

DIGITAL MANUFACTURING TRANSFORMATION (INNOVATIVE BUSINESS OPPORTUNITIES FOR MANUFACTURERS)

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ABSTRACT

The digital thread represents the origination, flow, and consumption of data through machines, people, and systems across the enterprise of a manufacturer. In this paper, we explore unique manufacturing use cases and business opportunities derived from, and driven by, the digital thread and enabling technologies, with machine asset data as the cornerstone. The digital thread connects the various processes, entities, actions, and decisions across a company's supply chain through data and data relationships, helping to ensure an organization runs efficiently and in unison. By stitching together critical product information with digital assets across the full product lifecycle, a digital thread empowers manufacturing companies to drive continuous improvement and innovative new business processes and models. The benefits of data-driven manufacturing are far too significant to ignore and will enable many to deliver competitive advantages in an ever-competitive landscape. Digital transformation is about changing business models and about companies not just taking advantage of the huge opportunities created by these latest technologies but also preparing for their constant evolution. Amid the hype surrounding Industry 4.0, IIOT, and digital transformation, the introduction of Industry 4.0 has caused a bit of a culture shock for manufacturers. To build a roadmap to digital transformation, most companies are looking into the future, attempting to visualize where they want or need to be in twenty years, and planning backwards. However, a great deal of hesitancy exists for many manufacturers to embrace the technology and modernization that solves these new challenges.

KEYWORDS: *Industry 4.0, IIOT, Manufacturing's industrial iot platform.*

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Introduction

Amid the hype surrounding Industry 4.0, IIOT, and digital transformation, the introduction of Industry 4.0 has caused a bit of a culture shock for manufacturers. The benefits of data-driven manufacturing are far too significant to ignore and will enable many to deliver competitive advantages in an ever-competitive landscape. Digital transformation is about changing business models and about companies not just taking advantage of the huge opportunities created by these latest technologies but also preparing for their constant evolution [1].

These new models for technology-enabled manufacturing have already moved into the implementation phase by many of the world's top manufacturers. However, a great deal of hesitancy exists for many manufacturers to embrace the technology and modernization that solves these new challenges. This hesitancy is a product of a few specific factors:

- **Lack of clear vision and strategy**

Roughly 50% of US companies admit to not having a systematic roadmap or toolbox for easy rollout of digital manufacturing solutions. Because no standard roadmap for digital manufacturing exists, companies are often uncertain around where to start and what foundational capabilities are required to succeed.

- **Lack of competent tech partners**

15% of all US companies identify lack of knowledge about suitable providers as their biggest obstacle. Business leaders need to understand which technology solutions address their core business problems as well as the right criteria for evaluating solution providers.

- **Difficulty managing and attracting digital talent**

21% of all US companies are facing a talent war as their biggest obstacle in transformation – companies need to build capabilities in-house in order to implement new strategies and tactics; experiential learning is the most effective way to build capabilities quickly.

Innovative business opportunities for manufacturers

Despite producing the most data, manufacturing is ranked last in digital transformation efforts. Compared to all other global industries, manufacturing is still caught in a state of reactivity. While some analytics companies have attempted to develop various solutions to address this problem, it has yet to be truly solved. There is no silver bullet. There is, however, a starting point.

Industry 4.0 help companies overcome the challenges along the digital transformation journey and to advance them forward from reactivity, to proactivity, and to predictivity. We are dedicated to empowering our customers to not just employ the latest technology but to achieve success along their individual journeys. How do

we do this where so many other companies have failed? It's all about knowing where you stand and planning for the road ahead.

Most manufacturers are caught in a state of reactivity. Despite producing the most data, manufacturing is ranked last in digital transformation efforts. Compared to all other global industries, manufacturing is still caught in a state of reactivity. While some analytics companies have attempted to develop various solutions to address this problem, it has yet to be truly solved. There is, however, a starting point.

To build a roadmap to digital transformation, most companies are looking into the future, attempting to visualize where they want or need to be in twenty years, and planning back-wards. We often talk to companies who have predictive and preventative aspirations but who still don't have machines networked, the necessary IT infrastructure to capture and aggregate machine data, or the internal organizational resources required to decipher the data and implement continuous process changes.

For many however, a more proactive approach to planning would be to accept that "You can't know where you're going without knowing where you are now."

