WORLD ECONOMIC FORUM

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White Paper

Share to Gain:
Unlocking Data Value in Manufacturing

In collaboration with Boston Consulting Group

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Executive summary

Emerging technologies, such as advanced analytics and artificial intelligence (AI), are transforming the world of production and creating new opportunities for industry, society and the environment. Data is critical, as is companies' ability to manage it effectively. While manufacturers are making strides in this area, most focus on data within their companies and have difficulty maximizing their return on investment and driving innovation at scale. Yet by sharing data across companies, manufacturers can unlock additional value and accelerate innovation. The potential value of data sharing simply by focusing on manufacturing process optimization has been estimated at over $100 billion, based on best practices. True masters of data improve existing solutions by using shared data and implement solutions impossible without data sharing.

How can a manufacturer begin to unlock innovation and value through data sharing?

Data sharing in manufacturing provides value in five main areas by:

– **Enhancing asset optimization.** Combining data from multiple users of the same type of machinery allows manufacturers to improve algorithms that, for example, enable predictive maintenance. Sharing data can thus optimize asset performance by increasing machine uptime and product quality, creating a win-win situation for all stakeholders. This is particularly important for manufacturers who lack the amount of data needed to fuel robust analytics algorithms.

– **Tracking products along the value chain.** By gaining end-to-end visibility of their value chains, manufacturers can react quickly to unexpected events and reduce inventory. Although manufacturers already track products along supply chains, they must collaborate, share data and make use of common systems to establish true end-to-end visibility.

– **Tracing process conditions along the value chain.** Manufacturers can instil trust and more efficiently comply with stringent regulatory requirements by having access to a continuous and complete digital record along the value chain. This allows them to ensure that suppliers follow the agreed production processes, and suppliers can use these records as proof in warranty discussions. Companies in the food and pharmaceutical industries are already building data alliances to achieve these benefits.

– **Exchanging digital product characteristics.** Sharing data on product shape and composition allows manufacturers to synchronize and optimize connected production processes. A digital product twin that is shared between a supplier and an original equipment manufacturer (OEM) can, for example, help to eliminate incoming quality inspections or topographical measurements needed to automatically process parts.

– **Verifying provenance.** Customers increasingly demand more transparency regarding where their products come from and they want to verify authenticity. To do so, manufacturers need transparency with regard to where and how their supplies are processed and to their authenticity. To provide this transparency, several companies have joined forces to collaborate on blockchain solutions.

For collaboration on data sharing to be successful, stakeholders need a good understanding of how to promote value together. In the five main areas or application domains identified, three factors promote success:

– A clear value proposition and rationale for data sharing
– Mutually beneficial agreements
– The use of secure technologies and common standards.

Key to getting started is finding the right applications where sharing data offers clear value, and building trust between the partners sharing the data. This White Paper proposes a five-step framework to help manufacturers start the process before fully engaging in a data-sharing relationship:

1. Understand the business challenges to be addressed by data sharing
2. Develop specific applications related to the business challenges
3. Assess and select viable applications
4. Identify and assess partners for each application
5. Define the right set-up for the data-sharing relationship.

When prioritizing data sharing applications, examining the value proposition and the risks as well as the data accessibility and quality is essential. An assessment is needed to identify the right partners and understand the organizational and infrastructural readiness of all stakeholders. Finally, the right set-up, sharing mechanisms, a compensation model and the necessary technology architecture, among other aspects, need to be discussed.

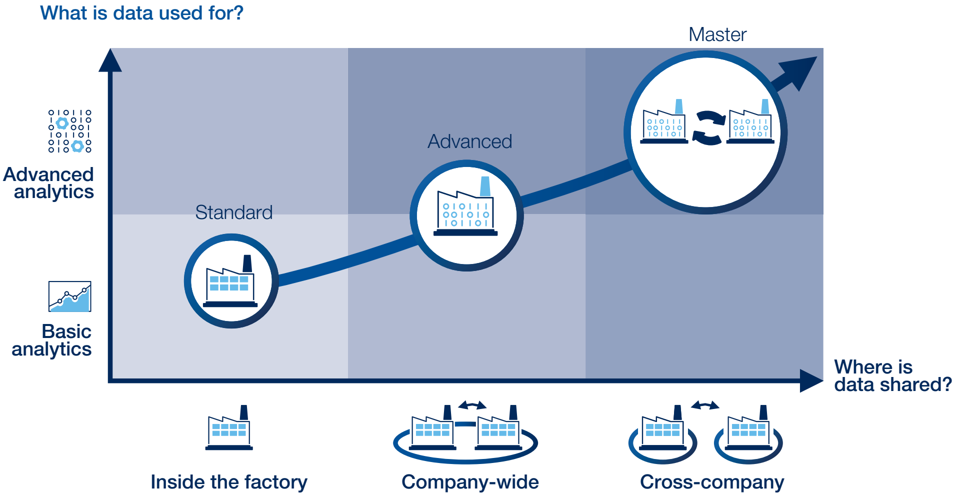
Selecting the right technologies and using common standards help to overcome the main perceived barriers to data sharing, such as interoperability issues and risks. New technologies and the push towards industry-wide standardization and common reference architectures hold promise and should be further encouraged.

This White Paper is a starting point for a new journey on data sharing in manufacturing. It aims to promote the development of new tools, policies and business models to help manufacturers unlock value and create ecosystems in which innovation thrives. Success will be achieved if all stakeholders in manufacturing environments work together to solve important policy, standardization and technological questions raised by data sharing. This work on data-sharing areas, collaboration models, technologies and standards related to the sharing of data will inform further conversations in this field. The World Economic Forum Platform for Shaping the Future of Advanced Manufacturing and Production provides a unique space for these discussions and for developing new collaborations aimed at facilitating data sharing in manufacturing and across value chains.

1. Introduction

Advanced analytics and artificial intelligence (AI) are transforming the world of manufacturing. As data becomes increasingly important in their factories and supply chains, most manufacturers have applied these emerging technologies within their companies. Yet manufacturers can capture even more value by going beyond their own four walls to leverage data shared across value chain steps and companies. True masters of digitalization not only apply their own data, but also improve existing applications by sharing data and applying new ones that would not be possible without data sharing (see Figure 1).

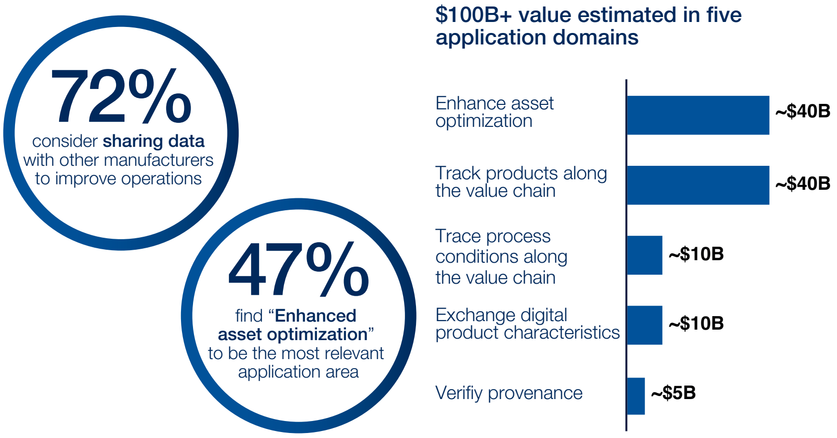
Figure 1: True masters of digitalization share data



Source: Authors

The total value that companies can create in five key areas of data sharing is estimated to be more than $100 billion, focusing on operational improvements alone (see Figure 2). To tap into this potential, manufacturers need to understand the mechanisms behind data sharing and the factors that make data-sharing relationships successful.

