaging protocols.

Integration

- Linchpin of the architecture.
- Aggregates the sensor data and integrates it with other external data for analysis that occurs in the augmented intelligence layer.
- Manages the sensor and network elements.

Augmented Intelligence

- Takes raw data from downstream, analyzes it and derive actionable insights.
- Two variants of information flow exist:
  − Variant 1: data in motion (for real-time, perishable insights)
  − Variant 2: data at rest (for insight that need large volumes of data)

Augmented Behavior

- Use the insight derived from IoT data to automatically trigger changes in human or machine behavior.
- Includes Edge Computing or Fog Computing defined by local (at the sensor or network layer) analysis and action without human intervention.

Using analytics on the gathered data through these intelligent devices gives systems the possibility to aggregate data, analyze trends, and perform predictive monitoring.

IoT Information Loop

Things

Sensor

Create

Network

Act

Communicate

Magnitude
Scope | Scale | Frequency
Risk
Security | Reliability | Accuracy
Time
Latency | Timeliness

Augmented
Behavior

Standards
& Protocols

Analyze

Aggregate

Augmented Intelligence

Applications and analytics

Today's supply chain challenges

Modern supply chains have become increasingly sophisticated, and their impact on the competitiveness of many companies is an important factor to take into account. The risks inherent in a supply chain are associated to its interlinked nature.

Risks for global supply chains are fed by numerous external and internal factors. Some of them are macro trends such as globalization and global connectivity, which are increasing the complexity of global supply chains. Others are inherent to the never-ending strive for efficiency, and aim to reduce the operating costs. Lean manufacturing, just-in-time inventory, reduced product lifecycles, outsourcing, and supplier consolidation are just part of the business models that brought both significant improvements and significant challenges to the supply management world.

Deloitte's 2013 Global Supply Chain Risk Survey identified the main impacts and causes of the risks and challenges:

• **Margin erosion and sudden demand changes:** Rapidly changing environments requires businesses to quickly react to sudden demand changes on an increasing frequency. With globalization came fiercer competition that put pressure on margins.

• **Ripple effect due to extended value chain:** Due to extensive supply chains, companies are facing significant variability risks. Several layers of stakeholders, including suppliers, distributors, and customers, significantly increase the supply chain risk.

• **Ineffective supply chain risk management:** Building effective supply chain risk management programs are key to accurately monitor and predict risk in order to react properly.

• **Lack of end-to-end visibility:** Companies are struggling to have a clear overview on their supply chains—both internally and externally. This exposes them to different kinds of risks such as fraud, code of conduct violations, and more.

• **Obsolescence of technologies:** Advanced supply chain management tools require significant and continuous investment. This also goes with inherent implementation risks that pose a major challenge for most businesses.

Through the next theoretical example, we will highlight the added value that blockchain and IoT can bring to supply chain management.