It's all about preparation

Here are a few areas of focus for any company to consider when building out their roadmap:

- *Organization*

To understand what you are solving for, it's essential firstly to be aware of what the problems are, and then to become capable of not just solving those problems but to ready ourselves for the greater problems in the journey ahead. Transformation requires buy-in at all levels, from the front office and on the shop floor, but it also requires internal leadership. It's critical for manufacturers to recognize the important role organizational attributes play in long-term project success and begin discussions about how the odds of project success can be increased by evaluating organizational gaps. Ask yourself: Where do we stand now? Does your team have the right people in place to implement new technology? Are there project leaders capable of owning this project?

- *Communication*

The information we need is available, but the hard part is actually applying it. Avoiding an "us vs. them" mentality is critical in this transition stage. It is vital to build trust between everyone involved in the manufacturing process so problems can be quickly identified, and new solutions can be effectively implemented as a team. Don't let a lack of communication stand in the way of change. Ask yourself: Does your team have an environment capable of communication and applying process changes not just from the top down but from the bottom up?

- *Waste reduction*

Before you embark on our digital transformation journey, it's important to get as lean as possible with your current capabilities. The goal of lean manufacturing is

continuous improvement of production processes, while eliminating waste and cutting costs. However, setting the stage for a lean process is just the first step; implementing a system that allows you to maximize your manufacturing productivity results will take your lean model to the next level. Ask yourself: Are we lean? Do we know what our top areas of waste are? Have we embraced lean manufacturing principles?

- *Key performance indicators*

Depending on the systems and processes you have in place on your factory floor, you may face one of two problems; either you don't know which key performance indicators (KPIs) you should track to enable you to improve your factory performance, or you are unable to collect sufficient data to accurately measure the KPIs you want to track. Having specific KPI's will allow you to assess, analyze and track our manufacturing processes, as well as to evaluate success in relation to goals and objectives. Ask yourself: What are our key performance indicators that we want to measure as a benchmark for our improvement? Do we have any information now that we can use for this benchmarking? Some of our top suggestions to get started? OEE, Machine Utilization, Set Up Time, Cycle Time, and Scrap Rate.

- *Tools*

Digital manufacturing will transform every link in the manufacturing value chain, from research and development, supply chain, and factory operations to marketing, sales, and service. Having tools to measure your efforts, for designers, managers, workers, consumers, and physical industrial assets will unlock enormous value and change the manufacturing landscape forever.

Of course, every company will need tools to help them optimize their capabilities, but for this job some tools will make more sense than others. Your KPI's will help you assess which tool will allow you to capture the information you are looking for that best fit your company's needs. Ask yourself: What tools do we want to use to measure our efforts? What tools are we already using that we can leverage now?

- *Digital connectivity*

The cloud can be your best friend, and with security being better than most on-site solutions systems, the benefits are tremendous. Increasingly more companies are developing or moving their workloads to the cloud by the day, aiming to migrate everything onto the cloud over the next few years. This digitization of data will enable you to deliver competitive advantages in an ever-competitive landscape. Networking your machines and ensuring that all production data can be captured is one of the most essential capabilities for real-time analytics. Ask yourself: Are you ready to digitize our assets? Do you have the technical assets in place to capture and store the data?

Once you've completed your capabilities reality check, it's time to begin building your roadmap. Using our areas

of focus, your roadmap should actually be quite logical at its core.

STEP 1: get capable

Let's become as capable as we can and have all our ducks in a row to ready ourselves for the greater journey ahead.

STEP 2: digitize

Once we've optimized capability, it's time to digitize our assets, visualize our manufacturing data in real-time, and measure the success of our KPI's using our tools

STEP 3: analyze

We can then advance our use of this data to begin applying predictive and preventative models to our processes with the hopes of furthering our optimization efforts.

STEP 4: virtualize

We can then virtualize these efforts into an integrated manufacturing system framework to support the interoperability between our digital factory tools to solve any real time problems as they arise

STEP 5: automate

Link design, engineering, manufacturing, supply chain, distribution and services into one intelligent (smart) automated system that can be used to self-improve both products and processes within the system.