Figure 2: An estimated value of more than $100 billion in improved operations alone



Note: The estimated value only considers efficiency improvements in operations through data sharing. Quantification is based on a global BCG survey (among 996 manufacturing managers) and available industry examples.

Source: Authors

How can a manufacturer begin to unlock this potential?

To answer this question, section 2 in this paper investigates in more detail the application domains that can benefit from, or be realized by, data sharing across companies. Based on this investigation, section 3 presents common patterns in the applications, such as collaboration models, as well as the success factors but also barriers to data sharing. Section 4 introduces a framework to help manufacturers select applications, identify partners and discuss with them the ideal set-up for their data collaborations. Finally, section 5 outlines the key enablers of successful data sharing: selecting technologies, using common standards, building trust and having legal and regulatory certainty.

2. Exploring data-sharing areas in manufacturing

Five application domains for data sharing in manufacturing were used to illustrate the potential of data sharing and the mechanisms behind them. In the first domain discussed, data sharing enhances an existing solution for advanced analytics and AI. In the others, data sharing makes these application domains possible.

Table 1: Data-sharing areas and value mechanisms

Application domain	Value mechanism
Enhance asset optimization	…by sharing and combining data of similar production equipment across companies to increase machine uptime and product quality
Track products along the value chain	…by sharing product location, time and quantity data to optimize and automate end-to-end processes
Trace process conditions along the value chain	…by sharing data on product and process conditions to create a continuous digital product record
Exchange digital product characteristics	…on product shape, geometry and composition to create a digital product twin and automate processes
Verify provenance	…by sharing data along the supply chain to ensure the origin of raw materials, the components and the products are as expected

Enhance asset optimization. Leading manufacturers are already using advanced analytics and AI to predict machine failures and improve quality performance. Manufacturers can use machine data to develop prediction algorithms and increase machine uptime. Producers can also reduce problems related to quality as well as energy and utility consumption by analysing data.

On a technical level, this is enabled by establishing connections between different process parameters and the desired performance or undesired failure event. As the number of failure instances or attributes that describe a process increases, the algorithm can better predict future failures or pinpoint the cause of an undesired outcome.

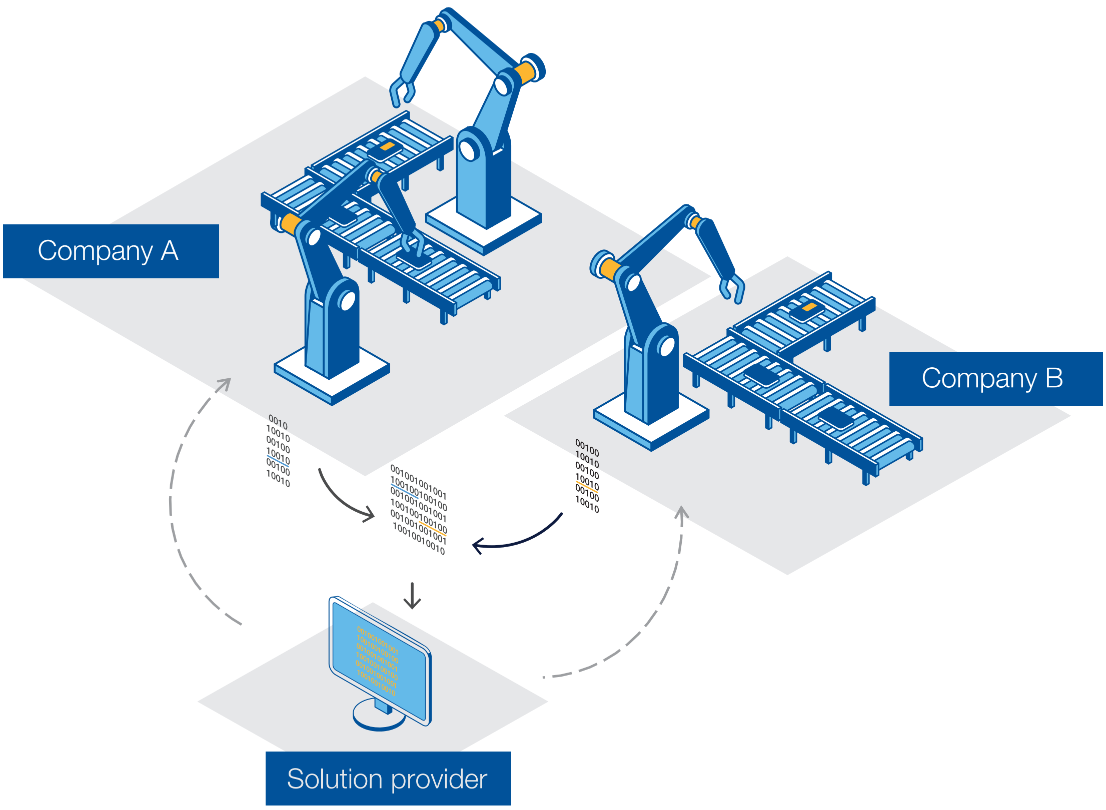
What is the challenge?
First, to create a robust prediction algorithm that can provide valuable insights effectively, a company needs large amounts of data, with many instances of unexpected machine failures. Prediction algorithms built on inadequate data are ineffective over the long term. However, data on unexpected machine failures is, by definition, rare. As a result, most manufacturers do not have a sufficient amount of data relating to machine failures – small manufacturers are affected the most.

Second, successfully optimizing process parameters depends on combining data from various sources and sensors, so that the algorithm can understand all factors that influence the process outcomes. Yet, even within the same company, this can be challenging. To illustrate this, consider the example of a computer numerical control (CNC) machine and cutting tool producer. Today, machining centres use embedded sensors to monitor aspects of the process (such as vibrations or collision risks). Combining this data with other machine control data and the product design would allow the supplier to suggest a more efficient cutting path, cutting tool or process parameters. Collaboration at this level would be difficult, however, due to interoperability issues between different systems generating the data or accessibility issues (such as accessing machine, sensor or design data).

How does data sharing help?
In both cases, data sharing offers a solution. A company can obtain data on machine failure modes from other companies and feed it into prediction algorithms that can "learn" from the different failure modes. Fanuc, a robotics manufacturer, provides a preventive maintenance solution using data from its robots. To do so, it collaborated with Cisco and set up a data warehouse in which its customers can securely share their failure data. By using this data, Fanuc can understand failure modes from all of its clients and provide a better uptime and predictive maintenance service to its customers.

How would that work?
To implement both applications, the most feasible option seems to be for manufacturers to work with a third party (such as a machine supplier or service provider) to combine, clean and analyse data. This is because, by necessity, the data-sharing arrangements involve companies in the same industry that might be in direct competition with one another. Additionally, a third party can bring the needed expertise and facilitate the data-sharing relationship (see Figure 3).

