THE ADAPTIVE DIGITAL FACTORY™

The Internet of Everything in End-To-End Manufacturing and Product Lifecycle Management

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BUILD FOR CHANGE®

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Foreword

Digital Transformation has arrived in global manufacturing, and "manufacturing" as we've known it – in the value streams of making things as well as the industrial systems that surrounds them – will never be the same.

In The Adaptive Digital Factory, my colleagues at Pegasystems and Jabil Circuit have outlined in detail the impacts of the digitization phenomenon now flooding across global manufacturing. This treatise addresses the full range of emerging technologies and how they are transforming the very nature and performance characteristics of the manufacturing industry. Digitizing the value stream and aligning the digital world with physical devices enables new ways of working across the product life cycle – from design to sourcing, through the supply chain, across the shop floor and into the all-important aftermarket. The technologies themselves – social, mobile, big data, analytics, cloud and of course the Internet of Things – are re-defining everyone's roles and operating models. It's clear that the fundamental landscape of the industry is in transformation, and that within the next decade, many manufacturers will find themselves managing operations so new and different as to be virtually unrecognizable from the past century of industrial manufacturing.

At Pega, we are very excited by how well we are aligned and suited to support the convergence of these industry and technical forces. Enabling this transformation requires enterprise software built with unprecedented levels of ease, utility and flexibility. Applications must be business-centric, process-oriented and robustly adaptive to continuous change. They must now include all forms of actors, including people, systems and things. And they must support both established and emerging practices such as Dynamic Case Management, Lean Six Sigma, and Industrie 4.0. Pega technology and applications natively support all of this at the speed and scale required.

The Adaptive Digital Factory is a comprehensive survey of the drivers, the methods, technologies and innovations at play across the manufacturing landscape. The authors also include example use cases and specific applications. It's presented in an easy-to-read, one-page-per-topic format that serves both as a primer and a reference.

Manufacturing – of devices, materials and energy – represents over a third of the world's total economic output. The changes being wrought throughout these industries from digitization represent one of the great macro-scale movements of our time. The authors of The Adaptive Digital Factory are experts in this transformation. They have smartly compiled an overview for quick consumption and provocative consideration for the profound implications.

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.01 Why the Adaptive Digital Factory?

The Internet of Things,[1] also referred to as the Internet of Everything, the Industrial IoT,[2] Machine to Machine, or "connected devices," has the potential to transform and disrupt traditional manufacturing models. The connection of devices through IoT provides transformational opportunities for managing the shop floor, product lifecycle, supply chain, and the manufactured devices themselves.

DEFINING THE DIGITAL FACTORY

The revolutionary digitization of decisioning for end-to-end business processes and dynamic cases[3] is an essential enabler of digital factories. By leveraging the capabilities of the Internet of Things, manufacturers remain connected to edge devices 24/7 and, through that connection, their end consumers.

Consider the following interrelated and interdependent dimensions for digital factories.

OPTIMIZED FACTORY ASSETS

In traditional manufacturing, the majority of assets on the shop floor are not interconnected. As a result, the function and status of those assets are, for all practical purposes, invisible to the manufacturer. With IoT connectivity, all assets and machines can be connected, monitored, controlled, and optimized.

PRESCRIPTIVE MAINTENANCE[4]

The digital factory's connected machines, whether on the shop floor or manufactured devices, can be maintained proactively and prescriptively. This prescriptive approach is a key advantage of the IoT model in terms of maintenance, monitoring, controlling, and updating of connected products.

LIFETIME VALUE OF MACHINES

IoT leverages Big Data[5] analytics to optimize the lifetime value of manufacturing machines. Furthermore, with digitized and connected manufacturing, the lifetime value of manufactured devices also improves.

BIG DATA PREDICTIVE MODELING

Manufactured devices continually generate enormous amounts of sensor data. The digital factory mines this data for potential patterns, and identifies the preventive maintenance actions required to avoid potential incidents or failures.

3D PRINTING[6] AND IOT

The advent of affordable 3D printing will allow organizations to manufacture connected products cost effectively and engage multiple innovators through a connected fabric of manufacturers.

Digitization enables the digital factory manufacturer to innovate on the shop floor in real-time, as well as throughout the lifetime of connected products.

With digitized dynamic cases, Things, people, analytics, and process connectivity streamlines manufacturing from suppliers to consumers, and allows for significantly increased adaptability.

.02 SMAC'T Digitization Trends

Considering Social Networking, Mobile, Analytics, and Cloud Computing

Digital factories must take advantage of other digitization trends including social networking, mobile, analytics, and cloud computing. The phrase "SMAC'T"[7] references these important trends as well as the IoT (which supplies the "T" for Things[8]).

IMPACT ON MANUFACTURING[9]

Let's examine how these four digitization trends provide value to manufacturers.

SOCIAL NETWORKING

Social networking has a positive and sometimes challenging impact upon manufacturers. The customer's[10] social postings may support or damage manufacturers. On the other hand, social collaboration aligns customers with dealers and distributors, as well as manufacturing service and production teams.

MOBILE

Mobile omni-channel and omni-device interaction allows manufacturers to seamlessly initiate and complete automated casework end-to-end through mobile devices. Omni-channel refers to the consistency of the customer experience across different channels. Omni-device refers to consistent connectivity, maintenance, and optimized experience with the connected device.

ANALYTICS

Analytics provides manufacturers with necessary tools to mine the hidden gems buried in overwhelming amounts of data. Once identified, manufacturers can act upon key information pertaining to their products, services, and the processing of manufacturing materials. Emerging trends in Big Data and real-time analytics enable manufacturers to optimize their manufacturing, maintenance, and other processes.

CLOUD COMPUTING

Cloud computing allows the entire manufacturing value chain (from consumers to manufacturing management to employees) to access any phase of the product lifecycle. Cloud computing services delivered over the Internet through networks, servers, storage, and business applications offer convenience and on-demand access.

When the power of IoT connected devices is added to the capabilities of mobile, social, cloud, and analytics, traditional manufacturing can embrace the transformation to Adaptive Digital Factories.

.03 Internet of Everything for Manufacturing

The Most Significant Digitization Trend

The Internet revolution, which connected people through digital devices such as wearables, unmanned cars, and smart homes, is poised for further expansion through a massive network of sensors and actuators. For manufacturing, the revolution continues with the advent of connected assets and manufactured devices that are continuously connected, monitored, and optimized by the adaptive digital factory.

Manufacturers have begun to use connected devices on the shop floor, and now must look to the IoT[10] to access uniquely addressable physical devices over the Internet. They need to work with and create Things that increase the connectivity between the manufacturer and consumer. These connected devices can have on-board diagnostics software that manufacturers can use for monitoring, control, and management.

WHAT ARE THINGS?

Things by themselves have little value. However, when considering the health and maintenance of Things, it is important to take a holistic view of how these connected devices fit into the IoT. For that view, Cisco describes IoT as Internet of Everything[11] with a holistic view:

1. **Things:** Connected devices, each with a unique addressable URL over the Internet.
2. **People:** Participants in end-to-end processes or dynamic cases, in partnership with Things.
3. **Process:** At the most basic level, coordination of multiple activities or tasks for a business objective. The participants in processes will include people, Things, enterprise applications, and business partners.
4. **Data:** Generated by Things at an even greater rate than people or applications, IoT data needs to be analyzed and responded to, often in real-time.

There are core relationships between and among these four entity types. The process defined here is a generic term referring to any type of process, whether structured or dynamic (including dynamic cases).

.04 Dynamic Case Management

The Optimized, Automated, and Adaptive Digital Factory

Shop floors involve complex processes, each of which may encompass multiple milestones, tasks, and business units in the workflow required to handle and produce a manufactured good. Manufacturing aftermarkets (e.g., maintenance and support) also depend upon and involve complex processes[12] that reach beyond the confines of the factory and present challenges for coordinating and managing these interconnected yet distinct resources.

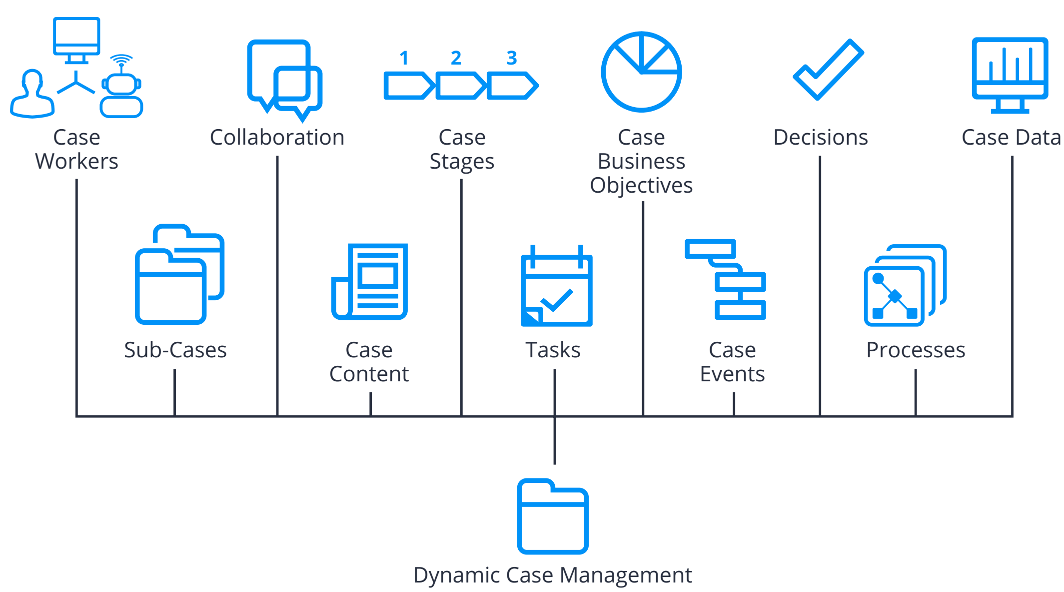
Dynamic case management's sophisticated end-to-end support of connected devices proves it's the optimal methodology for facing the challenges (and opportunities) of the digital factory.