Main stakeholders in a supply chain

As explained above, today's supply chain stakeholders are global, multi-layered, and open systems. We can represent one layer of the supply chain as follows:
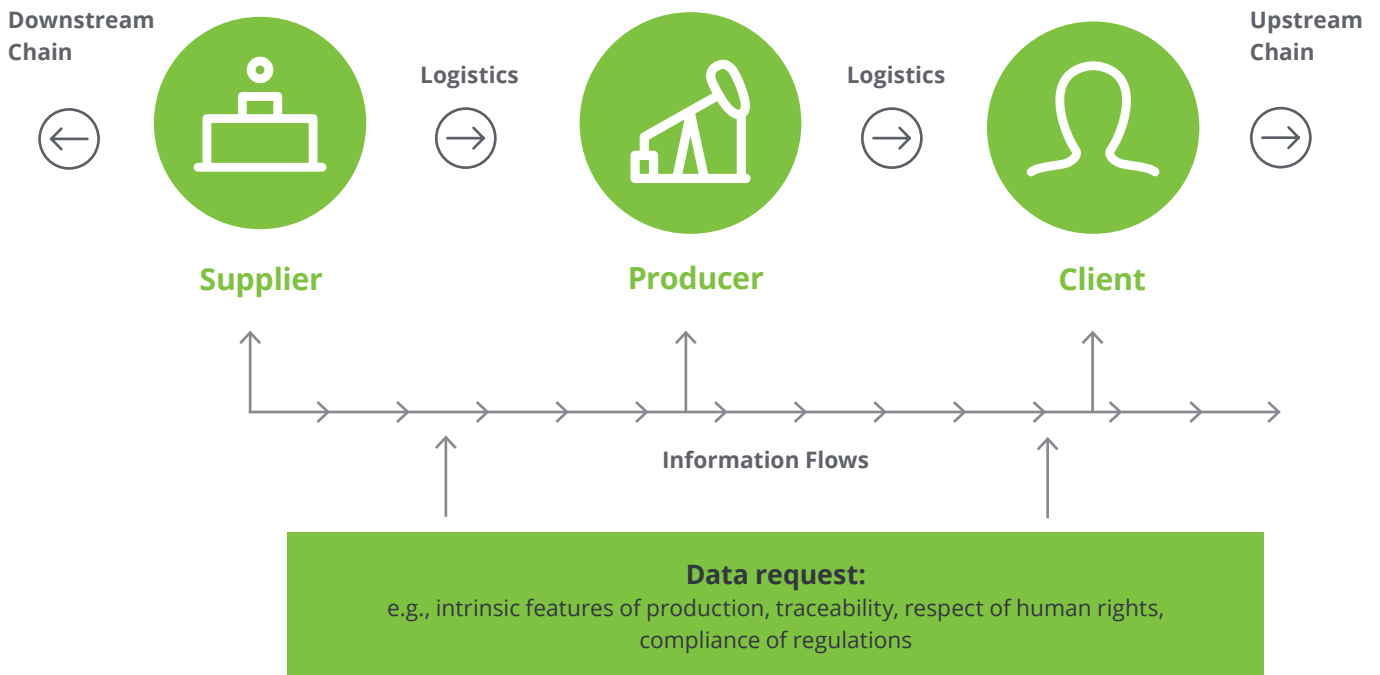

Illustration of one layer in a supply chain.

Even with this simple example of a few stakeholders demonstrating both the physical and information flows, we can already understand that it gets challenging when it comes to efficiently tracking the production and information flows. The information flows rely on the data being effectively collected and made available by the information systems of the various stakeholders. Hence, the whole system relies on:

• **Trust:** Every stakeholder has to trust one another in their willingness to communicate true information.

• **Effectiveness of the lowest common denominator:** This depends on the ability of systems to effectively collect correct data, record it in a secure way, and produce accurate information to

other systems. The effectiveness of an end-to-end supply chain information flow is limited by its weakest link, or its "most wicked" link.

• **Reconciliation:** Because supply chains are not integrated end-to-end and because there are limited standards, there is no continuity in the provision of information. Each stakeholder needs to reconcile the data to ensure accuracy and effectiveness, which impairs efficiency.

• **Limited manifestation of the information flow:** The ability of the collected data to effectively and accurately represent real-life objects or events is limited by the systems put on the supply chains to monitor them and track the supply.

Accurately tracking an entire supply chain from raw material extraction to a factory-made product ready to be sold to a retail customer might quickly become a feat.

The above elements highlight the importance of reliability. If you are not able to control everything in the chain, a single grain of sand can block the wheels.