Figure 3: Enhance asset optimization



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For specific applications, these third parties can be companies such as DataProphet, which promises to combine data from different sources and use machine learning to reduce quality defects and scrap. Machine suppliers can also take on this role, undertaking to improve the services they are providing through data sharing. Manufacturers working with a few machine and equipment suppliers might prefer this option for building long-term collaborations.

In such arrangements, it is critical to guarantee that the data-sharing architecture and the third parties are secure. Lacking a standard way to assess the technical capabilities of solution providers, manufacturers might prefer collaborating with the machine suppliers with which they already have established relationships.

Furthermore, combining data from different systems, with multiple stakeholders providing various access to their data, requires diverse parties to address such issues as interoperability and data ownership, and to share the benefits of the arrangement.

Track products along the value chain. By tracking products and components in their supply chains, manufacturers can make sure they get the materials they need, when they need them. This visibility allows manufacturers to improve their production planning, reduce inventory levels and react faster to unexpected events in the supply chain.

Tracking products and components in the supply chain is a well-established practice. Companies can already track the components' locations and quantities within their operations by using a radio-frequency identification (RFID) tag (on either the product or containers) and carefully placed scanning systems.

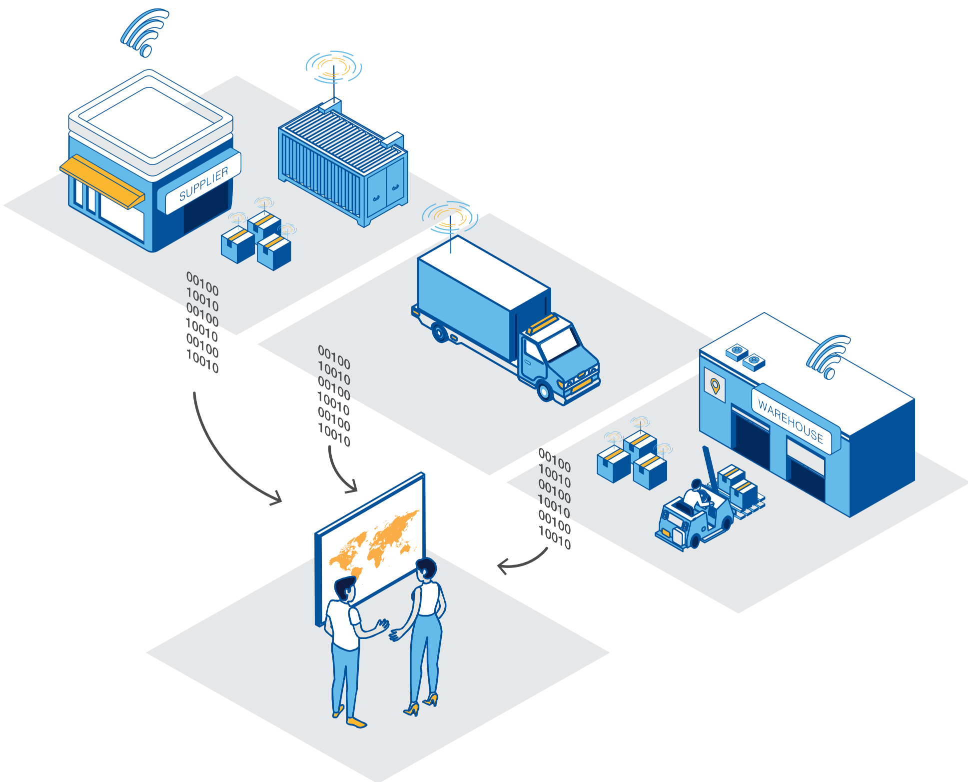
What is the challenge?

While this type of tracking is helpful, it falls short of providing true end-to-end visibility. To establish such visibility, all suppliers in a supply chain must combine their data in a single shared system and use a common standard for supply chain transactions. This visibility would benefit all supply chain participants by allowing them to reduce inventory safety buffers and react to unexpected events as either a sender or receiver. Additional advantages include fewer lost parts during shipment, reduced expedition fees, fewer interruptions in production and optimized transport.

How does data sharing help?

By using a common shared system from end to end, supply chain participants can also automate certain transactions at the supply chain level. For example, if a disruption occurs, a manufacturer can automatically engage alternative suppliers and shift resources. Additionally, the ability to monitor the quantities of resources consumed allows companies to implement automatic replenishment solutions within their supply chains (see Figure 4).

Figure 4: Track products along the value chain



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How would that work?
Leading companies in the automotive industry are already collaborating to achieve end-to-end tracking within solutions like AutoSphere, a community of automobile OEMs and suppliers established by a company called Surgere. Participating companies use a common database to better manage their supply chain transactions. Surgere serves as a secure third party that collects, shares and analyses the community's transactions. It also provides the RFID tags and the necessary software and hardware solutions. The founding members of the community are Honda, Toyota, Nissan and GM. They are tracking millions of tagged assets together with their suppliers.

To capture the benefits of this approach, companies must overcome two types of trust-related challenges. First, some tier-1 suppliers might fear losing their negotiation power or competitive advantage if they reveal to manufacturers which companies supply them with components and the volume of products they are trading or producing. Second, even if a supplier participates in such a digital community, it might be reluctant to commit to one type of technology and standards, owing to the difficulty of subsequently switching to other types for other customers.

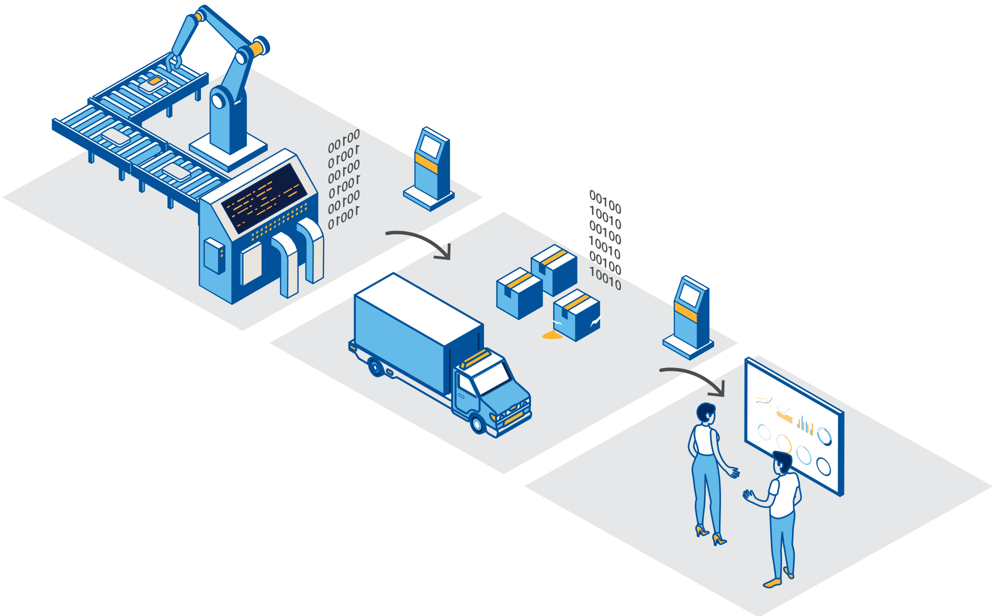
Trace process conditions along the value chain.
In addition to tracking product location and quantity, it is important to monitor product condition and process parameters along the supply chain. This is especially true in the food and pharmaceutical industry. In these industries, manufacturers must prove safety and traceability to comply with stringent regulatory requirements.