DYNAMIC CASE MANAGEMENT CAPABILITIES

DCM capabilities address each of the complex components inherent in IoT cases, including:

- **Case Stages and Objectives:** Create, manage, and report on the processes and Cases of Everything. The model-driven design of cases is achieved by identifying the milestones (stages) of each case. Pega's manufacturing solutions easily map value streams spanning customers, manufacturers, suppliers, and field through stages in DCM.
- **Things as Participants [13] in DCM.** Case stages and processes are acted upon by numerous participants, including manufacturing, back-office staff, field service providers, customers, and Things. DCM allows multiple entities (humans or Things) to view, review, work, and subscribe to a case and its processes.
- **Monitor and Improve:** DCM portals and real-time reports allow business activity monitoring of the manufacturing case stages. Users track the progress of work throughout each stage of the case. Pega Business Intelligence Exchange allows data to be exported to a data warehouse, providing complete DCM visibility throughout the enterprise.
- **Case Collaboration—Pulse:** Collaboration takes the form of instant messages, files, and URLs that can be shared with other users within a work group. Posts are designated as public or private.
- **Case Data (Properties):** Cases and processes may employ different data models from a variety of sources, including user input, external systems, the result of business rules, and calculations. This data may be propagated throughout all of the processes in the case, which enhances case and process functionality.
- **Dynamic and Ad-Hoc Tasks:** Tasks are assigned to humans, Things, or automated agents (bots, robots, etc.) based on identity, role, skills, or a combination of all three. Workers and managers can dynamically introduce ad-hoc tasks and even discover the need for new processes in the context of an individual case. Dynamic and ad-hoc task capability supports inevitable variations in work, smarter work processing, and social collaboration to achieve business objectives.

Dynamic case management supports end-to-end connectivity from the edge devices—on the shop floor, in the field, or with the consumer—to the rest of the enterprise.



.05 IT and Operational Technology Integration

Integrating Operational Technology Systems with IT[14]

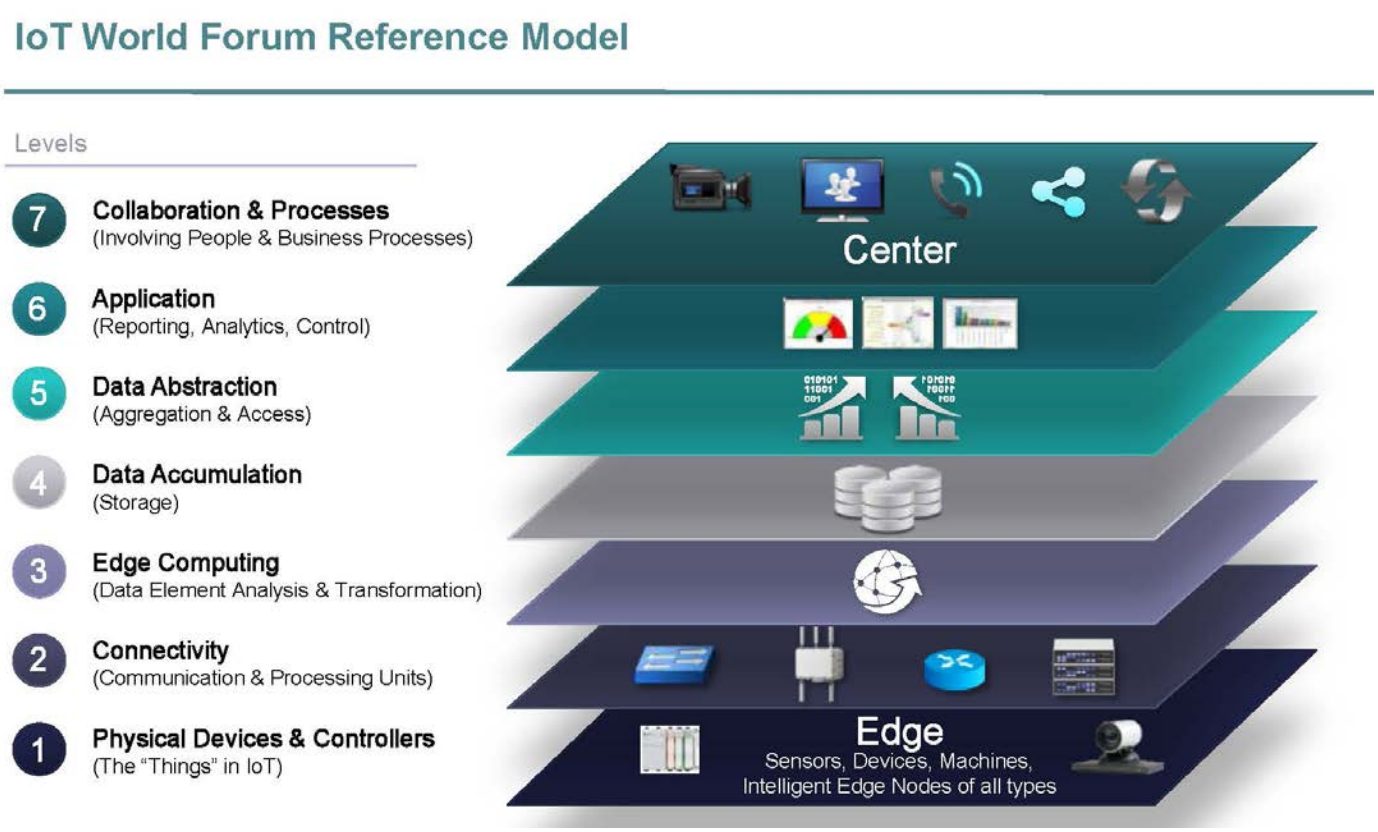
Historically, manufacturing has had two different domains: operational and informational. Operational Technology (OT) concentrates on assets or devices that need to be sensed, monitored, and controlled in real time, whereas IT focuses on managing the portfolio of applications across the enterprise.

Today, the physical world and the Internet are converging at a rapid pace because businesses want to integrate data from MES, SCADA, PLM, and process control systems for new types of analytics and intelligence.

OT MEETS IT IN THE ADAPTIVE DIGITAL FACTORY®

In the Adaptive Digital Factory® devices are becoming increasingly smart and automated for monitoring, maintenance, and continuous improvement. These devices, which may be human- or computer-controlled, are connected to the full suite of production IT applications. In order to create connections among the organizational silos and improve the flow of value to customers, process flows must be digitized and operationalized.

There are emerging reference architectures and communications standards for OT-IT integration. One of these is the ISA-95[15] standard, which is designed to integrate IT enterprise software with manufacturing shop floors. The following illustrates the levels and the various systems involved.



Sourced from: IoT World Forum Reference Model
http://www.1otwf.com/resources

.06 Compelling Use Cases

Connected Devices for Manufacturing

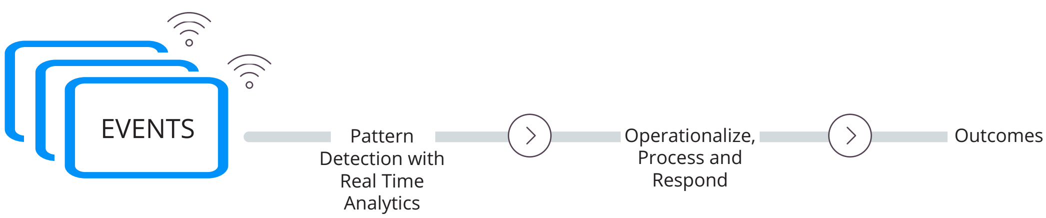
As stated earlier, Things by themselves have limited value. There are three key Process of Everything (PoE)[16] transformational use cases for manufacturing: a focus on intelligent digitized processes, sensing and responding to exception events, and operationalizing big data generated by Things.

DIGITIZING PROCESSES

Elevating the focus from technology stack to intelligent digitized processes

A key requirement for truly successful digital transformation of IoT is the end-to-end digitization of processes. A process has inputs, orchestration of tasks, and business outcomes upon its completion as output. Traditionally, process automation orchestrated humans, business partners, or enterprise applications. That landscape of process participants is changing with the rise of Things.

Consider the coordination of the supply chain involving the supplier, OEM manufacturer that assembles the connected Things, distributors and potentially retailer, or dealer. The participants include staff from different organizations on the supply chain as well. Things can be queried for sensor data, or they can be ordered to carry out tasks. Autonomous or semi-autonomous Things are becoming active participants in business processes.