Hierarchical representation of the different stakeholders in a supply chain

Customer Demand

Value Chain to the final customer

TIER **0**
Car manufacturer

TIER **1**
Components supplier

TIER **2**
Sensors supplier

TIER **3**
Raw material provider
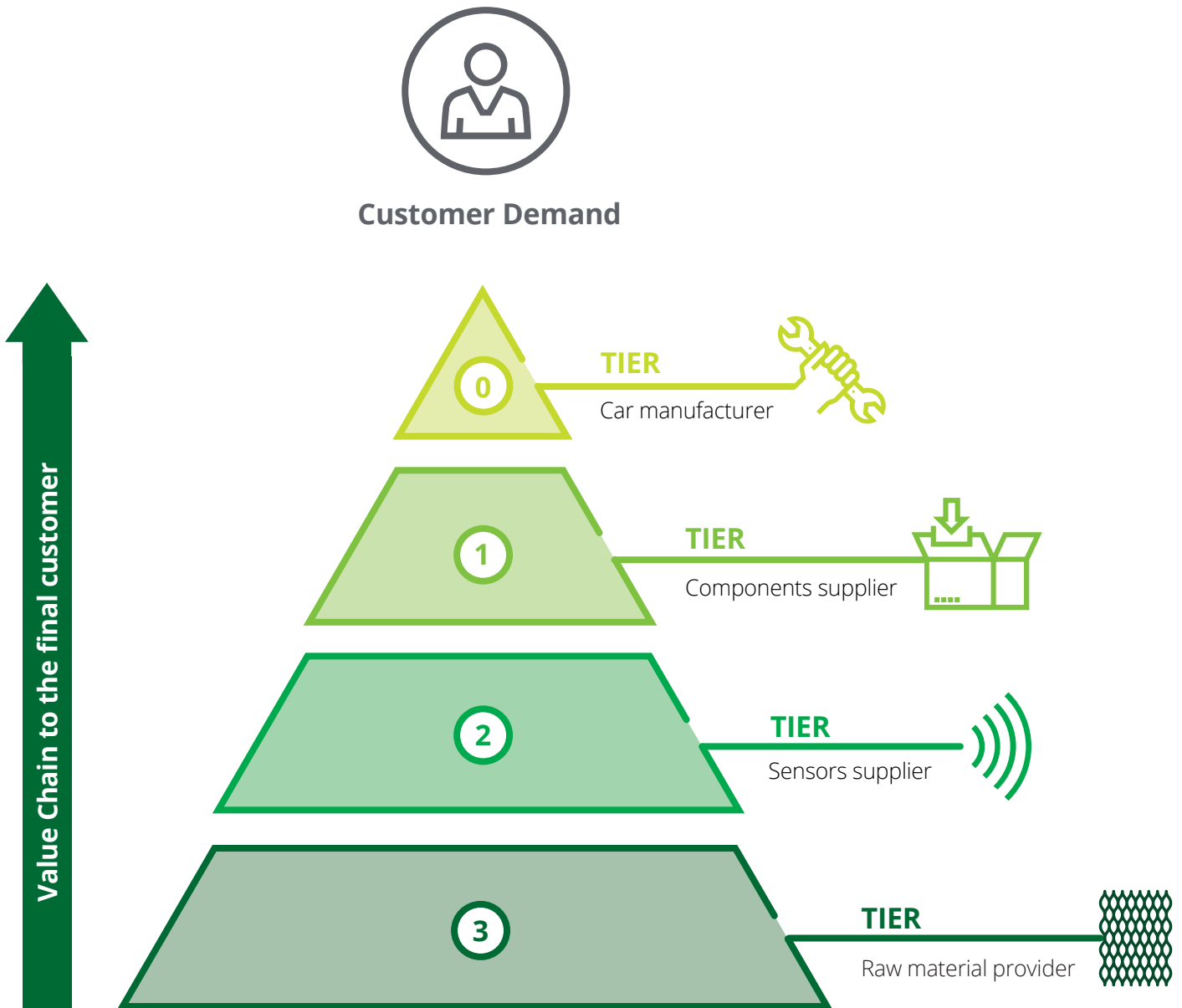
Guidelines for an ideal supply chain

From these challenges, we can derive that to be reliable, efficient, trusted, and resilient, supply chains require:

End-to-End Visibility

Monitoring supply chain events and processes assess pain points and identify problems and issues—even proactively. This concept is key to increase efficiency along the supply chain and ensure traceability.

Flexibility

The ability to adapt and respond to issues rapidly with no critical impact on operational costs is necessary to stay competitive on the market.

Inferred trust

The stakeholders should not have to trust each other but should trust the security integrated into the system to collect and provide true and accurate data.

Control

Policies, monitoring capabilities, and control mechanisms are of prime importance.

How can blockchain and IoT assist?

As shown above, major challenges faced by supply chains relate to information sharing and trust. With its intrinsic properties, blockchain and IoT offer bright opportunities to tackle these challenges.