Several solutions are available to prove that a product is in proper condition during transport. Companies are already using sensors and tags to record environmental factors such as temperature and humidity in their storage locations and during transportation. Additionally, manufacturers have systems in place to track production batch numbers, expiration dates and various other records on production processes.

What is the challenge?
Today, however, documentation is generally created by diverse stakeholders in the value chain, applying different capabilities and using various systems and sensors. This means the manufacturer generally has a passive record of production conditions and characteristics at the end of a long communication chain. If a manufacturer discovers a bad batch at the end of this chain, it needs to work with all stakeholders to understand what caused the problem and cannot take action in time to switch suppliers.

How does data sharing help?
Through data sharing, companies can establish a continuous and complete digital record along the supply chain, with live updates that allow companies to take immediate action to prevent waste. Continuous digital product records allow companies to easily process warranty claims from end customers and find the root causes of quality issues. Manufacturers can also provide end customers with information from the digital product record to address any concerns about food and drug safety, as well as other aspects of production, such as worker safety and environmental impact (see Figure 5).

Figure 5: Trace process conditions along the value chain



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How would that work?
BeeBeacon, a mobile sensor technology that regularly reports on various conditions (such as temperature, humidity and altitude) along the value chain, provides a good example of how this works. Because the updates are stored in the cloud and uploaded in short time intervals, managers can immediately react if they see that a product's condition is getting out of specification, wherever it might be.

In the food industry, two initiatives are comprehensively establishing traceability and enabling condition monitoring. An initiative called OpenSC uses a blockchain architecture to track temperatures in the food supply chain from end to end. It also provides consumers with verifications of producers' claims regarding food, such as legal fishing, free range and fair trade assertions. IBM Food Trust, another blockchain-based initiative, also tracks and provides additional types of information (such as when food items were harvested and packaged) to consumers about the items they buy. The French multinational corporation Carrefour, which participates in the initiative, reports that additional information on food products has helped it establish more trust with its consumers.

Applying these solutions entails several challenges. All value chain participants – suppliers, producers and farmers – need to collaborate and instal sensors, and other data technologies. However, farmers and other players along the supply chain might not have the required digital capabilities or maturity to participate in an expensive, advanced solution. Additionally, supply chain participants might be reluctant to share data due to concerns about harming their reputation. As always, gaining the support of all critical supply chain participants is essential to making data sharing successful.

Exchange digital product characteristics. In discrete manufacturing today, most components are already designed digitally using computer-aided design (CAD) software. Even if manufacturers originate the product design using a CAD model, paper records are still used to document and communicate the actual dimensions of the product created in different production steps.

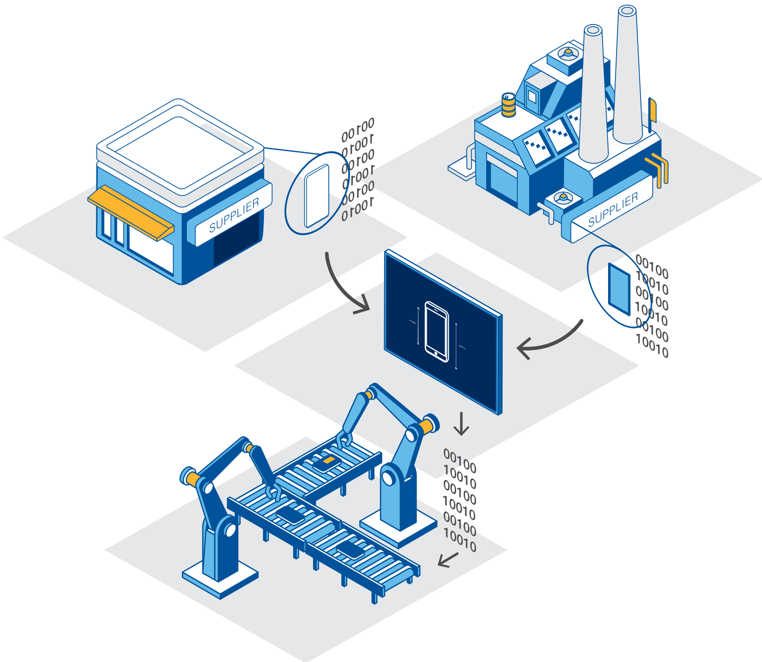
What is the challenge?
Because records are kept by individual stakeholders along the value chain, in many cases, it is necessary to manually exchange records. Manufacturers must also conduct audits and quality checks to confirm that selected dimensions will meet the tolerances specified.

Digital product twins provide a solution to these challenges. These are digital representations of a product, including its actual dimensions and shape characteristics. A digital product twin expands upon the original CAD model by adding information on actual dimensions and quality from various production steps – creating a merged model of design data and actual characteristics. Yet creating a digital twin that follows the whole life cycle of the product, combining data on components, requires a high level of cooperation and coordination.

How does data sharing help?
By sharing and combining data, manufacturers can realize the full potential of digital twins. For example, a supplier can record the actual dimensions and geometries it is responsible for in the digital representation of the product. Suppliers responsible for subsequent process steps can seamlessly expand this model with actual dimensions and geometries that they have worked on. Blockchain or distributed ledger technologies seem especially suitable for such records because they can create a single version of the truth that is easy to audit and immutable.

A digital representation with actual dimensions, tolerances and geometry information from multiple parties creates important benefits (see Figure 6). For example, as soon as a specific component reaches the next production step, the production equipment can use the dimension information to automatically adjust the production parameters to suit the incoming piece.

Figure 6: Exchange digital product characteristics



Source: Authors

The use of a digital twin also eliminates the need to manually exchange and check quality records. By aligning their quality control and return processes using a digital twin, companies can automate or eliminate unnecessary quality assurance processes.

How would that work?
As one example, a manufacturer can use a digital twin to stay within tolerance specifications, thereby preventing tolerance stacking. Tolerance stacking occurs when minor differences in the product dimensions stack up, until eventually the final product is out of specification. If a company along the value chain knows the exact dimensions of incoming materials, it can automatically adjust its process parameters to stay within the end customer's ultimate tolerance limit.

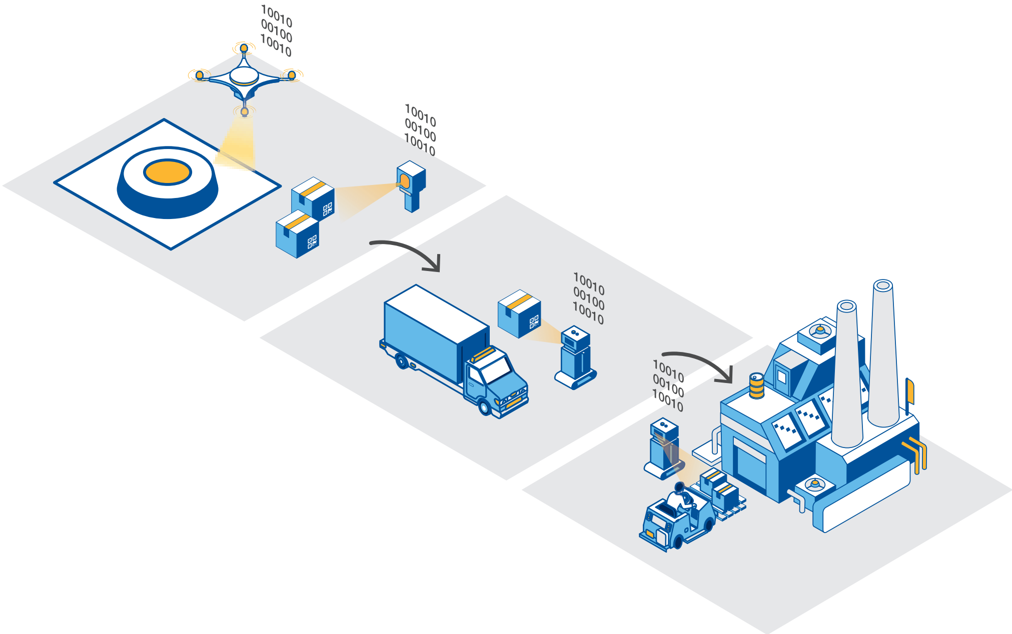
An OEM in the automobile industry has already used a digital product twin with a windshield supplier to adjust the final assembly process, to compensate for slight changes in the dimensional characteristics of windshields.

