SIEMENS
Ingenuity for life

Siemens

MindSphere

Enabling the world's industries to drive their digital transformations

Executive summary

Siemens' MindSphere, a cloud-based, open Internet of Things (IoT) operating system, enables industries worldwide to link their machines and physical infrastructure to the digital world easily, quickly and economically. Harnessing data from virtually any number of connected intelligent devices, enterprise systems and federated sources allows for analysis of real-time operational data. This analysis then leads to optimized processes, resource and productivity gains, the development of new business models and the reduction of operations and maintenance costs. Companies leveraging MindSphere boost performance, sharpen their competitive advantage and realize much more profitability.

www.siemens.com/mindsphere

Contents

Abstract

The arrival of the Fourth Industrial Revolution – Industry 4.0 – is affecting every industry, disrupting current leaders and creating new business opportunities. Surviving this disruption and remaining competitive in an increasingly connected world requires companies to turn to digitization – using digital technologies to transform business operations.

Becoming a digital enterprise in the manufacturing industry means taking advantage of the Industrial Internet of Things (IIoT) to centrally collect, analyze and visualize all data across products, plants, systems and machines. By combining data from physical assets and enterprise systems, companies have unprecedented visibility and control over industrial assets. However, industries undertaking IIoT initiatives face the distinctive challenge of unifying assets that have no standards or universal method to connect. Linking disparate assets that have different protocols – quickly, affordably and securely – has been a defining obstacle for industrial manufacturers.

But companies that have managed to incorporate IIoT technologies have seen their profitability increase. IIoT leads to transparent and optimized operations, gains in productivity, reduced risk and the development of new business models with the implementation of condition monitoring, predictive/prescriptive maintenance, asset performance management, inventory management and complete digital twins – precise digital models of products and production operations.

"To survive disruption and thrive in the digital era, incumbents need to become digital enterprises, rethinking every element of their business."

"Four themes of becoming a digital enterprise"
World Economic Forum

MindSphere is shaping digitization

MindSphere is a cloud-based, open IoT operating system developed by Siemens, which enables companies to connect physical, web- and enterprise-based systems in one central location. By supporting multiple protocols concurrently, MindSphere uniquely simplifies and streamlines the connectivity challenges that most industries face – making it possible for every company to become a digital enterprise.

MindSphere also enables powerful data analysis and visualization so users can gain insight to make changes with real productivity impact. As an open platform as a service (PaaS), there is a rich (and expanding) partner ecosystem that is developing and delivering new applications for the world's many industrial sectors.

Leveraging Siemens

With MindSphere, users are able to leverage Siemens' deep knowledge and domain expertise in automation and digital services. In fact, Siemens is a leading automation provider, delivering critical operation and automation technology through global deployments of:

• 30 million automation systems
• 75 million contracted smart meters
• 1 million-plus connected products in the field