We have identified four challenges that the combination of IoT and blockchain will bring to supply chain management:

- **Continuity of information:** Through the immutable and irrevocable properties of blockchain, sharing information effectively between the different stakeholders involved in the global supply chain will be key to ensure traceability and reduce inherent risks.

- **Accessibility to information:** Fast and transparent blockchains will provide the necessary access to information in the future to effectively leverage on the massive amount of data produced along the supply chain.

- **Link between physical and information flows:** Thanks to IoT, the data will be linked to the materials and products on the stages of the supply chain where matter is transformed physically.

- **Code of conduct violations and fraud detection:** The need to ensure human rights and codes of conduct are respected along the chain is necessary to lower reputation risk. Effective fraud detection processes supported by appropriate technologies will be increasingly important to lower business risk. This will be enabled by the transparent and auditable features of blockchain.

To better illustrate these risks and where they have an impact on the supply chain, you can find an example below of the life cycle of a car, including some the issues that can be seen regarding the four challenges.

The information sharing between the different stakeholders is a major challenge (e.g., each has its own information system) and affects the traceability of information along the chain. Furthermore, due to the complexity of interactions between the stakeholders, it becomes challenging to accurately track and link information to material without any bias. All stakeholders struggle at some point during the process to access information effectively due to the lack of secure sharing, strengthened by the fact that information is split among many stakeholders. As mentioned, the various fraud scandals that have recently occurred brought the business risks along the global supply chain to light. Identifying code of conduct violations is nowadays one of the hottest concerns that needs to be taken into consideration.

Use case representing the potential challenges and pain points along an illustrative supply chain

Extract and transform raw materials

Sell materials through a broker

Load materials

Transport to nearest port

Load materials on ship

Transform raw materials into end-product

Transport materials to production chain

Unload materials on truck

Ship to destination port

Reuse the recycled materials in production

Load the recycled materials

Recycle product at end-of-life

Maintain the product

Load end-product on transport

Transport and load onto train

Unload onto trucks

Transport to the final shop

Sell the final product to the consumers

Discontinuity of information

Fraud detection

Accessibility to information

Link materials to information

Production

Broker

Freight

Consumer

Recycle

Shared traceability

More practically...

With its ability to provide continuity in information sharing, blockchain and IoT capabilities can significantly help global businesses mitigate their operational risks by ensuring temper-proof and reliable consecutive flows.

Stakeholder	Now	Future
Producer: Adds value to the raw materials into other consumables and finally the end-product	• Has a limited ability to control and verify the flows coming from its suppliers (e.g. compliance to standards, respect of requirements)	• Benefits from an integrated and distributed ledger that enables them to control the inputs and keep track of its production
Freight Forwarder: Responsible for transporting materials and products to and from the different stakeholders	• Reliable but one-sided tracking system • Limited certification ability and complex tracking (e.g., heat or pressure variations) • Difficulty to certify a code of conduct	• Shared information system • Client can benefit from a distributed and certified system • Client can make sure his goods are transported in the right conditions and timing
Broker: Makes the link between the stakeholders	• Difficulty to certify the origin and path of the goods bought and sold	• Can easily check the origin of the goods and their transformation path on the blockchain • With sealed IoT devices put on the goods, the broker can check and prove its authenticity and provenance
Consumer: The final consumer of the product	• Difficulty to verify the compliance, origin, and composition of the goods to be bought	• Has a full view on the goods bought (i.e., provenance, transformation process, transportation) directly on the blockchain

Use cases

The technology behind sensors and electronic chips is evolving rapidly and renders them increasingly portable. This evolution gives companies the opportunity to attach sensors to physical goods to track their evolution and thereby detect potential failures and fraud. If you combine these sensors collecting massive amounts of data with a blockchain providing standardization, transparency, and traceability, you create value on the collected data.

Using a "sealed" smart device to authenticate the goods allows trust along the supply chain. These electronic seals uniquely identify the object on which they are attached, and detect or simply break upon an attempt to tamper with the object.