All suppliers contributing to the digital twin share the benefits of reducing manual quality controls and preventing tolerance stacking – but collaboration and trust between suppliers and manufacturers are prerequisites. Suppliers, for example, might be reluctant to share their data on the quality performance of their components. To encourage further trust and collaboration in such situations, contracts across the value chain should focus on participants' common key performance indicators (for example, quality delivered to the end customer).

Verify provenance. It has become more important for supply chain participants to know each component's point of origin and whether it is authentic (see Figure 7). At each production step, the producer must trust the supplier to provide a product with the characteristics that were specified in the order. Currently, producers verify this information through quality checks, audits and record keeping.

What is the challenge?
Unfortunately, in complex and heavily regulated supply chains, it is difficult to verify such information through these traditional methods, creating many opportunities for dishonesty and fraud. For high-value components or products, in particular, information regarding product origin or composition can be falsified, providing customers with a counterfeit component with lower quality characteristics than purchased. Another example is grey market diversion, with a supplier producing a higher volume of a specific component than requested and selling the excess units in a market other than the one originally intended.

Figure 7: Verify provenance



Source: Authors

How does data sharing help?
By sharing data, value chain participants can help identify fraud and establish provenance and authenticity. This requires a combination of technologies, where the raw material gets a tamper-proof unique identification that follows the material along its production life cycle. By sharing data, stakeholders along the value chain can create a continuous trail of records around this unique identification. With a tamper-proof trail, producers can then provide provenance and authenticity information as necessary by using this unique ID. The benefits are especially visible in industries that are heavily regulated, and where fraud and counterfeiting can be costly and the origin of products are of particular interest. In the diamond industry, for example, it is essential to establish authenticity and provenance to ensure that the diamonds have been ethically and responsibly harvested.

How would that work?
As good examples, Tracr and Everledger have introduced blockchain technology in the diamond industry to combat fraud and counterfeiting. Each company has developed a solution that assigns a unique identity to each diamond, records its characteristics and quality, and tracks each step of the process from the mine to the retailers.

To make such technology-driven solutions viable, it is essential that all stakeholders along the supply chain have adequate digital capabilities. For example, some suppliers might lack the digital capabilities or maturity needed to participate in a blockchain solution. The parties must also establish a secure identification solution for each product in the system that is tamper-proof throughout the product's journey.

Introducing the five application domains in which data sharing in manufacturing can be beneficial and providing real-world examples of various applications raised during interviews and a global survey of approximately 1,000 manufacturing managers conducted for this White Paper help to illustrate what data sharing means and how it works. In the following section, collaboration patterns common to these applications are briefly summarized, as are the barriers to collaboration.

3. Common collaboration patterns across data-sharing areas

A review of diverse areas in which data sharing can be applied reveals certain commonalties. This section describes the common aspects of collaboration and summarizes the main drivers and barriers that can be observed. Not all ways of collaborating related to data sharing are covered here, as the focus is on the findings from the interviews and survey conducted for this paper.

Starting with who collaborates with whom, three main models emerge:

– Between manufacturers through a third-party solution provider
– Between direct suppliers and manufacturers in a supply chain
– Between manufacturers through a machine supplier

Direct collaboration on product and production-related data between companies in the same value chain step is rare due to competitive and compliance challenges. For instance, two automotive OEMs will probably not share data on their products and production with each other directly, but if they wished to collaborate, they could do so through a third party.

In all these models, the two main factors that motivate data sharing are:

– **Robust analytics for high performance.** Manufacturers need sufficient data to further optimize production equipment. By sharing data and combining data sets, companies can implement solutions they would not be able to realize alone.
– **Increased transparency in value chains.** Manufacturers increasingly need more visibility into products (including their origin, authenticity, location and condition) and production processes in the end-to-end value chain. They can gain this transparency by establishing tracking and monitoring systems, continuous digital records and process automation along the value chain.

Manufacturers can choose from two levels of collaboration to support these motivations:

– A focus on a specific application either supported by a third party or coordinated by itself (for example, condition monitoring along the value chain using a specific sensor and a cloud solution)
– A more comprehensive partnership (for example, using a blockchain architecture to simultaneously address all related supply chain applications), establishing tracking, traceability, provenance, authenticity and a digital twin.

Looking at the mechanisms behind the data-sharing areas, the following barriers to data-sharing collaborations can be observed:

Table 2: Trust-related and technical barriers to data sharing

Trust-related barriers	Fear of unintentionally giving away valuable or sensitive data about the business
	Fear of losing negotiation power or a competitive advantage
	Lack of visibility into data usage and analysis once shared
Technical barriers	Risk of data breaches and losses
	Accessibility and interoperability issues that arise from combining data
	Different digital maturity levels among participants in the same solution
	Costs of switching technologies (or fear of technological lock-in)

To address these issues, successful collaborations use:

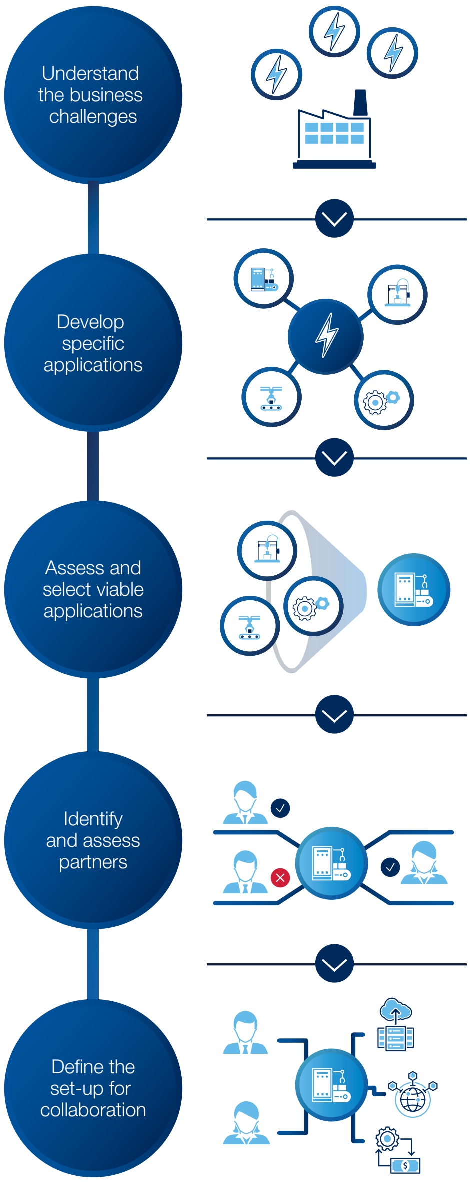
– A clear value proposition and rationale for data sharing
– Mutually beneficial agreements
– Secure technologies and common standards.