SENSING EVENTS AND DIGITIZING CHANGE

Handling events and digitizing change

One of the most pervasive use cases for Things is sensing (through IoT sensors) an exception event and then activating a digitized end-to-end process to respond and resolve it. This happens when there is a mechanical or software failure on a device. The Thing autonomously senses and then either directly, or through a brokering layer, activates an exception process. This typically includes monitoring back-office and field workers to respond and resolve it. There are many policies in play when executing end-to-end digitized processes with IoT.

TRANSFORMING THING DATA INTO DIGITAL PROCESSES

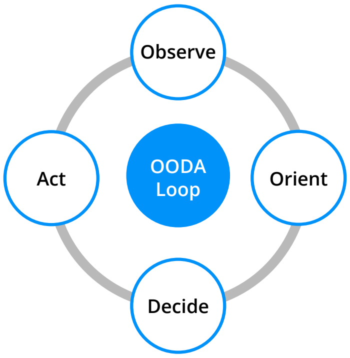
Operationalizing Thing data analytics

Often, it is not merely an individual event that instantiates a process. Big Data will eventually become "Thing Data."[17] Over time, Thing data (and digital processes) will be stored and analyzed. Then, through analytic techniques, predictive models can be mined for information that will become a leading source of Big Data.

Digital Transformation discovers patterns in Thing Data and then operationalizes those patterns in digital processes. Sometimes as these events occur, they must be correlated in real-time analytics. Based on either predictive analytics models or real-time event correlation, a digital transformation solution can take action or suggest the next-best-action to humans or smart Things (e.g. robots).

.07 The OODA Loop in Manufacturing

Strategic Decisioning in the Digital Factory



The OODA[18] Loop stands for observe, orient, decide, and act. It's also known as the Boyd Cycle, named after retired USAF Colonel James Boyd and his approach to gaining strategic advantage over enemies in battle.

OODA also correlates to the Lean manufacturing P-D-C-A Cycle (Plan–Do–Check–Act). Both OODA and PDCA are concerned with how decisions are made. Simply put, they stress the need to observe data and events, determine the meaning, filter out the noise, reorient as new information comes in, and take action all in a continuous iterative loop.

THE OODA MODEL

When employed in the digital factory, the flow of actions and reactions in the OODA model is a process that includes humans, machines, and data from things. In a tough market challenged by low operating margins, the ability to think and act more quickly than the competition creates a distinct advantage. In fact, improved supply chain management and lower operational cost are the key drivers of many current PoE initiatives in the manufacturing and high tech industries.

Let's examine how the components of OODA apply within the digital factory.

OBSERVATION: Observation corresponds to either the experience or intuition of a digital factory knowledge worker or the collection of the data (increasingly Thing Data) for discovery. Sources of this data include Things, processes, and enterprise applications.

ORIENTATION: Orientation emanates from the knowledge and insight within a particular context. The orientation comes from capturing and digitizing the expert's knowledge or through business rules. Alternatively, orientation can be mined through discovering models (e.g., predictive analytics) from data.

DECISION: From the observations and orientation, a prioritized set of decisioning options can be presented. The user or the system needs to pick the course of action, which in most cases will be the first option or best action from a list of potential actions.

ACTIONS: These are actions taken in the implementation and application of a decision in a particular context within the digital factory. Here the user acts upon a prioritized list of decisions, also known as the Next-Best-Action, in a particular context or situation.[19]

TYPICAL USE CASES

In fact, the majority of IoT use cases that our customers focus on are:

- Detecting what is happening whether from streaming data from machines and devices or from the occurrence of complex or anomalous events.
- Automating the triage, diagnosis, and recommended actions with the highest propensity to fix the problem (or better yet to prevent the problem from happening in the first place).
- Executing on actions to resolve the problem, typically using Dynamic Case Management. Over time as the system detects and resolves enough problems, it eventually becomes self-learning and automatically begins the next iteration of the continuous OODA Loop.

.08 Big Data Becomes Thing Data

Building a Data Infrastructure for Adaptive Digital Factories

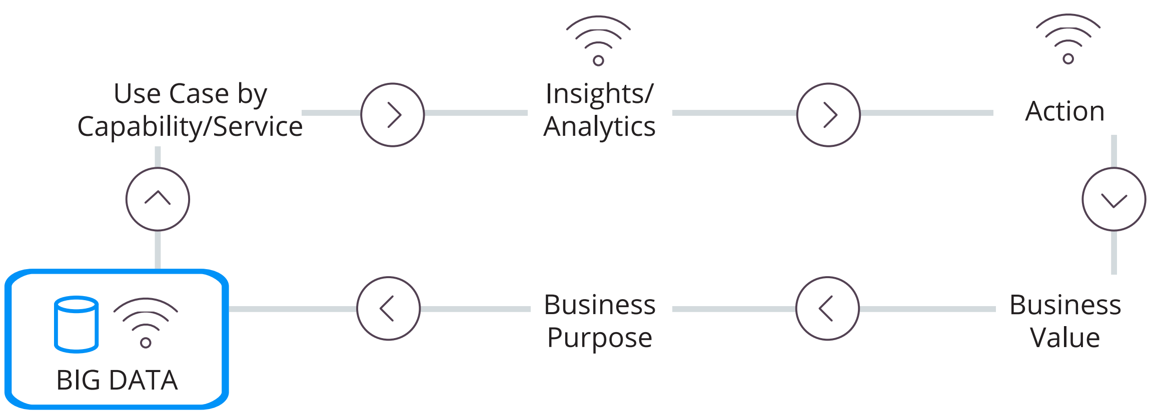
With all the data that is accumulating from all the devices, networks, people, links, machines and so on, there is no wonder we term this accumulation Big Data.[5] In just a few years, we will have access to petabytes of structured, unstructured, and semi-structured data. With that quantity of data at our fingertips, it would be unwise to define Big Data as a repository. It would be the best way of losing sight of the hidden insights and knowledge that the data is providing.

BUILDING A THING DATA/BIG DATA INFRASTRUCTURE

One of the most effective approaches to managing Big Data is building the repository use case by use case. By taking a use case approach, it is possible to understand and know our data, its nomenclature, its function, and its transformational needs. Additionally, analyzed use cases that produce positive outcomes (e.g., concrete action) trigger new questions and birth new use-cases.

Combined, the accumulation of use cases, related insights, and the resulting actions all contribute to building an effective Big Data platform. This Thing Data/Big Data platform develops from an intelligent, ordered, and structured methodology, which allows decentralized analysis teams to leverage the previously worked use cases.

One additional significant technical advantage of employing a use case methodology—it facilitates the scaling of the infrastructure. There is no need to commit significant resources to developing an immense infrastructure at the onset. Rather, the platform starts small and then expands as the need increases.



In the manufacturing world, data is generated by each machine, by each interaction between machines, by each sensor within/amongst machines, testing machines, controlling systems, operators, engineers, and so on. Today, only a fraction of that data can analyzed.

As products become more and more intelligent, they produce valuable data. Now that systems, tools, and repositories are friendly enough to consume all this data, the manufacturing world must acquire the tools to access this untapped knowledge.

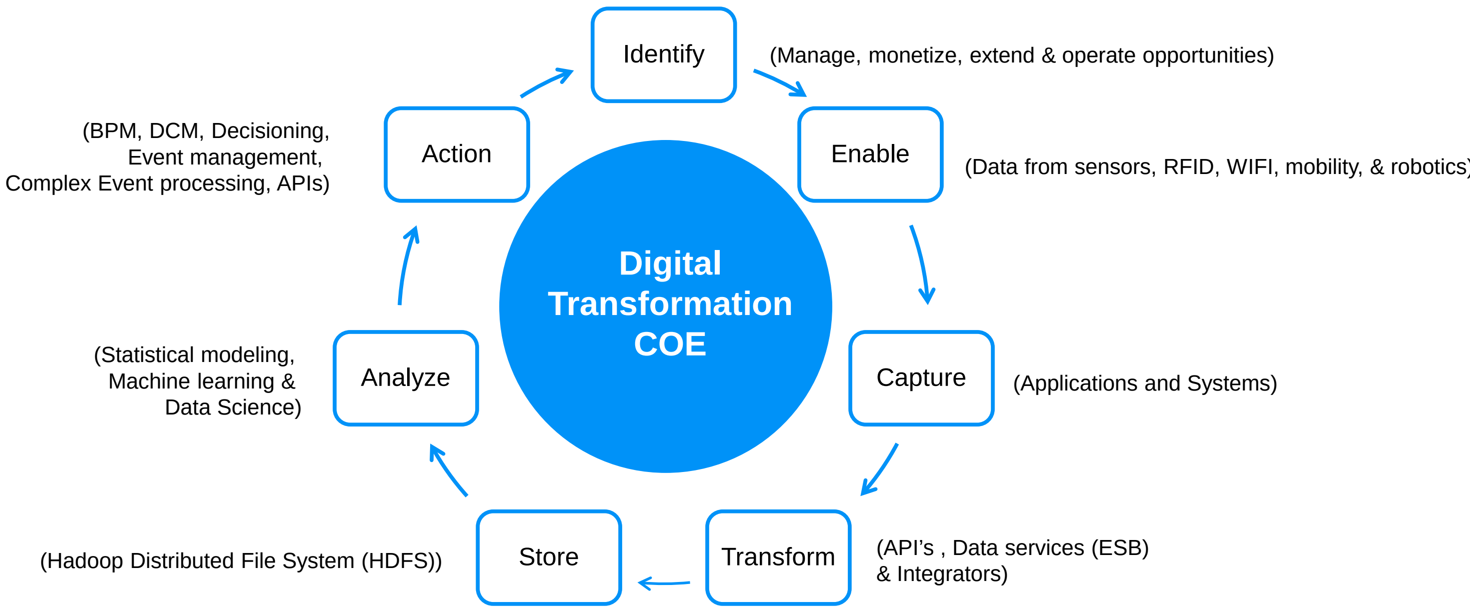
Consider the near future: a simple production line will soon be able to communicate, send data, and save it in the cloud in order to build use cases from it. One possible use case could be decreasing the Takt time of the line, an action that has clear benefits in manufacturing. In this example, data about the production times might be captured every second and sent to a SaaS (Software as a Service) repository like a Hadoop[20] environment. The data would then be analyzed using sophisticated statistical tools, and a concrete action would be taken to change pricing requirements based on knowledge gained from the analysis. In turn, this use case might provide new insights on the same problem, bringing new data to light that informs new analysis, producing new actions, and delivering new business value.