In some cases it is not possible to attach sensors to the good itself due to its size, material, or in order to preserve its integrity. In those cases, attaching the electronic seal to the packaging of the good is a viable workaround to accurately track and monitor the object through the supply chain.

Many use cases to apply blockchain and IoT technologies to supply chain management can be imagined in all industries.

For instance, using tags on packaging in the healthcare industry could help track and secure medical supplies. If this technology is then combined to a blockchain by collecting the captured information and certifying its authenticity, you can assure the viability of the supplies along the entire supply chain, as well as identify potential fraud and manipulation that could induce dangerous consequences for the patients.

A similar example could be applied to the food industry, packaging sensitive products with tags, as well as putting smart thermometers in containers and at different key locations to effectively track and monitor that the maximum temperature has not been breached along the process.
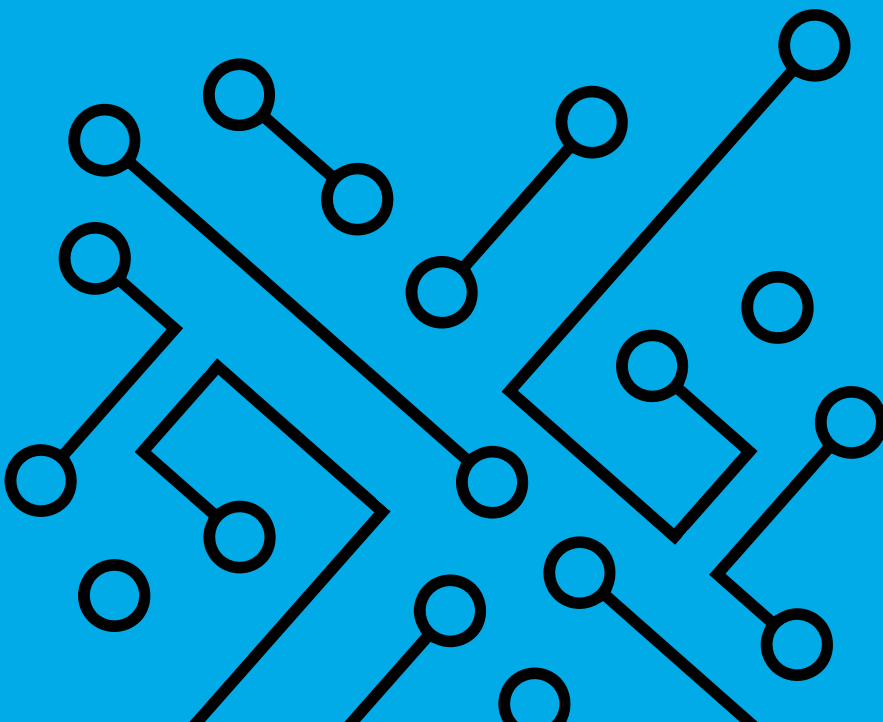
Another use case would be to apply the combination of RFID seals and blockchain to the world of arts and luxury wares. One could imagine embedding technologies to new works of art directly into the material to guarantee its authenticity, using, for instance, DNA identification. RFID seals can also be attached to luxury goods. Any attempt to replace them would destroy the seals or damage the good itself, making it unsellable.

Sensors can be used to capture identification and send it to a blockchain for authentication. The work of art can be scanned using the proper technology (DNA reader) and immediately be identified as authentic.

Several actors have already positioned themselves by combining blockchain technology and supply chain

- **BlockVerify:** Proposes to use blockchain's traceability and transparency to effectively detect and combat fraud in the drug industry using IoT capabilities.

- **Kuovola Innovation:** Aims to use RFID tags in order to track products along the supply chain and store the collected data on a blockchain.