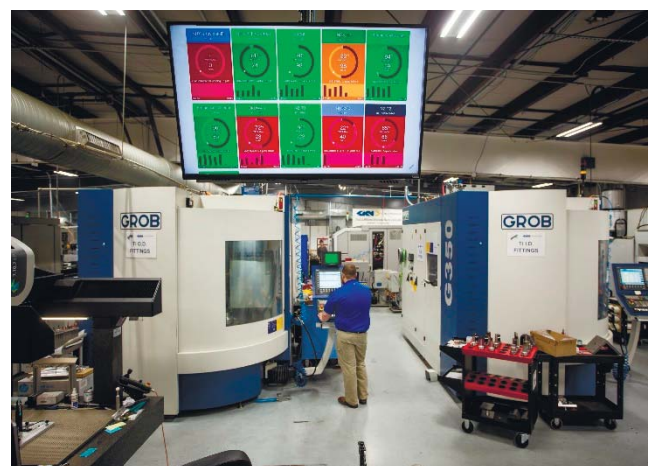
It's time to shift the focus from the future to the now. Factory Floor Monitoring & Analytics. The problem:

- Poor production visibility
- Lack of communication
- Shop-floor data isolated in silos
- Underutilized equipment
- Process inefficiency

The challenge:

- Roughly 50% of US companies admit they lack a systematic roadmap to digital manufacturing solutions and automation.

- Over 90% of companies have yet to attempt to integrate solutions.

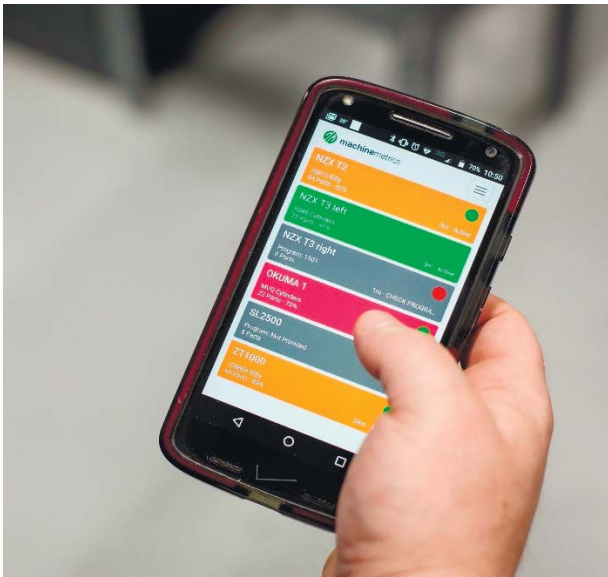


We gathered feedback from 100+ manufacturers on why current solutions did not fit their needs – and how they could be designed better.

Despite producing the greatest amount of data, manufacturing is the furthest behind any other global industry in their digital transformation efforts. With simple "self-install" IIoT connectivity, it is predictive analytics and machine learning platform allows manufacturers to harness, structure, and take action on this data, driving manufacturing efficiency by more than 20% on average for customers.

Machine learning platform

Fully automated machine monitoring solution provides visualizations of real-time manufacturing production data, notifications, as well as historical analytics, allowing factory workers to make faster, smarter, more confident decisions based on real-time data.



Touchscreen interface allows for operators to add human-context to machine data with touch screen tablet interfaces mounted right at the machine tool. Having a touchscreen at each machine with an intuitive interface that asks the operator to categorize downtime as it's happening allows this information to be made available in real-time to managers in downtime pareto charts. Operators can also reject a part using the Operator View to manage and record quality data. Quality managers are able to view the quality pareto in real-time and when there are new rejects, head to the machine in question, re-inspect the parts and re-allocate as necessary.

From the performance dashboard to the operator workcenter to our reporting features, the interface is designed to be user-friendly for operators, managers, and upper-management. Our customers agree is that our aesthetic is both visually appealing and intuitive. Because of the platform's simplicity, minimal training is required to get your team using the system and confident interfacing with the product.

MachineMetrics is incredibly easy to integrate and requires far less time for setup than most other machine analytics and monitoring platforms. We allow for the option of self-integration or to work with our on-site integration team. Manufacturers can start collecting data in minutes from networked machines. As a cloud application, there are no servers to manage, and no applications to update. All that's required is available internet and that your machines are on your network and accessible from our gateway.