.09 Digital Transformation Framework

Strategic Harnessing of Valuable Data

The manufacturing industry has come a long way from the mechanical processes introduced by the Industrial Revolution,[21] and has enjoyed the efficiencies of decades of computerized manufacturing processes. Even greater benefit is promised, however, as we move into the era of digital information revolution. Valuable data is proliferating, and manufacturing must harness it to reach the next level of competitiveness.

It is clear that the manufacturing industry will transform as the result of the inevitable digitization of many production processes. The following describes one way of facilitating this transformation.



- **Identify:** First, we must identify the use case and decide, for example, whether we want to optimize a particular process, manage another, or monetize a third.
- **Enable:** Something must be designed to produce data so that information and insights can be produced. This data may be inherent to the systems being used, or may need to be implemented in order to produce that data (install, configure, connect, and disseminate). Examples of this "enabling" are different types of sensors including RFID, WIFI, mobility devices, robots, and so on.
- **Capture:** Devices produce data, but without interpretation, it is unintelligible. To capture data, applications are developed on top of these devices to produce outcomes. At this level, applications capture the raw data emanating from devices.
- **Transform:** To analyze the captured data, it often needs to be transformed so that it is either coherent with other sources of data, joined to other data, or loaded to a specific data repository. This stage performs the extraction, transformation, and loading (ETL) required so that the data can be consumed for analysis.
- **Store:** As data increases exponentially, it needs to be stored to be consumed by use cases. This repository aspect of the transformation takes into consideration the type of data (structured, unstructured, semi-structured), volumes, ease of access, security, recovery, and others.
- **Analyze:** The analysis phase takes into account internal and external macro/micro economic considerations and the acquired knowledge of the data, and then applies statistical or mathematical modeling to gain insights in order to take action.
- **Action:** Having gained informed insights, action is taken and new use cases are defined.

.10 Digitizing the Supply Chain

Improving End-to End Performance with Dynamic Data Mining

One needs look no further than the evolution of supply chain capabilities to see how manufacturing is becoming digitally connected. Digitization of the supply chain through monitoring, connectivity, and end-to-end automated dynamic cases has provided many new opportunities to optimize the supply chain[22] processes.

With the emergence of additive 3D printing[23] for "social" manufacturing, optimization within supply chain management is critical. Companies rely on the timely supply of material or 3D components in order to produce at increasingly demanding service levels. Any disruption to the supply chain has a negative impact.

From a financial perspective, costly disruptions may result in overstocking, underproduction, waste, and, ultimately, the visibility into the supply chain from end-to-end. For that reason, disruptions in the supply chain represent a significant risk for the company.

In order to minimize that risk, companies must identify the sources of the disruptions.

DISRUPTIONS IN SUPPLY CHAIN

Some of the critical sources of supply chain disruptions include:

- Weather (e.g., hurricanes)
- Civil unrest (e.g., protests)
- Labor union challenges (e.g., ports labor dispute)
- Fuel prices (e.g., unwarranted hikes in the rates)
- Vendor market status (e.g., hostile takeovers of suppliers)

In order to minimize disruption risks, data is mined and transformed into information used to take mitigating actions. These mined actions are automated and executed through end-to-end dynamic cases spanning the entire supply chain.

MITIGATION BY PREDICTION

Some of the sources of data for analytics, decisioning, and especially operationalizing in the supply chain processes include:

- **Social media:** Useful for trending on possible civil unrest or labor union issues
- **Text analysis:** Used to analyze social media input, define trends in communications, preferences, and ideas (e.g., millennials versus baby boomers)
- **Risk prediction:** Derived from information about weather, climate, or geological predictions
- **Machine learning:** Algorithms that learn, adapt, and become more accurate at predicting with more information

The data from these sources are also supported by sensor data from the transportation logistics or the devices themselves.

Digitizing the supply chain is innovative and inevitable. The predictive models, sensor (IoT) events, and business rules for optimized supply chain execution are all automated and operationalized through dynamic case management. Digitization spans the extended manufacturing digital enterprise, including OEMs, parts suppliers, logistics, and transportation, to name a few.

.11 Innovations on the Shop Floor

Introducing Machine Learning Strategies to Provide Predictive Analysis

What innovations can be introduced on the shop floor?

Machine learning software uses computational statistics to learn and then predict outcomes based on independent feedback entered into the model. Many online search engines use this self-learning approach, which, in fact, is also a type or subset of artificial intelligence.

Today's most reliable search engine models incorporate an underlying human behavior distribution model, derived from years of data collected from the Internet. Take, for example, searches you've conducted on Google or Amazon. How often did their algorithms predict what you were searching for?

MACHINE LEARNING ON THE SHOP FLOOR

We can apply the machine-learning strategies from these efficient search engine models to the manufacturing shop floor.

We know that:

- Machines are very good at performing tasks repetitively based on parameterized configuration
- Machines are not as good at auto-adapting to special circumstances
- Humans, on the other hand, are very good at adapting to special circumstances

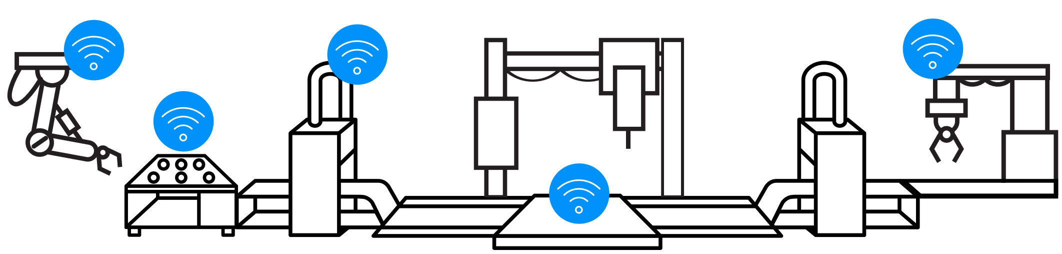
To improve the adaptability of machines, we must model the human in such a way that machines will be able to adapt to certain sets of circumstances. The auto-learning (auto-adapting) factory will use machine learning, incorporating feedback from operators and engineers (human), as well as inter-machine information. The goal is auto-predicting and prescribing actions around special circumstances.

USE CASE

In companies using hundreds and thousands of machines for production, it is often hard to know which machine to work on or investigate first when processes start to go out of control.

Today we have an operator or engineer on each machine to start that investigation, but with machine learning, incorporating user feedback (operator or engineer) can optimize the process by indicating which machines to investigate first. The model could predict which one, based on parameters, SPC charts and previous engineer/operator input.

The engineer or operator who accesses this new knowledge would in turn provide feedback so that the machine-learning algorithm would reevaluate the model to make a more precise prediction in the future.



.12 The Shop Floor

Improved Processes Through Data-Based Next Best Action Predictions

If we envision the future of manufacturing, we can easily imagine a centralized cloud platform collecting machine data such as Statistical Process Control (statistical models that can highlight when there are potential problems in a process or machine) information and predicting which machines to investigate in the case of a suspect out-of-control process.

This future offers the "next best action" type of prediction for defects and defective products. It optimizes the lifetime value of the machines without having to rely upon a significant number of operators or engineers.

Predictions:

- Which machine to investigate next out of control
- Machine learning for optimal investigation (learn from humans)

Prescription:

- Next best action for defects or defectives
- Increase value lifetime of machines and production line

NEXT BEST ACTION

Tying the next best action predictions (prescriptive) to information that not only comes from the shop floor but also from the products produced (external) could have the following advantages:

- Capturing data from the device about which components are potentially at the end of their useful life
- Enabling the input of external data into the algorithm related to the functioning of the system components
- Creating a new external feedback system to determine potential unforeseen out-of-control processes

Ultimately, employing next best action predictions creates a prescriptive process that is significantly more efficient than one relying solely on feedback input from the engineer or operator.