- **Riddle & Code:** Is developing end-to-end security for IoT capabilities using distributed ledger technologies to keep data and communications confidential.
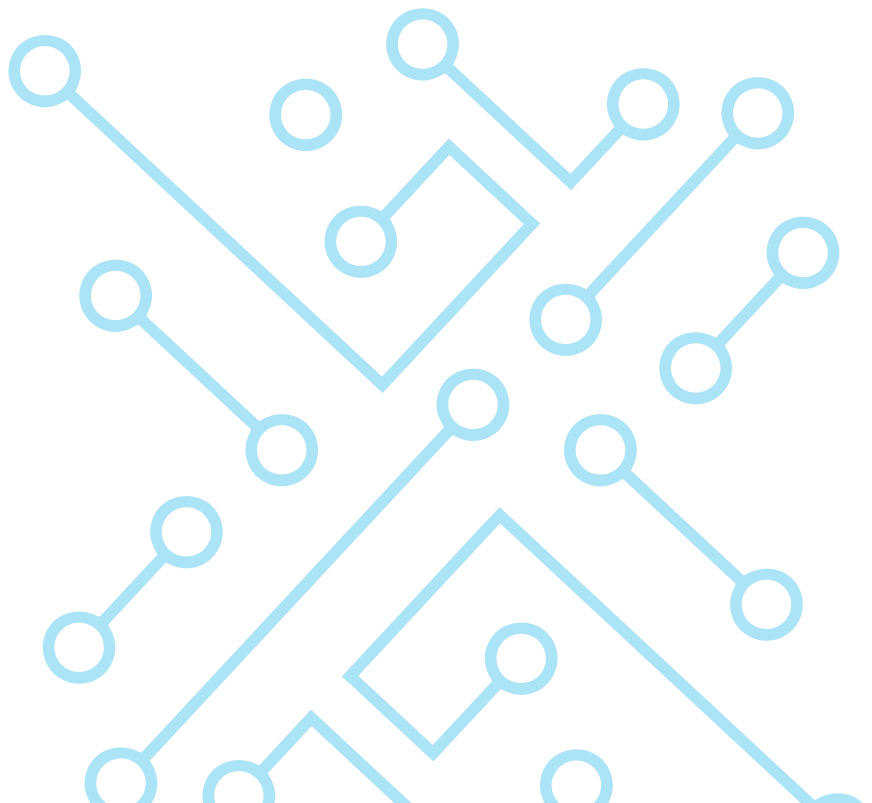
A twist in the chain

It is undeniable that blockchain and IoT will play a major role in the optimization, but they will need to overcome some challenges in order to become standards on the market in the long term.

Nascent technology
The technologies developed today are yet to be proven. Blockchain technology is effective in securing transactions, but can be limited in performance, scalability, and confidentiality. IoT technology also needs to prove that the entire IoT infrastructure is effective, efficient, secure, and resilient. Because it is a combination of many technologies, standards will have to be defined and accepted so that they can work together. This will take time.

Digital/physical link
One of the main roles of a blockchain is sharing information on a trusted platform, but collecting this information means that the physical world needs to be linked to the digital world. Different schemes will be used, but they still must prove that they can effectively seal the object and authenticate them uniquely over time.

The same is also true for the sensors; the devices capturing the data must also be certified and authenticated. In turn, if the devices are secure, then the resources calibrating and maintaining them also need to be certified and authenticated.

In theory, every object will need a seal, every resource will need a certificate, and all communication between things and sensors will have to be secure.

Indeed, making sure the link between the physical and the digital world is valid will be a challenge in its own that will need to take the risk versus the costs into consideration, as well as the value of the goods being traced and the value of the information being captured.

Conceptually, all components and materials used along the chain needs to be recorded on the blockchain.

Modelization of information

Another major challenge will be the level of granularity at which the information is captured. Conceptually, all components and materials used along the chain needs to be recorded on the blockchain.
To better illustrate this challenge, let's use an example. A car is designed using hundreds of components which themselves are again built using different materials and components. The ultimate objective would be to get a representation on the blockchain (a so-called "token") of all those components, so that they can be traced individually, but also as constituents of other products.

Modeling raw material is also a challenge. It would make no sense to create a token and attach an electronic seal to each apple used to produce apple juice. Rather, a first token would be associated to a batch. A second token would be associated to the apple juice bottle produced from the apple batch. And the second token would be linked to the first one as a product of it. But at which level of granularity do you start associating a token? What will make economic sense? Again, it should be a trade-off between risks, inferred trust, and value added.

Definition of infrastructure to include

The integration of blockchain with IoT technologies includes not only the implementation of its capabilities but also all the surrounding infrastructure that needs to support it.