Siemens business units have developed IoT solutions for their industries and are building additional ones, contributing to the continuing growth of MindSphere applications and capabilities (figure 1):
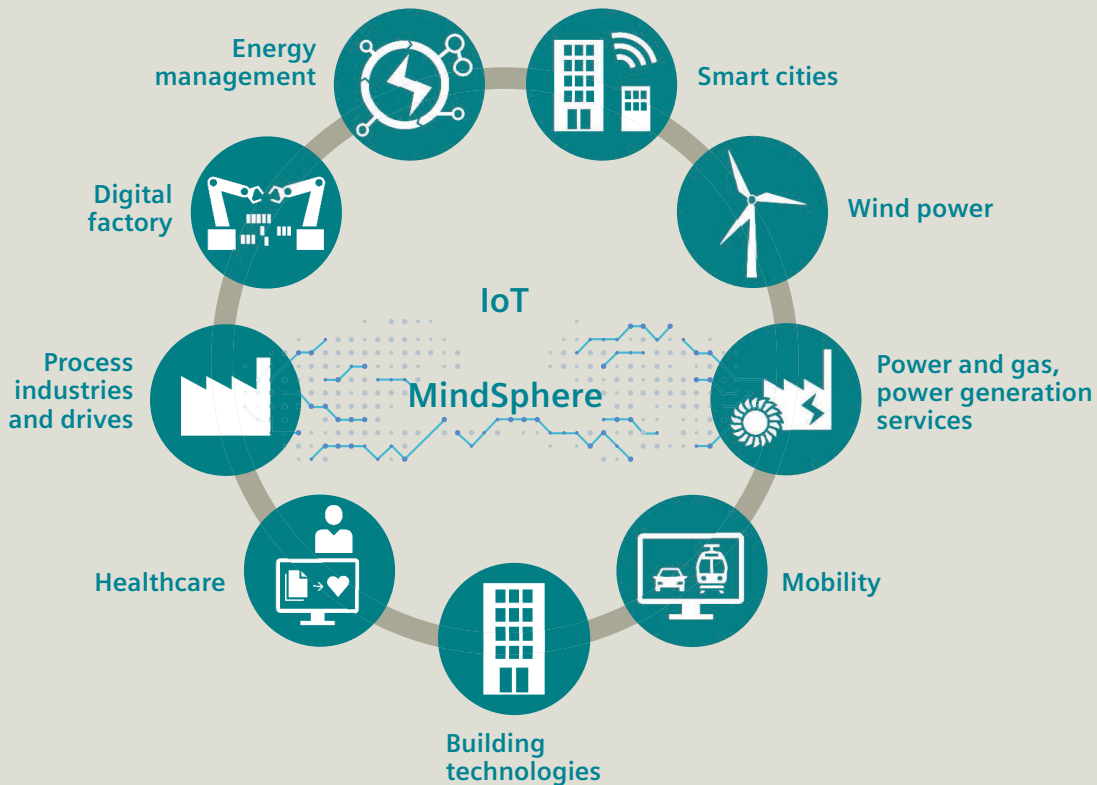
Figure 1: These vertical industries are working on IoT solutions with MindSphere, the cloud-based, open IoT operating system.

MindSphere architecture

MindSphere is the operating system that Siemens' IoT solutions run on. To make MindSphere work and enhance its usability, Siemens created a multi-tiered, federated architecture (figure 2) that builds connectivity and applications on top of the platform:

1. Applications. MindSphere applications are developed by Siemens' global domain experts across diverse industries as well as by third-party developers. Siemens has cultivated a diverse and highly experienced partner ecosystem of well-known independent software vendors (ISVs) to also develop applications.

2. Open PaaS. The MindSphere platform is a PaaS that is hosted in secure data centers of qualified cloud providers worldwide – AWS, Azure and others. It offers complete production, operation and developer environments.

3. Connectivity. The connectivity layer enables a company to connect all physical assets, (both Siemens and non-Siemens) web and enterprise information technology systems to MindSphere. The Siemens solution that provides this connectivity for MindSphere is called MindConnect. The security framework embedded in MindConnect aligns with the most stringent industry standards and governmental recommendations.

Figure 2: The MindSphere federated architecture builds connectivity and applications on top of an open PaaS.