USE CASE

Imagine that information was fed to robots that fix machines or to self-healing machines. Sensors providing information about the lifespan of a component on the shop floor are augmented with return information of sensors in products for the sake of sustainability.

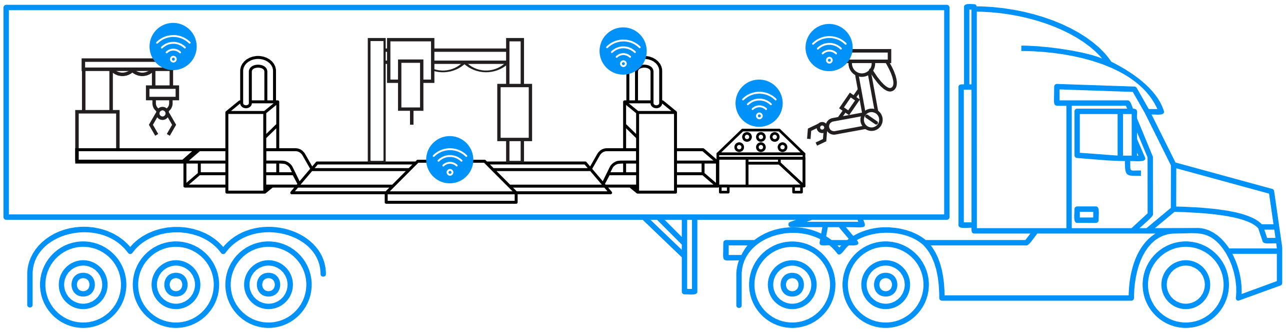
Extending this vision further, as shop floors become more efficient with the use of external data for preventative maintenance and sustainability motives, it is easy to see that the supply chain will become efficient as well. In this ultra-informed environment, the supply chain can become a "bid-on-demand" model—a supply chain market similar to a commodities market.

Imagine a shop floor that bids when it predicts resource needs, identifying the best bidder with the fastest turnaround. Bids are based on production, life of the machine, life of the product, life of the component, and sustainability requirements. The whole shop floor is working in synchrony and quasi-automatically.

This is the future of manufacturing, and it is within reach now.

.13 The End of Monolithic Manufacturing?

Specialized Manufacturing Strategies Providing Agility and Customer Input



Predictions:

- Automatic Self-service supply chain
- Micro and mobile factories – directly attached to need
- Sentiment/text analysis to predict optimal location

Prescription:

- Timely and optimized location
- Adaptive needs based on geography and demographics

With the proliferation of 3D printing, together with social and additive manufacturing, smaller innovative manufacturing corporations have the potential of competing with the biggest mega manufacturers…the latter will have to adapt.

NEW MODELS OF MANUFACTURING

Mega manufacturers need to keep in mind that trends like the following will enhance their business:

- Micro manufacturing:[24] The paradigm shift to smaller manufacturing plants producing customized products, where the extreme micro-plant is the garage or basement of an individual
- Social manufacturing:[25] Linking multiple, smaller agile manufacturers to produce a larger aggregated product.
- Mobile manufacturing:[26] Mobile micro manufacturing able to move from one geographical location to another.

Internet innovation is unstoppable. One emerging trend we have witnessed over the last few years is social manufacturing. Imagine living on a street with four houses in rainy Seattle. Three of the houses each have a 3D printer (purchased at Home Depot for less than $1,000/each[27]). The last house has a sewing machine.

The first house uses its 3D printer to produce the rounded handle of an umbrella, and the second house produces the shaft. The third house produces the skeleton to the fabric, and the fourth sews fabric for this umbrella. Working in tandem, they've produced a product that is invaluable at that location and can be customized quite easily.

Each house is an example of micro manufacturing as it focuses on a specific custom product built in small capacities for a very specific need. If we imagine that the house is mobile and can be placed at the center of an event for instant production of a product directly linked to the event, we now have an example of mobile manufacturing.

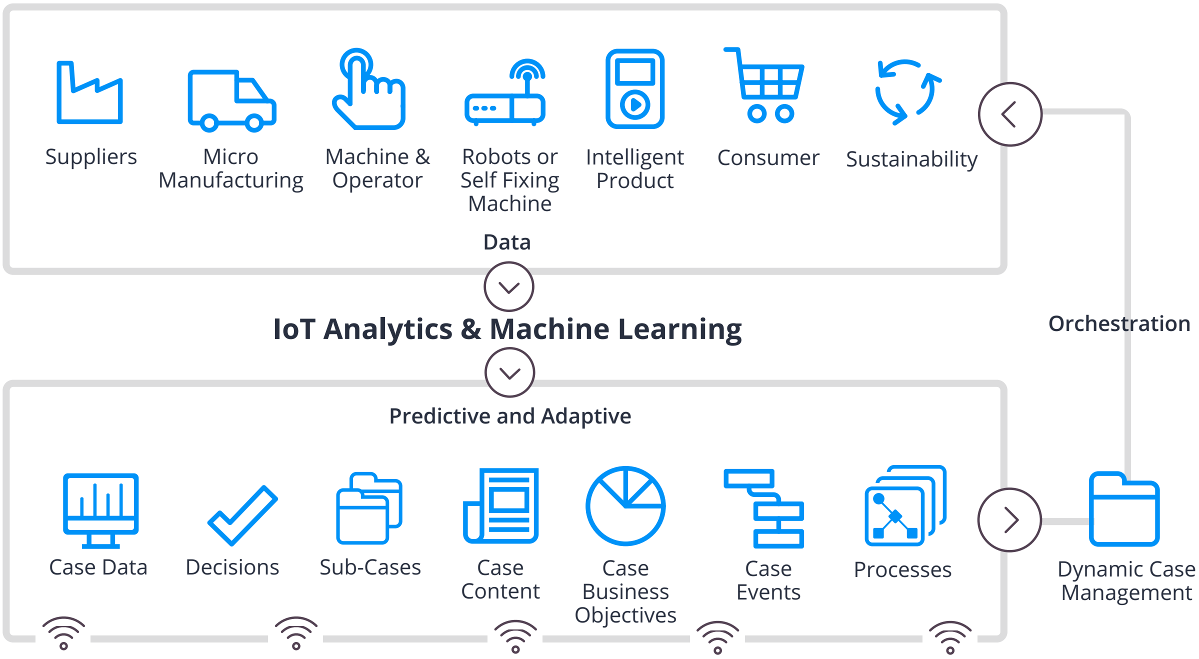
Although it may seem unconceivable today, in a few years this type of social manufacturing model may revolutionize the way manufacturing is done.

Each one of these trends allows the manufacturer to become more agile and more in tune with constantly changing needs. The manufacturer is closer to the consumer, and can be more innovative, changing the supply chain methods.

To negotiate this paradigm shift successfully, manufacturers must have the right tools.

.14 Dynamic Case Orchestration

Realizing the Power of all Assets in the Adaptive Digital Factory



Now we bring it all together—the execution and continuous optimization of the adaptive digital factory. Information is generated from a diverse set of sources, such as suppliers, manufacturing units, machines and operators, robots, products, consumers and sustainability systems. A system will be required to orchestrate it all. Data from all of these sources is transformed so that it can be analyzed. This analysis in turn enables predictions and self-learning outcomes.

DYNAMIC CASE MANAGEMENT IN ACTION

As indicated earlier, dynamic case management is the platform that aggregates, orchestrates, and facilitates the execution of all the assets enabling the adaptive digital factory. These assets include process fragments, predictive and self- or machine-learning adaptive models, as well as data or content from systems of records.

The dynamic cases are executed in the adaptive steady-state execution of the adaptive digital factory. These cases orchestrate the entire lifecycle from production to execution[28]—connecting the consumer to manufacturers, services, and support.

Events in any phase of the production or servicing may trigger dynamic cases that will orchestrate the decisions, sub-cases, and business processes to respond or handle the event. If machine learning is used in the predictions or any type of adaptive predictions, it is conceivable that the actions, cases, and business processes actually may be enhanced on the fly.

This process is adaptive, in terms of both orchestrated execution as well as continuous improvements in the models or assets themselves (i.e., changes in processes, rules, decisions, etc.).

.15 Security Concerns

For Adaptive Digital Factories

The dynamic case management platform aggregates, orchestrates, and facilitates the execution of all the assets enabling the adaptive digital factory to build optimal connectivity on the shop floor and external connectivity with the suppliers, Things, and the consumer. This adaptive process delivers the benefit of continuous improvements in the models and assets, but it also requires careful consideration of the privacy and security issues related to connectivity.[29]

SECURITY THREATS: In any network, security breaches are a regular and serious concern. Hacking typically focuses on stealing information or penetrating an environment to add malware to take control of it. Within the world of Big Data, IoT, and the factory of the future, one needs to be conscious of how these and additional threats impact the adaptive digital factory.

Consider the following examples:

- A hack designed to control remote connected devices—either machines on the shop floor or the manufactured connected product.
- A hack that accesses and manipulates sensitive or private consumer data, creating malicious executions of decisions, business processes, or dynamic cases.
- A hack that implants malicious errors into sensitive data. Machine learning and adaptive predictions models depend on good data to produce positive and realistic predictions. Any malicious data introduced into the models will in effect create wrong predictions, potentially creating negative or even hazardous outcomes.