Based on this knowledge, a framework and set of tools can help manufacturers get started. The next section introduces this framework in detail.

4. How to get started

A five-step framework can help manufacturers start a data-sharing relationship (see Figure 8). This framework does not cover all aspects of building a complex data-sharing collaboration. Rather, it is a starting point for an informed discussion on the data-sharing applications and building successful data-sharing relationships, which the partners can then use to prepare their collaboration in detail.

Figure 8: Five-step framework



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The key to getting started is finding the right partners to pursue the value proposition and building their trust. Yet, data-sharing collaborations include unique challenges:

– Difficulty estimating the value of the data and the costs associated with the related risks without context information
– Necessity to assess the readiness of the entire group participating in the collaboration (to close skill gaps in the partnership if necessary)
– Need for iteration as the collaboration set-up the partners select might affect the risks, costs or type of data associated with the application.

To address these complexities, the framework proposed is iterative and contains checklists and assessments to:

– Assess and select data-sharing applications (checklist)
– Identify the right partners for the application (assessment)
– Define the right set-up for the collaboration (checklist).

While several factors must be examined when using these tools, the following points will help address the main issues.

Assess and select data-sharing applications. To understand data-sharing applications, companies must, at a minimum, investigate four aspects of data sharing: scope, accessibility and quality, value and risk.

– **Scope.** Clearly define the scope of the data: which data will be shared and when (for example, continuously or batched daily). This allows all partners to better understand the effort required to implement the application and associated risks.
– **Accessibility and quality.** Assess the availability and quality of the data necessary for the application. This will help to determine the amount of effort needed for data preparation.
– **Value.** Estimate the potential value of the data-sharing application and compare it to the cost of implementing and running the application.
– **Risk.** Clarify associated risks and other possible legal barriers to data sharing in this context.

It can be difficult to assess the value and risk associated with sharing data because they are largely determined by the context in which the data is being used. As a result, a careful assessment requires bringing together a variety of experts who can consider the applications from different angles.

Identify the right partners for the application. Identifying or selecting partners for collaboration is a complex task with several dimensions. The technical readiness and capabilities necessary for successful data sharing are:

– **Data availability and accessibility:** The availability and accessibility of data for the application, as well as mechanisms for changing, terminating and updating access rights to the data
– **Data organization:** Organizational structures, roles and expertise enabling data sharing
– **Data infrastructure:** Platforms, tools, models and architectures currently in use and applicable for data sharing and guaranteeing security.

For a data-sharing alliance to succeed, partners must have the technical capabilities required to implement the application together. All participants must have similar digital maturity levels to enable a common system to function securely.

Assessing these factors for all possible partners allows the collaborators to perceive the strengths and weaknesses of the alliance. If the participants find that one dimension critical to the application is not properly addressed, they can bring on board an additional partner to raise the technical readiness to an acceptable level.

Define the right set-up for the collaboration. The participants must consider multiple dimensions to select the right set-up for the collaboration. The following three aspects are the most relevant as they allow more targeted discussions when preparing the implementation:

- **Mechanism and governance.** How will the data-sharing relationship be structured (for example, direct sharing, through a machine supplier or through a service provider)? Who will own the data?
- **Compensation.** How will the parties share the value created (for example, no compensation, service as compensation or shared according to an agreement)?
- **Technology.** What specific technical and architectural elements must be considered (for example, data flows, data security and data interfaces)?

The right set-up strongly correlates with the type of application and is based on the common collaboration models discussed earlier. For some applications, such as implementing preventive maintenance, the sharing mechanism could be through a machine supplier, compensation could be through an increased level of service, and processing could occur in a data warehouse.

An overview of how the framework functions appears in Figure 9, which provides an illustrative example, detailing the steps, checklists and assessment tools.

Figure 9: Illustrative example of the framework

Understand the business challenges

Challenge: An **engine manufacturer** continuously receives **damaged**, **out of specification parts**, which disrupts production processes.

Develop specific applications

Applications: The manufacturer considers two applications to solve the problem.

Example for next steps

Instal sensors to record transportation conditions (vibration, temperature, etc.)

Share process characteristics to understand the production parameters along the supply chain

Assess and select viable applications

Assessment: The manufacturer selects applications based on the assessment.

Scope	Data concerning the vibration, temperature, orientation and humidity are continuously tracked.
Accessibility and quality	Wireless data loggers are needed to ensure continuous monitoring.
Value	Positive business case proved, allowing savings from less damaged parts due to lack of careful handling by truck drivers and low costs of installing sensors and scanners at critical interfaces.
Risk	Minor data leakage risks; no legal barriers are identified.

Identify and assess partners

Readiness check: The manufacturer identifies partners and assesses data-sharing

	Supplier ✓	**Logistics provider** ✓
Data availability and accessibility	Installation of data loggers with supplier possible	Logistics provider and drivers allow tracking process
Data organization	No specific data organization necessary	No specific data organization necessary
Data infrastructure	No special infrastructure for data transmission needed	Infrastructure needed to frequently transmit data

Define the set-up for collaboration

Set-up definition: The manufacturer, supplier and logistics provider define the-data-sharing mechanism, compensation model and technology.

	Manufacturer, supplier, logistics provider
Mechanism and governance	The logistics provider and manufacturers both have visibility into data and agree on an automated processes to resolve out-of-spec issues.
Compensation	The manufacturer covers full implementation costs and contractually agrees with supplier and logistics provider on future claim management.
Technology	Condition data is acquired via wireless data loggers; the data is sent and processed to a cloud solution via mobile data through the logistics provider.

Source: Authors

5. Key enablers of successful data sharing in manufacturing

After applying the framework proposed in the previous section, manufacturers still have a lot of work to do to prepare the sharing of the data. Data sharing between companies is complex and partners need to overcome numerous barriers.

Participants in the survey and interviews cited many reasons for not sharing data. Chief among their concerns are security and safety, the potential loss of trade secrets, the fear of losing negotiation power and the difficulty of measuring the value of data. Those manufacturers that already share data reported that their main challenges are legal uncertainties pertaining to ownership, restrictions and regulations, and technical obstacles (such as interoperability issues).

The research conducted for this paper identified four key enablers of successful data sharing that can help manufacturers address these challenges:

– Selecting technologies
– Using common standards
– Building trust
– Having legal and regulatory certainty

a. Selecting the right technology

Manufacturers have several options today for enabling secure data-sharing collaborations. Risks will always exist, but companies that select the right technology infrastructure and architecture can reduce these risks to an acceptable level.

Companies have several options to consider in their selection of data repositories, platforms and cryptographic techniques. A data lake on a cloud service might be sufficient for one application, while another might require a blockchain solution. Additionally, companies in the financial and insurance industries are implementing new privacy-enhancing techniques that might enable interesting applications in manufacturing. This paper's appendix provides a brief overview of these technologies, their advantages and disadvantages, and how they relate to data sharing in manufacturing.

b. Using common standards

Data sharing in manufacturing requires machines and sensors as well as companies that speak the same language so they can easily aggregate and analyse data. To overcome interoperability issues, data-sharing arrangements require several layers of standardization.