Solving the connectivity challenge

When assets fluidly connect, insights from both current and historical operational and performance data becomes possible. Data processed into one centralized system allows operation teams, business 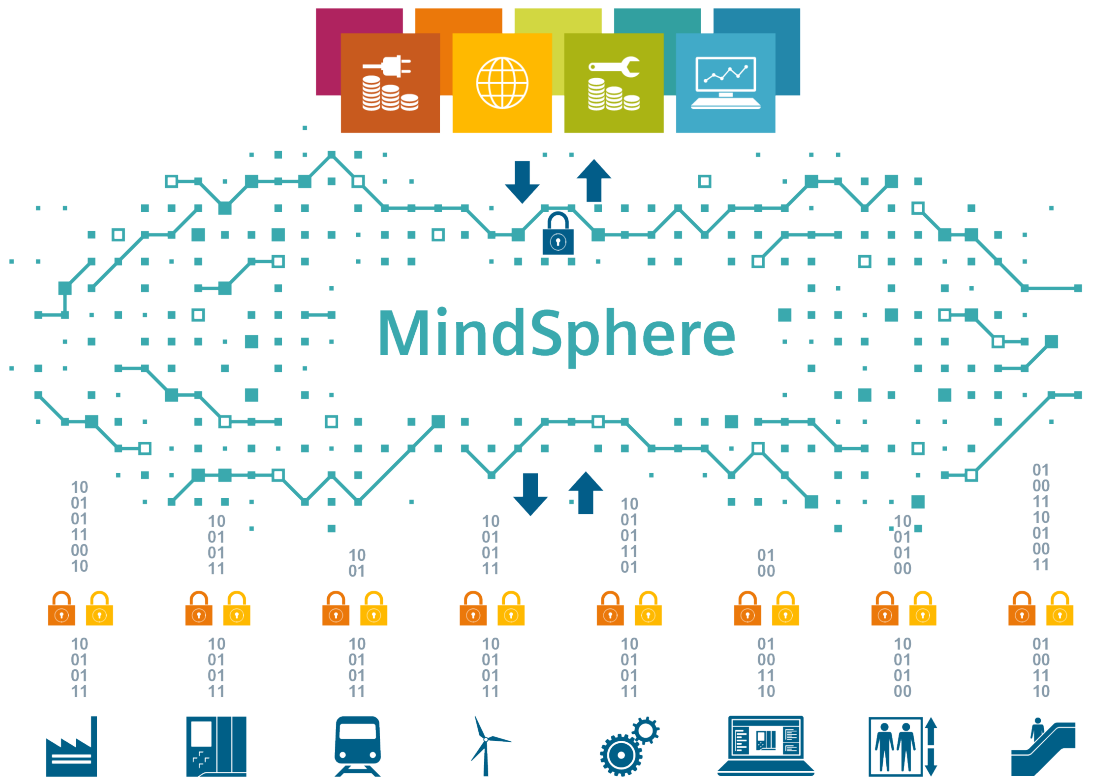analysts and data scientists to discover valuable and actionable insights that can profitably transform a business. But there is a challenge. How do companies connect every asset in every location to just one centralized system? With a wide variety of asset types, protocols and communication standards, this type of digitization is out of reach of most IoT systems.

To address this situation, Siemens developed MindConnect, hardware and software solutions and IoT services that offer flexible, open connectivity solutions for physical assets (Siemens and non-Siemens with any protocol or communication standard) as well as multiple systems, including historians, enterprise resource planning (ERP), manufacturing execution systems (MES), supervisory control and data acquisition (SCADA) and distributed control systems (DCS).

Adding this connectivity layer allows customers to flexibly access a global base of ready assets within MindSphere and efficiently extract data for observation and analysis – enabling endless possibilities for all kinds of assets from any supplier.

How MindConnect works
Protocols
MindConnect provides secured connectivity options to link devices, machines and plants to MindSphere in the cloud. Cloud connectivity is provided via protocols, such as HTTPS or MQTT, while supporting a wide range of device protocols, such as S7, Open Platform Communication Unified Architecture (OPC UA), LoRaWAN, Modbus, CoAP, XMPP, 6LowPan, LWM2M, AMQP and others.

Specifically, the OPC UA protocol is a global, machine-to-machine communications protocol as defined by the OPC Foundation and International Electrotechnical Commission (IEC) 62541. It enables all elements interconnected by MindSphere to communicate with each other. This means that up to 80 percent of the world's automation devices deployed in the past decade can be connected to, and covered by solutions that are enabled for MindSphere.