Clearly, security for Big Data, IoT, and factory of the future needs to be in the forefront of planning[30].

SECURITY PLANNING: Given the execution stack of the adaptive digital factory, you must address privacy and security at all levels—from the lower or bottom edge devices all the way to the consumer interacting with the connected products. **Each of the following requires serious security consideration.**

EDGE DEVICES: Connected products and smart machines on the shop floor need to be able to protect the controls (and the information they sense or generate) from unauthorized access.

SHOP FLOORS: The vulnerabilities of increasingly automated controllers (e.g., those leveraging robotics) and the systems of adaptive digital factory shop floors must be addressed. As operational robots and machines connect to the information technologies and applications of the enterprise, the potential for privacy and security violations will only increase.

THE CLOUD DATA AND CONTROLS: Increasingly, Adaptive Digital Factories rely on the cloud for storing product and sensor data, as well as various types of controls for connected products. A variety of cloud security standards and protection from public cloud to hybrid cloud and private clouds do exist, and should be evaluated.

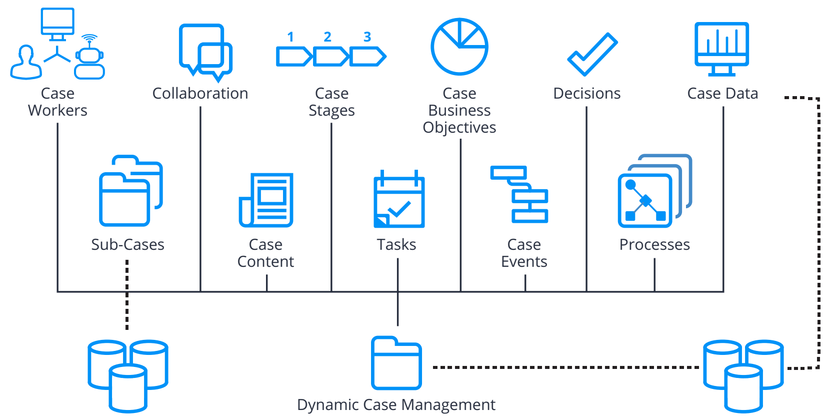
BIG DATA/THING DATA: Of paramount concern is the privacy and security of data gathered and analyzed throughout the entire lifecycle of production. Access control authorization, authentication for individual data entities and aggregate data must be enacted together, using automated risk mitigation policies.

REMOTE CONTROL: Manufacturer or service providers occasionally control the connected products remotely, typically through automated software updates and controls for maintenance. In either case, unauthorized access checks must be embedded in the remote interactions with the connected products.

DYNAMIC (BUSINESS) CASES: Finally, dynamic cases orchestrate humans, Things, and enterprise applications, as well as trading partners. For that reason, security, privacy authorization, and authentication with multiple levels must be enacted for each category of participants (humans, robots, applications, etc.) in the end–to-end production servicing dynamic cases.

.16 Master Data and Master Policy Management

The Value of Top Down Digital Business Transformation



The products, parts, and suppliers that make up Adaptive Digital Factories may suffer from poor data quality and inconsistencies, which can lead to flawed and even risky decisions. Master data management (MDM)[31] is essential in modern manufacturing. However, not all MDM approaches efficiently manage consistency across the value chain.

MASTER DATA MANAGEMENT

The "bottom up" IT approach : Often organizations attempt to address the MDM issues through "big bang" master data projects, tools, and even MDM centers of excellence for governance. The technology and data consistencies are formidable and important to address, including data cleansing, addressing missing data, data consistency, ETL, and data integration.

The danger is the enormous effort required to normalize master data without prioritizing through the business objectives. One common problem is that initiatives attempting to resolve master data challenges often do so in a silo.

The "top down" digital business transformation approach: A more optimal approach is to treat MDM challenges as part of overall continuous improvement initiatives, especially through end-to-end dynamic case management solutions that connect silos that touch and manipulate master data. This "top down" approach prioritizes transformational projects with MDM improvements and balances risk with business value.

These technical database issues must be addressed, but with a revamped approach to priorities. In the adaptive digital factory, solutions to master data issues are now driven by a "Think Big...But Start Small" governance. Earn quick wins, build or achieve the needed master data rigor, and then expand with additional transformational solutions that include MDM.

The core to this approach is a DCM-enabled layer that wraps and modernizes legacy systems. Iterative and agile methodologies provide the adaptive case management solutions that are essential to the digital business transformation. The MDM governance and implementation can be embedded in the DNA of the case automation methodologies and lead to the discovery of data sources and the optimization needed to manage data within the DCM layer.

MASTER POLICY MANAGEMENT

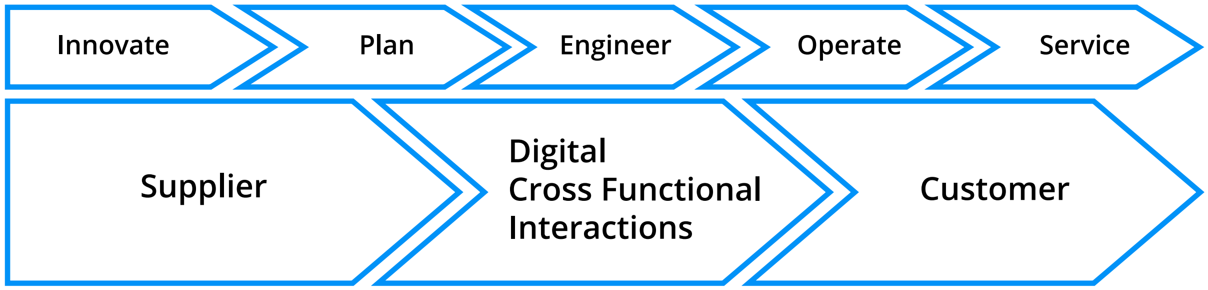
Digital business transformation needs a top down approach for master data. It also needs a top down approach for master policies.

Consider the scenario where your discount depends upon the channel you use to interact with the digital enterprise. If you go to the Web, you get one discounted price, but if you call a customer sales representative, you get another! Both channels might have the exact and precise information about you as customer or the product or service you are trying to purchase (master data), but the pricing is defined by the channel.

This frustrating consumer purchase scenario clearly illustrates a lack of master policy, which would guarantee consistency in the various phases of digital manufacturing. These decisioning policies apply to price in our example, but just as easily could pertain to regulatory compliance, supplier policies, warranty policies, production, and quality.

.17 Evolved Product Lifecycle Management (PLM)

Transformative Digital End-to-End PLM[32] Process



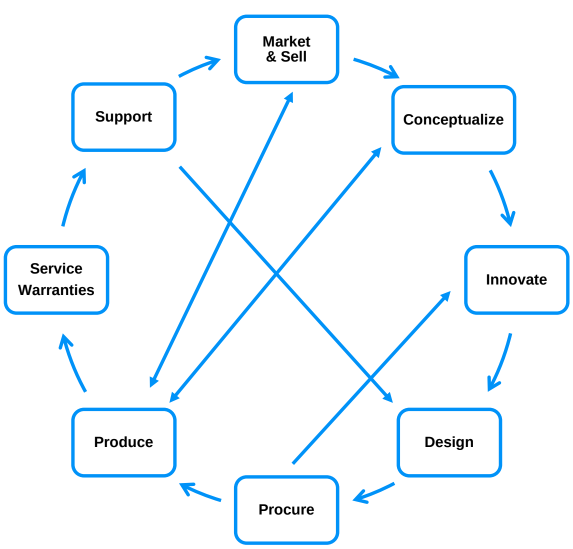
The Adaptive Digital Factory of the future will manage the product lifecycle more efficiently than ever by leveraging the value from smart connected assets, such as machinery and assembly tools on the shop floor.[33] Real-time data from physical assets can be integrated with other systems, such as ERP, CRM and data warehouses, to provide in-depth understanding of the production flow and quality.

TRANSFORMING THE PRODUCT LIFECYCLE

In the adaptive digital factory, IoT data from connected assets provides visibility into new opportunities to improve daily operations. The following are some examples of those potential improvements:

- By monitoring the usage and behavior of the equipment, the manufacturer can discover better ways to perform maintenance. By measuring and analyzing critical data points, the factory can improve its overall equipment efficiency.
- Early detection and notification of issues can trigger proactive resolution of the problem and prevent costly downtime.
- When alerted to a potential issue, the engineers will also be informed of any critical information such as whether the repair is covered under warranty or not.
- The equipment manufacturer can use real-world usage data from the devices to enhance or upgrade features and functionality in the planning and design of the next-generation of products.
- Reacting dynamically to detected usage patterns and recurring issues will positively impact customer satisfaction and loyalty.
- Product development enhanced by using real-time data to improve and streamline product design, resulting in faster time to market and increased competitive advantage.

The proliferation of low cost 3D printers has contributed to the acceleration of rapid prototyping and new product introduction.



In the adaptive digital factory, new products are developed in days, not months. Smart connected devices improve the collaboration and flexibility across the entire value chain from the supplier to the factory to the end customer. Harnessing IoT data allows the plant manager to adapt to changes more quickly, whether it is a new product introduction, or fluctuations in the supply of a particular component or in customer demand.