We provides robust and superior reporting features including better OEE reports, job reports, downtime and quality pareto reports. Realtime OEE is available in various reports including the real-time dashboard, historical reports that can be compared by shift, and when viewing individual job/ part reports. Utilization, TEEP and OOE are also measured and visible in historical reports. Information such as cycle times, performance, number of parts produced, rejects, downtime reasons, and reject reasons can be reported on for each part operation.

This information is presented in eminently understandable form, allowing managers to quickly identify issues that are related to a specific machining operation and help measure the effect of process improvements.

MachineMetrics has the unique capability to connect to other types of software, including the ability to tie into a manufacturer's production goals / ERP to give real-time feedback on a job's performance, and a comparison with previous job runs. To date we have released deep integrations with Epicor and Infor Visual and our open API will allow to directly integrate with any ERP. By partnering with other best in class manufacturing software, we provide seamless connectivity of information silos via our digital threading.

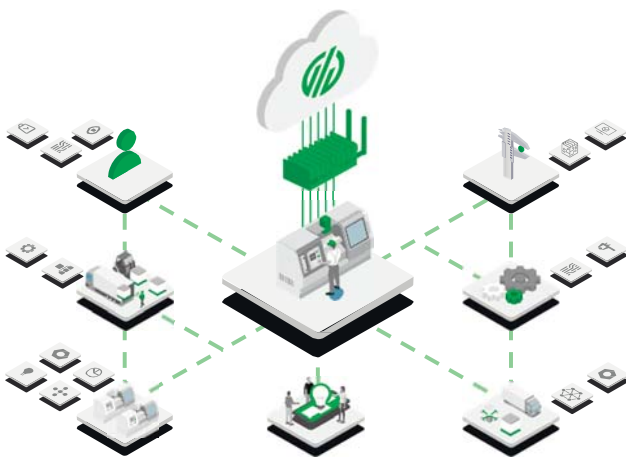
We have a team of developers that are adding new features weekly including ideas brought to us by our current customers. We understand that every manufacturer is unique and we don't want to shoe-horn them into a profile to sell them our software. Rather, we offer a set of tools to our customers and support them to use the tools for whatever fits them best.

There's minimal IT infrastructure required. Our mobile friendly software allows you to access your data from anywhere with a secure connection from your mobile phone or home PC without IT support or complicated firewalls and VPNs.

We can also roll out new features instantly upon approval, provides Full-Time unlimited support forever, with absolutely no hidden costs and provides all customers with a customer success manager (CSM) that, through routine meetings, helps train their team on our software and meeting their performance goals. Customers often make feature suggestions, and CSMs are dedicated to making those requests a reality.

Digital manufacturing

The digital thread represents the origination, flow, and consumption of data through machines, people, and systems across the enterprise of a manufacturer. In this paper, we explore unique manufacturing use cases and business opportunities derived from, and driven by, the digital thread and enabling technologies, with machine asset data as the cornerstone. The digital thread connects the various processes, entities, actions, and decisions across a company's supply chain through data and data relationships, helping to ensure an organization runs efficiently and in unison. By stitching together critical product information with digital assets across the full product lifecycle, a digital thread empowers manufacturing companies to drive continuous improvement and innovative new business processes and models [2].



Data as a foundation

At the heart of every manufacturing operation is the machine assets and the people that make the products. Machine assets in manufacturing plants produce thousands of data points every second and represent the preeminent component of the digital thread.

The insights and actions driven from the data provides the foundation for manufacturers to grow their business and differentiate themselves competitively. Today, manufacturers find themselves at different stages of a journey to leverage data and the digital thread to optimize and automate their business processes. We engage with many manufacturers who discover early in their journey that data from their plant operations is insufficient and unreliable. For key metrics such as equipment utilization, manufacturers, who do not have automated systems for capturing transformed, or contextualized, data from their machine assets, are often under the mistaken belief they are performing at a satisfactory level.

Our average manufacturing customer starts with a utilization of 28%, significantly lower than what is

perceived. Similar unsatisfactory statistics are also found for OEE, downtime, and other key metrics.

The underlying cause of the subpar, yet inflated, perception of performance originates with data that is captured manually. Manual data capture often results in data that is inaccurate, manipulated, or missing. It is a shaky foundation that cracks and buckles when attempts are made to drive continuous improvement and innovation. On the other hand, accurate real-time data automatically captured and transformed from machine assets creates a solid base for capturing insights and driving value.