Initiatives are under way to help manufacturers meet the challenges. Some organizations are developing standards that facilitate the communication of manufacturing data, while others are developing common reference architectures to use industry-wide. Additionally, alliances are emerging to define common data models that will help make sense of data.

However, because more work is still needed, a global standard governing all aspects of data sharing will probably not be available in the near term. Despite the absence of a global standard, manufacturers have several options and resources available to them. The appendix provides a brief overview of these standards and reference architectures and why they are relevant to manufacturing.

c. Building trust

The main barrier to successful data-sharing relationships is building trust between collaborating partners around a clear value proposition. To promote trust, companies need to:

– Regard data as a business asset and consider it in their value proposition
– Build relational contracts that focus on common goals and mutual benefit.

View data as an asset. The concept of data as an asset is not new. However, advances in the internet of things, analytics and AI have elevated the importance of properly understanding, categorizing and managing data. Seeing its data as a business asset helps a company to place a value on it and take appropriate actions to protect, share or sell it.

As is true when sharing any asset, before a company shares data, it needs to understand the value it is offering and the value it is receiving in return. If the value a company receives in exchange for its data does not exceed the value of keeping the data in-house, it will not engage in data sharing. Unfortunately, establishing the value of data can be especially difficult.

Today, people can trade data in, for example, data marketplaces. Theoretically, by offering a data set in a marketplace, a manufacturer could gain an objective understanding of its value. However, no manufacturer would place its sensitive product and production-related data in a marketplace solely for this purpose.

Moreover, it is essential to consider context when assessing the value of data. A specific type of data might have value in one application, but might not be valuable for another application. For example, although data on machine vibration might not have value alone, this data becomes valuable when applied to reduce breakdowns and improve machine uptime. Thus, to place a value on data, a manufacturer needs to put this data into context and consider how it can be applied. Only then can it calculate a value for each application.

To fully assess the contextual value of data, a manufacturer must consider the risks that could arise from sharing data in a specific context. For example, the amount of storage space a company uses in a cloud system might initially seem like irrelevant "exhaust" data that it could share.

However, another party in a data-sharing relationship could use this information to gain insight into how the business is performing. So, even sharing exhaust data could be damaging to the business.

To meet the challenges of valuation, manufacturers need a structured way to manage their data assets, categorize them with respect to what is and what is not shareable, and carefully assess the value and risks arising from each use. Without this knowledge, companies will shy away from data sharing and prefer to keep their data, hampering innovation and making it difficult to generate value.

Focus on win-win solutions and build relational contracts. In data-sharing relationships and data value chains, it can be difficult to define the concept of ownership. For example, if a data service provider combines and transforms multiple data sets, the partners in the arrangement may find it difficult to claim ownership of the final data set. Beyond ownership, the service provider and partners must also manage data access and usage.

Companies in data-sharing relationships currently use contractual agreements to define which parties have access to which data and the permissible uses for the data. To enable successful data sharing, contractual agreements need to consider rules for accessing and storing data, limitations on aggregation, use and further sharing of the data, among other issues, as outlined in a paper on data as an asset by global law firm Baker McKenzie. The contracts also must define how the parties will be compensated and how they will share the benefits arising from data usage. To share the benefits, the parties need to align their different interests and focus on win-win solutions that create value for each of them.

The new concept of relational contracts introduced in *Harvard Business Review* offers a way to meet these challenges. In relational contracts, the parties specify mutual goals and establish structures to keep their interests aligned over the long term. Relational contracts focus on the parties' vested interests and aim to achieve a successful relationship that promotes these interests. By contrast, a traditional contractual agreement sets out all possible risks and attempts to govern all aspects of the relationship through strict clauses.

In the context of data sharing in manufacturing, a supplier and a producer each have a vested interest in the quality that the final customer receives. Suppose these parties can improve the quality of an end product through data sharing (for example, by jointly optimizing process parameters or creating a digital twin). In such a scenario, using a relational contract that focuses on quality targets would be much more effective than a traditional contract that defines the quality level that the supplier must provide to the producer.

Suppliers and OEMs in Japan have started to adopt these contracts. The OEMs collaborate closely with their main suppliers in many areas, including to reduce quality problems. In these arrangements, OEMs recognize that their success depends on their suppliers, and suppliers know they will get the support they need from OEMs by being transparent. These leading-edge companies understand that building trust into their relationship at the contractual level is an important aspect of their success.

d. Having legal and regulatory certainty

Governments have an important role in helping manufacturers realize the potential of data sharing. Regulations and policies relating to data can create barriers to data sharing. Localization requirements are an example. Countries use these requirements to make companies store specific data within their boundaries or to place restrictions on the flow of data. Such requirements can make cross-border data sharing in supply chains quite difficult. Indeed, the World Trade Organization has cited data localization laws as digital trade barriers.

At the same time, the developments are encouraging. For example, the European Union recently enacted a regulation that practically eliminates localization restrictions on non-personal data within its jurisdiction, thereby enabling this data to flow more freely.

Similarly, governments, industry and other public stakeholders can investigate together new ways of collaboration to unlock data and provide services in the public interest. One such development are data trusts. The Open Data Institute defines data trusts as new structures in which data owners give control over their data to a group of trustees that looks after the interests of the data owners as well as users – helping users provide benefits to society. Options like these can be further investigated to understand how they would apply to manufacturing.

Additional incentives and efforts are necessary. Governments, together with industry associations, can further support industry-wide standardization and incentivize the use of common architectures and standards. Finally, governments can choose to directly support business to help create a level field. The Korea Data Agency, for example, provides various data-related solutions for the manufacturing industry. This includes supporting small and medium-sized enterprises with "data vouchers".

6. Conclusion

So what does the future hold for data sharing in manufacturing?

In one vision of the future, advances in AI will lead manufacturers to become much more protective of their data assets and much less willing to share them. Working within closed ecosystems, businesses will compete to lock others into their structures. In another vision, manufacturers will freely share data using globally accepted standards, reference architectures and common models. Because all data will be available and easy to access as necessary, manufacturers will not even have to worry about specific applications. But in the short term, data-sharing practices will likely fall somewhere in between these two extremes.

Every manufacturer has an opportunity to immediately start unlocking value through data sharing. To make it happen, leaders in manufacturing must establish a clear vision, develop the right value proposition and select the right set of partners by building trust within its ecosystem.

Once these prerequisites are in place, manufacturers can focus on overcoming other barriers to data sharing, such as security, privacy and interoperability. By using a structured approach as presented in this White Paper, leaders can identify relevant applications and establish successful collaborations.

Despite many uncertainties, the recipe for success is clear: experts, industry participants and governments must intensify their collaboration around data sharing to enable more manufacturers to become masters of digitization.

This work and White Paper will inform further conversations in this field. The World Economic Forum Platform for Shaping the Future of Advanced Manufacturing and Production provides a space for these discussions and for developing new collaborations aimed at facilitating data-sharing opportunities.