.18 Device-Directed Warranty™

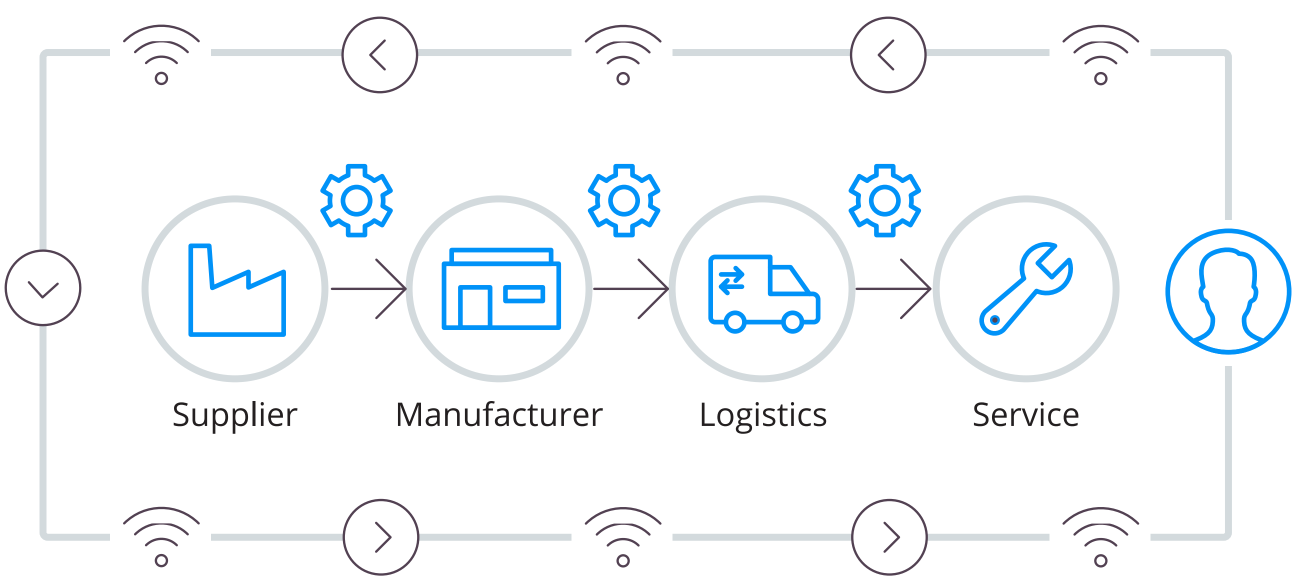
Pega's End-to-End Solution for Warranty Management

Device-Directed Warranty™[34] augments Pega's Manufacturing Application with connected devices. One of the most common warranty claim scenarios aligns with the use cases discussed in Chapter .06.

The Process of Everything[16] realizes the end-to-end warranty case processing with connected devices. More specifically, an exception event instantiates a dynamic case that manages the end-to-to-end processes involving Things, the OEM manufacturer, service technicians, potentially suppliers, the consumer, and, of course, the distributor or the dealer.

The Adaptive Digital Factory® leverages the powerful Pega platform with decision management in automated dynamic cases, the Pega Warranty Management configurable IP, and the Pega IoT connectivity capabilities. More specially, with Device-Directed Warranty™ manufacturers will gain the following capabilities:

- **IoT Diagnostics:** Things will have on-board CPU and execution capabilities or will be able to connect to a device that has on-board execution for the device or Thing via low power connectivity.
- **Automatic Updates of On-board Device Software:** Manufactured devices (either edge devices or gateways) often have sophisticated software that can be updated remotely by the manufacturer.
- **Automatic Sense and Data of Measures from Edge Device:** A manufacturer will have the capability to gather data from the device or ping it for specific measurements and analysis.
- **Automatic Control for Maintenance:** Devices can be controlled remotely or through on board decisioning software.
- **IoT Supply Chain and Parts Return:** The edge device that needs to replace a defective device can be monitored at any point in the supply chain—from the supplier to the distributor or customer. In this scenario, a defective device that needs to be replaced can be monitored to confirm its return to the supplier or the OEM manufacturer.
- **IoT Repair or Parts Validation:** Once a repair or replacement is completed, the manufacturer can validate the fix and its compliance to the manufacturing management policies and procedures.



.19 Digital Prescriptive Maintenance

The Power of End-to-End Digital Automation of Maintenance Processes

The Adaptive Digital Factory, as we have described it, goes well beyond reactive recalls and repairs, and offers improvements even beyond the Lean and Six Sigma methodologies that have improved operations for decades.

Lean manufacturers have long subscribed to the idea of total productive maintenance (TPM), which has the goal of improving overall equipment effectiveness as measured by performance x availability x quality. With TPM, techniques such as quick changeovers are used to increase productivity and reduce downtime.

In the Adaptive Digital Factory, digitization of processes and decision management are used to avoid the consequences of equipment failure. The idea is to prevent the failure before it occurs by replacing or repairing worn parts. In the current environment with IoT and Big Data, there is an opportunity to modernize maintenance proactively.

PREDICTIVE MAINTENANCE

The advent of predictive maintenance[4] represents an important milestone in the digital evolution of increasingly automated and intelligent maintenance.

With predictive maintenance, Big Data analytics of messages or events emanating from Things are analyzed to identify what could be done for maintenance. Data is available from sensors that track operating conditions, how equipment is being used, and even how and why breakdowns occur. These insights reduce waste and create a leaner organization.

Consider the example of a large farm equipment manufacturer using new technology to help farmers improve agricultural yields. The manufacturer has access to an unprecedented amount of performance data from connected devices.

The manufacturer's goal is to use data analytics to predict the point in the future when maintenance will be required. The IoT allows devices to collect data about the equipment and its condition, triggering an alert when certain thresholds are reached or an anomaly occurs, and providing recommended actions to take next.

PRESCRIPTIVE MAINTENANCE

By leveraging end-to-end digital automation of maintenance processes, as well as decisioning (self-learning or adaptive), the transformative optimization of maintenance is achieved through prescriptive maintenance.

With prescriptive maintenance, the objective is what maintenance should be done in an IoT digital environment. When paired with IoT, prescriptive maintenance[35] is holistic. It encompasses the following:

- **Total Productive Maintenance:**[36] Continuously improving overall equipment/device effectiveness.
- **Predictive Maintenance:** To analyze events and data streams especially from IoT Big Data sources and identify what could be done.
- **Self-Learning and Adaptive Maintenance:** Predictive analytics looks at past data and attempts to mine and discover models. A complimentary approach is to continuously monitor and learn from the behavior of IoT data and adapt maintenance priorities accordingly. Remote devices can track the machine's location, fuel consumption, and utilization. Data is analyzed to perform initial diagnostics and prevent problems from occurring. The end result is improved uptime and increased machine and operator productivity. New technology and predictive and adaptive analytics help ensure the future is leaner than ever before.
- **Knowledge Work and Policies:** The knowledge of the experts is captured in decision rules and involved throughout the maintenance lifecycle.
- **Automation of the Value Stream:** The automated value stream orchestrates end-to-end the connected device (IoT), supplier, manufacturer, and consumer. This value stream ties the consumer's device to the entire lifecycle of maintenance via automated and digitized processes, with complete visibility and control of the end-to-end processes.

.20 Aligning Customers and Manufacturers

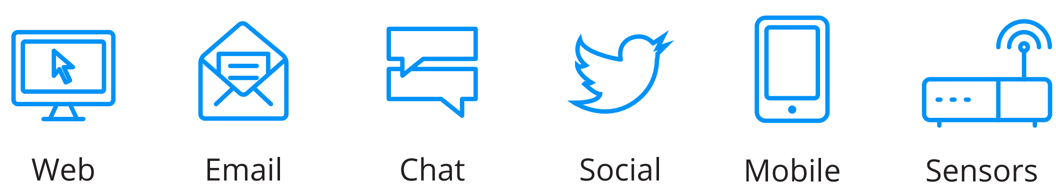
Omni-Channel to Omni-Device

The Internet of Things is also transforming the alignment of customers to the manufacturers.

Omni-device[37] is really a specialization of omni-channel that leverages Internet of Things. Typically, customers interact with digital enterprise across many channels:

Omni-device: With the rise of Things, devices in our homes (e.g., appliances), connected vehicles, workplaces, or connected wearables are becoming channels. What does omni-device mean and how does it manifest itself with IoT? There are four essential omni-device capabilities that provide significant potential in optimizing and transforming the customer experience through IoT:

1. **Customer-Device Interaction:** Manufacturing and High Tech companies are realizing the tremendous potential of smart connected devices for applications in connected homes, vehicles or industrial applications. GE for instance is adding if-then smarts and intelligence to connected appliances to allow the consumer the ability to indicate what they want to do with the appliance (e.g., turn it off after 20 minutes, inform via text message if the oven is heated, etc). The connected devices will of course provide both sales and marketing opportunities.
2. **Things as CRM Channels:** IoT devices are also becoming channels. Just as a mobile device or a browser handles customer service, Internet of Things or devices can also be used to promote products, services, cross-sell, or upsell. For instance, automobiles connected through 4G LTE connections can offer Wi-Fi as well as vehicle diagnostics and maintenance opportunities. However, this connectivity also provides opportunities for advertising, sales, and marketing – all convenient for the consumer
3. **Connecting With Manufacturers:** The third use case for omni-device deals with connecting the consumer with the manufacturer of the devices. With the emergence of connected products, manufacturers are now much closer to the consumers. Sensors are providing incredible feedback on how the device is being used as well as the preferences of the consumer. There are, of course, healthy discussions and concerns around privacy and security in this instance. Nevertheless, this connectivity and continuous sensor feedback is in fact transforming the relationship between the manufacturer and the consumer.
4. **Extending the Manufacturers' Ecosystem to Optimize the Customer Experience:** The consumer is constantly on the move and connected through their devices. This includes their offices, cars, and homes. Now, due to this connectivity Manufacturers are establishing new innovative relationships with other merchandising channels to conveniently cross-sell or up-sell to the customer. For instance, OnStar now offers AtYourService with various offers to the consumer (e.g. coupons for coffee, gas, restaurants, even retail) that conceivably takes into consideration the geolocation as well as the context of the customer.