Performance can be baselined across similar machines, lines, and plants with confidence knowing the underlying data is accurate. Machine asset performance can even be measured and compared to similar assets across a particular industry outside of the company. In the end, there is only one version of the truth and the machine does not lie. With accurate data capture and transformation, combined with visibility and actionability through notification and workflow triggers, a 15 to 20% improvement in utilization performance can be realized in a matter of months.

The operational thread

The most valuable assets of a manufacturing operation are the people who make the products. The machine operators, supervisors, and plant engineers are also significant contributors to the digital thread. Weaving the digital thread from machine assets through the people assets stitches together machine data with operational data, creating unique insights and improvement opportunities.

One such area of opportunity is downtime reduction. By enabling operators to categorize downtime events, manufacturers are provided with a thread that drives downtime reduction. Real-time machine data correlated with annotated downtime events from operators provides the foundation for optimizing processes that reduce downtime, such as machine and tooling setup processes. Additionally, the same data sets can be leveraged to generate algorithms and applications that predict tool wear and failure on critical machine assets.

GETTING OFF THE ISLAND

Data on an island, while not useless, does not deliver on the ultimate potential of the digital thread. Value achievement is accelerated by integrating data found in machine assets and operations with data residing on enterprise systems. Value realized from threading data through an ERP system uncovers multiple opportunities and use cases. For discrete manufacturers, a glaring example of lost opportunity associated with 'island data' lies in the inaccuracy of job standards and cycle times.

High mix discrete product manufacturers base their pricing, and by extension, their profitability, on the time it takes to machine a specific product. Inaccurate or sub-optimal job standards result in lost profits.

In many cases, job standards are entered and stored on an ERP system. How accurate are they? Are they updated? How are they calculated? Who entered the data? For many manufacturers, the subject of job standard accuracy leads to an ongoing debate without any clear answers. By capturing and tracking real-time machine and operational data, actual cycle times can be compared to those found in an ERP system, continuously updated, automated, and optimized.

By stitching together these key pieces of the digital thread, companies can optimize cycle times, reliably report on production performance indicators to their customers, and increase profitability.

Maintaining assets

The digital thread weaves its way through many facets of manufacturing operations and is key to maintaining critical manufacturing assets- both machine and people. The maintenance of critical machine assets in manufacturing plants is often accomplished by leveraging a Computerized Maintenance Management System (CMMS). One goal of a CMMS is to optimize the maintenance schedules of machine assets, minimizing the amount of scheduled machine downtime.

Achieving this, however, is difficult without threading, into the CMMS, real-time machine asset data that accounts for the actual operation of the asset itself. How do you optimize a maintenance schedule if you have no idea how long the machine has been running? Would knowing the load over time on the machine also be helpful in determining when a machine asset should be maintained? Threading machine asset data and insights into the CMMS can transform a maintenance strategy from reactive and calendar based to usage or condition based. Without a digital thread originating at the machine asset, the value a manufacturer can expect to achieve from a CMMS investment is significantly diminished.

And what about maintaining a manufacturer's most valuable asset- its people? Forward thinking companies are creatively weaving the digital thread into their Human Resource systems to enable innovative new processes. One example is generating performance reviews for plant personnel based on measured performance of the machine assets they are responsible for operating and maintaining. The same data can also be leveraged to capture best practices and improve operator and supervisor training programs.

Beyond a manufacturing plant

Extending the digital thread beyond the walls of a single manufacturing facility further increases opportunities to innovate and drive value. For manufacturers with multiple manufacturing facilities, for example, the digital thread enables operation of many facilities virtually as if they were all one. Business Intelligence (BI) systems enable manufacturers to create

dashboards and reports providing real-time visibility of key performance indicators across multiple plant sites. This enables comparative measure of performance across manufacturing plant machines, lines, cells, operators, and locations.

By having visibility into available capacity, manufacturers can make better decisions on where to manufacture their products, how to price them, and the timing of delivery. By weaving the digital thread through their planning, forecasting, and financial systems, manufacturers can also make more informed decisions on when plant capacity may need to be increased or decreased. In the past, decisions on capital purchases, specifically the purchase of new machine assets, was often made in a vacuum without the data required to justify the purchase.

Today, the digital thread ties together all required data and insights from multiple systems to ensure these critical financial decisions are data driven and justified.