Appendix

a. Technologies

Data sharing generally starts with combining data from various fragmented resources in one repository, which a company can then use to complete analyses and establish platforms. *Data warehouses* are repositories of structured data sets. The data has already been selected from different sources, cleaned and integrated in a predefined structure. *Data lakes* are repositories of unstructured data that has been combined without the initial cleaning step; a company can structure the data as needed for specific applications. Data lakes are useful for storing and utilizing live data, which makes them especially valuable in data-sharing areas that require continuous monitoring and fast reaction, such as tracking.

Companies may also choose to use data warehouses and data lakes in combination, depending on the applications. There are established technologies that allow companies to build data platforms using generic cloud services, such as Amazon Web Services (AWS), Google or Microsoft, or industry-specific service suppliers, such as Palantir. Several manufacturers, primarily larger companies, are already using such solutions in their supply chains to manage data from their suppliers.

Manufacturers can also set up platforms that are independent of specific applications and ask their suppliers and other companies to join them. In these platforms, multiple companies can share data and make use of different services. To set up such platforms, manufacturers can select from among a variety of technology solutions. Leading companies are already pursuing these options. For example, Volkswagen recently announced that it has created a collaboration platform on AWS to connect its own factories, with the goal of eventually integrating suppliers. BMW and Microsoft also recently announced the establishment of a platform in which several companies can combine their data using an open architecture and open source components to innovate on new solutions.

Challenges and security vulnerabilities come with preparing, cleaning and combining data in such arrangements. The Big Data Value Association in its recent position paper, "Towards a European Data Sharing Space: Enabling data exchange and unlocking AI potential", cites the following technical challenges:

– Preparing and cleaning data is time-consuming, especially if no standard naming conventions and reference architectures exist.
– Data owners have difficulty maintaining and managing their data ownership in a combined data repository.
– Guaranteeing what happens to the results of data analyses is difficult.
– Secure access control and confidentiality are difficult to guarantee.
– Tracking the accuracy and correctness of data is problematic and no widely accepted quality standards exist.

Blockchain technologies can address some of these issues by enabling a shared, distributed ledger of records or transactions. The ledger is open to inspection by every participant but not subject to central control. From a technical perspective, blockchain has several advantages, such as providing a single version of the truth, ease of auditing and the immutability of the record. These aspects of blockchain make the technology attractive to use in supply chains to establish provenance and traceability, streamline processes and automate selected processes.

Manufacturers, however, have been slow to adopt blockchain (or distributed ledger technologies in general). According to a global blockchain benchmarking study, companies are mainly concerned about privacy and confidentiality issues. Other concerns, such as scalability, performance, costs and finding suitable applications, are less prominent. Even though blockchain brings many advantages, it is not possible to fully eliminate the security risks arising from the fact that multiple participants can access data in the distributed ledger. Blockchain is also not the best solution in cases where personal privacy is an issue. Because it creates an immutable record, blockchain can make it difficult to comply with regulations regarding personally identifiable information.

Certain emerging technologies promise to increase privacy and reduce the risks associated with data sharing, by allowing users to analyse and work with data without seeing the underlying data. Several developments are relevant to manufacturing:

– Zero-knowledge proof is a cryptographic technique that helps users to prove their statement is true without revealing information about the statement itself.
– Homomorphic encryption entails encrypting individual data sets before they are combined and analysed, so only the data owner can decrypt and see the results. Google calls this technique "Private Join and Compute" and recently released it as an open-source cryptographic tool.
– Federated analysis entails parties' sharing insights from a local analysis of their data without having to combine data at a central location.
– Secure multiparty computation combines some of these techniques, where different parties work on the same problem without revealing their set of inputs and outputs.

These privacy-enhancing techniques, combined with blockchain, can provide a high level of security and trust between manufacturing companies that are sharing data and address most of the trust-related issues. Although companies in the finance and insurance industries have applied these privacy-enhancing technologies, their application in manufacturing requires further investigation.

In their efforts to gain value from data sharing, manufacturers should take cybersecurity seriously and build resilient systems, examining the means to secure their ecosystems and the level of security that is critical for success.

b. Standards

To avoid issues with interoperability, manufacturers must select the right architecture and standards for working with their shared data. Indeed, some experts regard interoperability as the main barrier to data sharing in the industry. On a technical level, standards ensure that every sensor, machine and company in a data-sharing relationship uses the same methods to collect, aggregate, communicate and analyse data. In the absence of this uniformity, companies cannot make use of certain different pockets of data.

Enabling interoperability for data sharing is analogous to enabling communication among people who speak different languages. Languages use different words to refer to the same object and different grammatical structures to convey the same message. But people who do not already use the same words and structures can refer to dictionaries and translate their languages in order to communicate.

The same logic applies to interoperability. Sensors, machines and products generally do not speak the same "language" today. What's more, companies use different methods to gather, aggregate and exchange data. By using common dictionaries, models and communication standards, companies can facilitate data sharing and accelerate data aggregation and analysis. Companies or their service providers can define proprietary structures for each data-sharing project or they can select from among widely accepted reference architectures and standards.

Several initiatives are under way to create data-sharing standards for manufacturers. For example, the OPC Foundation has developed the Open Platform Communications (OPC) Unified Architecture to provide standards for the communication of manufacturing data in various industries. Using these standards as a basis, organizations such as VDW (the German Machine Tool Builders' Association) are building common interfaces between machine tools, software and information technology systems. Various national and international organizations and industry associations have also proposed reference architectures for the manufacturing industry, such as:

- Reference Architecture Model Industrie 4.0
- Industrial Internet of Things Reference Architecture
- Industrial Value Chain Reference Architecture
- International Data Spaces Reference Architecture.

Additionally, technology companies have established proprietary reference architectures specific to their data platforms, such as the Microsoft Azure Industrial IoT Reference Architecture.

By using such reference architectures, common standards and models, companies can build alliances and unlock the data within each alliance's ecosystem. However, to take full advantage of data sharing over the long term, manufacturers need standardized interfaces not only within ecosystems but also between them. Some companies, especially small and medium-sized businesses, participate in multiple ecosystems. A small supplier that works with multiple customers in different ecosystems might be invited to join several alliances, each of which uses a different standard or technology. For example, there are currently several blockchain technology solutions, such as Hyperledger Fabric, R3 Corda and Ethereum Enterprise. A supplier might be locked into a specific solution so that it can work with a specific customer, or might encounter high costs to switch technologies.

Recognizing the challenges, various organizations are seeking to enable interoperability between ecosystems. For example:

- The International Organization for Standardization (ISO) and other standardization institutions have developed standards for increasing transparency and harmonization. An example of such a standard is ISO 20614, "Information and documentation – Data exchange protocol for interoperability and preservation".
- Enterprise Ethereum Alliance is a member-driven standards organization that aims to develop open specifications for blockchain applications.
- GS1, a not-for-profit organization, develops and applies standards for unique identification numbers, so that companies can bridge gaps between blockchain ecosystems, when needed.

Because many initiatives have been launched to develop standards and common models that govern data sharing, interoperability and communication at the interfaces will most likely not be the main impediments to data sharing, if companies select widely accepted common standards.

The application of standards and the use of common reference architectures will help companies make the most of their data. Further standardization should be pursued but it is not realistic to wait for a global standard to be adopted as manufacturers will always need to cope with regional differences, company preferences and industry-specific knowledge to understand data, legacy machines, custom-made systems and diverse digital maturity levels.

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