.21 Industry 4.0 and the Industrial Internet

The Impact of the Cyber-Physical Ecosystem

Even though connected devices on the Internet have been around since its inception, only recently has the Internet of Things had a significant impact on industries, especially manufacturing. From connected homes, cars, cities to industries, such as healthcare, insurance, manufacturing, and utilities, connected and increasingly intelligent devices are transforming entire ecosystems. The IoT sectors are often characterized or contrasted between Consumer IoT and Industrial IoT.

The connected (or "smart") home is the quintessential example of the former. Connected industries, such as process or discrete manufacturing, are the examples of the latter. Things could be small devices such as smart watches or health monitoring devises, that communicate to the Internet via smartphones (and increasingly the smart phone itself is providing sophisticated monitoring functions). The other end of the spectrum are huge machines, such as turbo engines, wind energy farms, oil wells, manufacturing robots, that are increasingly intelligent, semi-autonomous, or even targeting complete autonomy.

In fact, the impact of IoT on industrial ecosystems has been so great that the emergence of devices with robust physical-cyber connectivity, is often called the fourth industrial revolution (aka Industry 4.0[39]). Frost & Sullivan, the global research and consulting organization, dubbed the integration of these physical devices into the software systems "The Industrial Internet."[40] Frost & Sullivan sees the Industrial Internet (spanning the spectrum of machine-to-machine communication, people, software, and Big Data analytics) as the means to promote innovation, improve industrial machine maintenance, as well as operational processes.

This new connected ecosystem encompasses physical machines, devices, network connectivity, and various types of computing (process, operations, and analytics)—the short list of key elements for optimized asset management and business outcomes.

STANDARDIZATION AND INDUSTRY ALLIANCES FOR IOT

A number of consortia, initiatives, references architectures, and standardization efforts have arisen to address the wide spectrum of levels from the physical to reference architectures[41]. Robust interoperability within and across industries as well as standardization of protocols of IoT architecture stacks are necessary for successful IoT deployments. Standards for the IoT stack include ZigBee, Z-Wave, Bluetooth LE, 6LowPAN, Thread,WiFi, Cellular and others. Most of these standards support the 128-bit IPv6[42] addressing protocol. IPv6 will support 340 trillion, trillion, trillion IP addresses. In other words, almost an infinite number of Internet addressable devices and services. Industry solution and service providers in the IoT space have started to collaborate on a number of consortia that often span standards, interconnection technologies, reference architectures and best practices. Industry organizations include AllSeen Alliance, Open Interconnect Consortium, Industrial Internet Consortium, and Industry 4.0.[43] Let's look at the last two groups to get a sense of their mission.

- **Industrial Internet:** In 2014, AT&T, Cisco, General Electric, IBM, and Intel founded the Industrial Internet Consortium[44]. This consortium is "setting the architectural framework and direction for the Industrial Internet." Among many initiatives it has defined an overall reference architecture for the Industrial Internet application of IoT, encompassing all related phases, technologies, and solutions. This RA provides guidance covering all functional domains in industries leveraging IoT, including business, operations, applications, and especially controls involving connected devices. Manufacturing is, of course, a major sector, but other verticals, such as healthcare, public sector, transportation, and energy, are addressed as well. The scope of the RA and the IIC overall is to provide architectural best practices in combing, aggregating and connecting people, processes, data, and IoT.

- **Industry 4.0 (aka Industrie 4.0):** Industry 4.0 is a key high-tech manufacturing initiative introduced in 2011 by the German Federal Government. Industry 4.0 "is a term applied to a group of rapid transformations in the design, manufacture, operation and service of manufacturing systems and products."[45] This initiative encourages manufacturers of all sizes to achieve efficiencies in maintenance, operations, and energy savings. Cyber-physical systems with sensors are among the key digital technologies that are leveraged in Industy 4.0. Another major focus of Industry 4.0 is mining the data or information generated by the assets and applying real-time analytics to predict, for instance, failures in maintaining assets. With connected devices and assets, Industry 4.0 envisions active monitoring of data generated by the entire supply and value chain as a way of managing logistics and enacting real-time controls.

.22 The Digital Transformation of Manufacturing

As we have seen, digitization means disruptive megatrends in connectivity, social, Internet of Things, Big Data analytics, cloud, and mobility. The transformational aspect of digital technologies is paving the way for digital innovations that will change the landscape of manufacturing.

WHY DIGITAL TRANSFORMATION IN MANUFACTURING?

As digitization increases at a furious pace, so too does the pace of change for products and services. Yet, today's economy means "doing more with less," so companies face challenges in keeping up with demands from each link in the supply chain, through to the consumer.

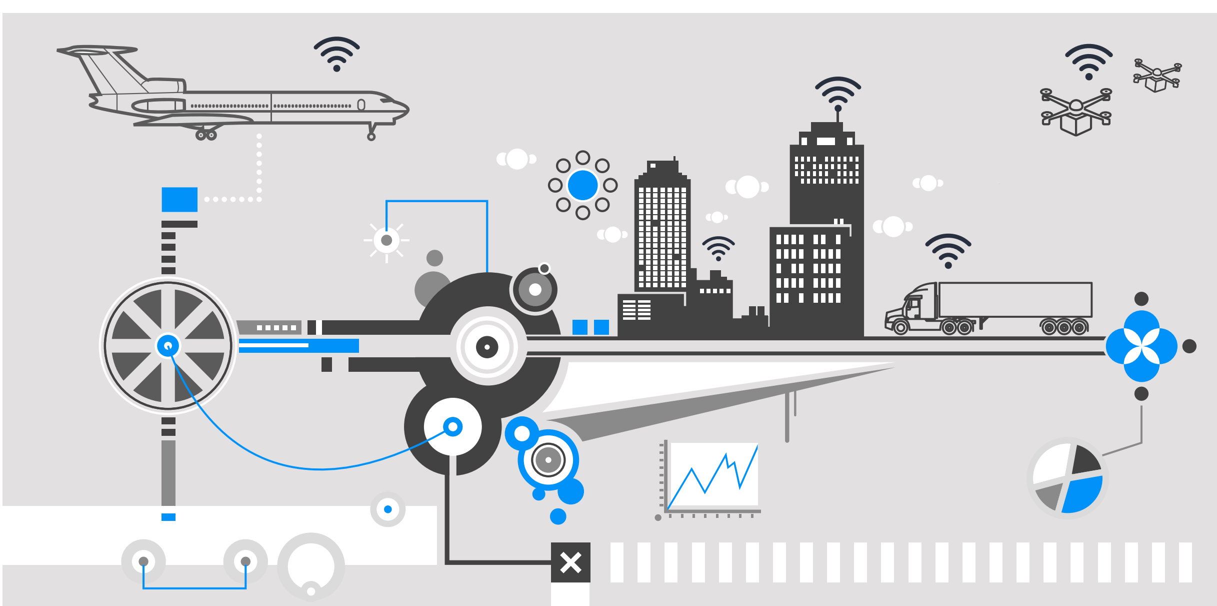
Within these companies, IT is challenged by the disruptive impact of IoT technologies and the needs of more tech savvy business stakeholders. The IoT is transforming the entire end-to-end manufacturing value stream.

Companies must not underestimate the impact of aligning the cyber world with physical connected devices. These devices generate enormous amounts of information that must be mined, analyzed, and acted upon. With the proliferation of connected devices, traditional manufacturing models no longer apply.

Historically, the physical Things and software in the realm of IT are in siloes. In the transformed manufacturing model, the traditional information technology model is augmented with operational technology (OT). Embedded software solutions with physical devices and the maintenance and control of Things is the realm of OT. The physical and virtual worlds are coalescing in the new digital enterprise.

Embedded sensors, software, controllers, and connectivity are creating a digital revolution in manufacturing and aftermarket services. Breakthroughs in networking, edge computing, cloud technology, energy efficiency, and miniaturization are converging to create low-cost processing power and data storage everywhere. Computers in machines, gadgets, and wearable devices are streaming data about their operations and conditions.

Things are already generating more data than people or applications. Translating that data into insights and intelligent decisions is the key to effective analytics. Intelligent, future-facing decisions can be derived from Thing Data, provided the company applies a digitized process context to orchestrate tasks for actions executed by humans, enterprise applications, supply chain partners, and increasingly smart Things or devices. The next industrial revolution is already here.



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