The digital thread drives a similar set of business cases for original equipment manufacturers (OEMs) and their component part suppliers. Traditionally, suppliers manually provided historical reports to document their ability to meet OEM requirements for a specific part or product. These reports were also part of a process to compete for, and obtain, the business from the OEM initially.

Today, static reports with dated information, are a thing of the past. OEMs can treat their suppliers as virtual extensions of their own business through the digital thread. By insisting on automated machine data capture and performance insights from operations, along with BI and other system technologies, OEMs can gain a real-time view of the performance of their suppliers and the status of their component products. This also results in a data driven approach for evaluating and selecting suppliers. For the suppliers, the enabling technology and systems that power the digital thread, will be a requirement to stay in business.

The product thread

Products are designed, developed, manufactured, sold, shipped, and serviced. The digital thread ties together the various life cycle stages, creating opportunities to innovate and optimize the processes and systems in each functional silo. When manufactured products are developed, or new features are added to existing products, it is often difficult to determine how effectively the products or features are being used once the product reaches the customer. The digital thread has created new opportunities to 'close the loop' between design and development, and the actual use of the product by the customer.

Advanced sensors built into manufactured products collect product usage data and transmit that data back to the manufacturer, allowing the manufacturer to obtain real-time feedback on the performance of the product. Stitching customer usage data into CAD/CAM and Product Lifecycle Management (PLM) systems provides the insights required to optimize the design and development

of new products and incremental product features and enhancements.

For a manufacturer, the digital thread also closes the loop between product design and the manufacturing process. Does the product, when manufactured, meet design requirements? If not, what adjustments need to be made to the manufacturing process? For discrete manufacturers, this often requires capturing specific data from machine control systems, machine tools, quality systems, and other systems, and weaving the data into design and 3D simulation systems.

The ability to leverage the digital thread to create 'digital twins' represents an advancement where objects, processes, and systems can be modeled and represented virtually. The virtual representation of a system, driven by data from the digital thread, can then be continuously optimized to meet the goals and objectives of the manufacturer.

Machine as a product

At MachineMetrics, we work closely with the manufacturers who manufacture the machines/machine builders. The machine builders are focused on ensuring their customer, the manufacturer, receives outstanding service and support. The digital thread facilitates this goal by enabling diagnostic data, related to the health and performance of the machine, to be accessed remotely by the machine builder.

By extending the digital thread to the machine service provider, the machine builder or distributor can remotely diagnose health related machine issues, potentially resolve the issue with the customer, or determine if a technician needs to be dispatched to the plant. If a service call at the plant is required, the technician can diagnose and identify issues ahead of time, ensure the right tools and spare parts are available. The result is a higher quality, more efficient service.

Some machine builders, either directly or through partners, provide turnkey systems that include performance guarantees around the operation of a machine, cell, or complete production line. Having remote access to key performance data allows the machine builder to monitor performance and ensure performance guarantees are being met. The machine building business is highly competitive. Machine builders and their distributors are often required to prove their capabilities in competitive run offs with other builders.

They are benchmarked and measured around a variety of factors ranging from speed, quality, and versatility. The ability to prove out any claims through data provides a competitive advantage. The ability to leverage the digital thread to document benefits and competitive advantages while the machine asset is in production on site creates an even more distinct advantage. This advantage is magnified when conveyed in the context of a manufacturer's specific needs and requirements-capacity constraints, machine asset bottlenecks, performance and benefits relative to

older equipment, etc. Tying this machine data thread to a Customer Relationship Management (CRM) system and targeted customer data can provide a potent weapon for a machine builder or distributor working to drive sales growth.

Digital thread as a service

The digital thread is accelerating the creation of new business models that promise to disrupt just about every industry. For manufacturers, whether it is selling complementary products or services around the manufactured product or providing the product as a service, the digital thread is creating opportunity for some while eliminating the need for others.