New data flows and storage need to be designed, tested, and implemented. If the company wants to surface this data, then new data visualization capabilities are also needed. Devices won't sustain themselves and will need a supporting infrastructure that is yet to be designed.

Overall agreement in the supply chain on using blockchain

Developing an end-to-end solution to cover the supply chain globally will require all the stakeholders to commit to investing in and using these new technologies. This is an unavoidable step for it to be viable and provide traceability along the entire chain.

In addition to that, it will be key to find the right balance between confidentiality and transparency that will convince all stakeholders to use a distributed ledger to record and share supply chain information. Indeed, if all the information is put on a ledger without enough confidentiality barriers, it would be easy to access one company's business activities and business strategy.

IoT Reference Architecture

Create | Communicate | Aggregate | Analyze

Things | Sensors | Gateway | IoT Platform | IoT/Analytics Platform | Visualization / Reports

Security

Billing

Protocols — Sensors to Gateway

Gateway (Data Ingestion)

Edge Computing

Protocols — Sensors to Internet

Device Management

Data Ingestion Point (Includes Short term storage)

Real-Time Event Management

Augmented Intelligence

Storage

Legacy/External System Connectors

Augmented Behavior

Blockchain

Act

Approach to apply blockchain and IoT in supply chain management

Companies—or a consortium of companies—that would like to apply blockchain and IoT to their supply chain should follow a pragmatic incremental approach. Prior to implementing an ambitious blockchain solution, here is a framework that might guide them:

1. Understand your supply chain weaknesses and risks.

2. Review your supply chains as upstream as possible to identify weaknesses and risks you will face.

3. Identify and classify those weaknesses and risks not only in function of their probability and impacts, but also in their nature (discontinuity of information, possibility of fraud by replacing goods or material, etc). This will give you a heat map of pain points of your supply chains.

4. For each of the pain points, rapidly assess how blockchain and IoT could help.

5. Start small. Select a pain point to resolve that would not incur too complex and costly a project, while being able to demonstrate the added value. Apply this to a small scope to start with (only some of your suppliers, items, etc.)

6. Try and fail until you are confident it is a good and sustainable solution.

7. Collaborate. Do not work alone, engage your supplier network and customers, partner with startups, technologists, and advisers who have an external view. Also onboard your competitors who deal with the same suppliers as you do. You will share the investments and force your suppliers to adhere to your project even more.

8. Scale progressively. Once you have learned your lessons, begin scaling the solution and extending it to a broader scope (by increasing the number of stakeholders, adding new sensors, securing new physical zones, etc.).

Conclusion and Summary

We have seen that supply chain is facing major challenges today, and will face more tomorrow. The demand for transparency and traceability has increased over the past few years as a direct consequence of the different food and automotive scandals that shook their respective industries.

In that regard, we also saw that the future combination of blockchain with IoT technologies would be able to help the different stakeholders to ensure traceability along the chain and reduce risks. Sharing a unique blockchain across the different stakeholders of the supply chain (production, freight, and consumer) will ensure that the exchanged and manipulated wares are authenticated, thus preventing potential fraud and making information accessible.

IoT, on the other hand, will serve as a link between the physical and the digital world by providing reliable information on the materials and products to the blockchain.

Today, IoT and blockchain technologies are in constant evolution and need to mature in order to support those kinds of challenges. Nevertheless, actors are actively contributing to the integration of these technologies into the supply chain world and proposing new ways to improve and to continually secure information sharing.

However, this evolution will not happen without an overall agreement between the different stakeholders to invest in these technologies. In addition, the regulatory environment will need to evolve to support the implementation of these technologies.

Overall, these technologies will revolutionize the way the different actors in a supply chain capture, communicate, and access information on a secure, shared, and transparent platform.

Key messages

- Today, supply chains are global and often involve many stakeholders in complex relationships

- Most major companies' challenges relate to a lack of trust-based information

- Blockchain and IoT features can bridge this need with portable solutions brought to complex structures

- Blockchain as an emerging trend is relying on immature technologies but these have a steep growing curve

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