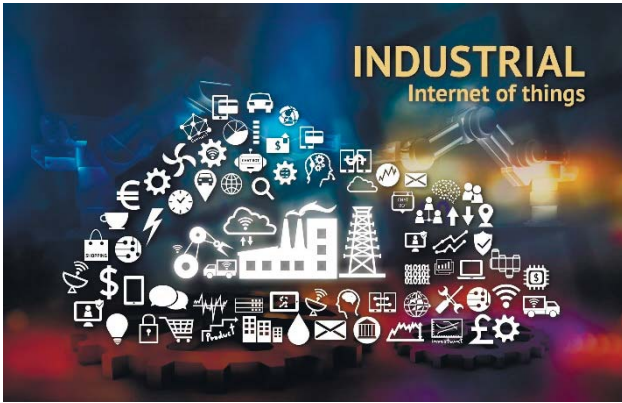
Participants in the manufacturing ecosystem need to understand the potential ramifications, both positive and negative, on their business going forward. One example of business model innovation brings us back to the machine builder. How does the manufacturing industry evolve if machine builders stop selling their machines and begin providing them as a service? In other words, the manufacturer would not buy or own the machine asset, they would purchase the right to run the machine for a specified time or to make a specified number of parts or products.

They would essentially be purchasing a machining service. That service would include training, support, maintenance, and servicing of the machine all included in the service fee. No hidden fees provided the machine is operated within specifications. But how do you determine if the machine is being operated properly? What if the machine is operated outside of the guidelines and parameters for performance and safety? With the digital thread, a machine builder would have remote monitoring capabilities, access to all critical operational data, and the ability to automatically trigger alerts, notifications, and work processes if specific operating parameters were exceeded.

What other services could the machine builder potentially offer under this arrangement? Perhaps a service to manage the tooling supply and processes for the machine equipment. Augmenting this with the ability to predict tool failure and guarantee uptimes would drive tremendous value for a manufacturer. What about managing spare parts inventory? And for those companies who provide specialized machinery, or turnkey machine cells and lines, this could extend to the complete manufacture of certain products as a service.

Conclusion

In this disruptive model, who takes the lead? The machine builder seems like the obvious choice with built in advantages and much to gain. But perhaps it is a different group – maybe insurance companies or the machine distributors? How about the control system suppliers? Who are the partners and who are the competitors? And who gets left out? Does the machine builder still need distributors?



What about many of the ancillary services that in the past were provided by others? And how might this impact the business of the manufacturer? This could lead to many functions of the manufacturer being outsourced to other entities, resulting in smaller, leaner, manufacturing companies.

While this entire discussion may sound hypothetical, I can assure you it is not. There are companies who are moving to some variant of this model as we speak. The digital thread and the technologies that enable and support both the thread and the business model exist today. First mover advantage is already underway.

The Industrial Internet of Things is fundamentally changing the entire economic model of supplier-consumer interaction. This allows:

- automate the process of monitoring and managing the life cycle of equipment;
- organize effective self-optimizing chains from enterprises-suppliers to companies-end consumers;
- move to "sharing economy" models and much more.

In the most advanced cases, the Industrial Internet of Things makes it possible not only to improve the quality of technical support for equipment using advanced telemetry tools, but also to ensure the transition to a new business model for its operation, when the equipment is paid for by the customer upon the fact of using its functions.

The introduction of network interaction between machines, equipment, buildings and information systems, the ability to monitor and analyze the environment, the production process and its own state in real time, the transfer of control and decision-making functions to intelligent systems lead to a change in the "paradigm" of technological development, also called "fourth industrial revolution".

References

- [1] Graham Immerman. Digital Manufacturing Transformation. Roadmap. machinemetrics.com.
- [2] David Westrom, Graham Immerman. Weaving the manufacturing digital thread. machinemetrics.com.
- [3] Abdel-Basset M., Moustafa N., Hawash H. Deep Learning Approaches for Security Threats in IoT Environments. Piscataway: Wiley-IEEE Press, 2022. 387 p.
- [4] Bell Charles. Beginning IoT Projects: Breadboard-less Electronic Projects. Apress, 2021. 875 p. ISBN 978-1-4842-7233-6.
- [5] Chaudhuri Abhik. Internet of Things, for Things, and by Things MOBI CRC Press, 2019. 303 p. ISBN: 978-1-315-20064-4
- [6] Dagnino A. Data Analytics in the Era of the Industrial Internet of Things. Springer, 2021. 150 p. ISBN 13 9783030631390
- [7] Tomar Pradeep. Integration and Implementation of the Internet of Things Through Cloud Computing. IGI Global, 2021. 388 p. ISBN 978-1799869818