Devices
Physical equipment connections can be made using a small MindConnect device: a MindConnect Nano or a MindConnect IoT2040. These devices create a direct and secure connection for both greenfield and brownfield installations. With plug-and-play connections, adding assets does not require production downtime.

Beyond the MindConnect devices, companies can also leverage existing Siemens S7-1500 programmable logic controllers (PLCs) to connect directly to MindSphere and the digital world using the Totally Integrated Automation (TIA) Portal STEP 7 library. The TIA Portal STEP 7 library extends the function of the S7-1500 PLC to transmit PLC data to MindSphere. It is also possible to connect computerized numerical controls (CNCs), such as the SINUMERIK 840D sl, to MindSphere to further expand the range of direct connections to equipment assets in production environments.

Using browser-based tools to graphically configure data value mapping, users can build a flexible integration to bring enterprise systems, both in the cloud and on-premise, into context with MindSphere. This connectivity option uses a hardened Siemens IoT edge gateway device to physically and securely link plant machines to the MindSphere PaaS using OPC UA protocols. Communications to the MindSphere PaaS are encrypted using 256-bit Secure Sockets Layer (SSL)/Transport Layer Security (TLS) encryption or better.

Data security
As one of the world's leading automation providers with 30 million automated systems, 75 million contracted smart meters and over one million connected products in the field, security is a top priority for Siemens. MindSphere provides state-of-the-art security during data acquisition in the field, and transmission and

storage in the cloud. The security framework is aligned to the principles of industry standards, for example, IEC 62443, International Organization for Standardization (ISO)/IEC 27001 and BSI, the German Federal Office for Information Security, and governmental recommendations for data handling in cloud environments.

Data-in-motion is always encrypted using 256-bit SSL/ TLS encryption or higher. Data-at-rest is stored on high-performance servers at Siemens' infrastructure provider data centers. All infrastructure data centers meet the highest standards for data security, safeguarded against cyber threats and natural disasters. As commercial cloud Infrastructure as a service (IaaS) providers, they offer higher security standards than typical private, on-premise and local data storage facilities. The data centers operate in accordance with industry best practices. As an extra layer of security, all cloud infrastructure partners must have onsite security that includes electronic photo ID badges, cardholder access control, biometrics, recorded digital video surveillance and alarm monitoring.

MindConnect device security

The MindConnect Nano and MindConnect IoT2040 gateways employ security mechanisms that connect and send data only to the MindSphere platform. It identifies the MindSphere back end by validating the latter's security certificate. Certificate and key management measures are applied to handle the certificates and keys used by the devices. To guard against attacks from unexpected, internal sources, the MindConnect Nano and MindConnect IoT2040 devices have no open inbound ports.

During the initial onboarding connection process, the MindConnect Nano and MindConnect IoT2040 devices go through an authentication process with MindSphere. Once this is accomplished, the two entities share private cryptographic keys for use in all future encrypted communications. As a result, the MindSphere platform is designed to receive data from only valid, authorized MindConnect Nano and MindConnect IoT2040 devices that have successfully completed the authentication procedures during the onboarding process.

All communications between the MindConnect Nano or MindConnect IoT2040 devices and the MindSphere platform are encrypted via the TLS 1.2 standard with a minimum encryption key length of 256 bits. The TLS configuration is regularly checked to comply with the applicable Siemens information security guidelines. This

helps guard against man-in-the-middle attacks or any manipulation of communication between the devices and the MindSphere platform.

Securing customer automation networks

The MindConnect Nano and MindConnect IoT2040 devices protect the integrity of MindSphere customers' corresponding automation networks with these features:

- **Separate physical interfaces:** The MindConnect Nano and the MindConnect IoT2040 devices use separate network interfaces for connecting to the automation network and the external network. They also have internal firewalls to reduce the exposure of the automation network to the external network. The internal firewall is specific to either the MindConnect Nano or MindConnect IoT2040 use cases and cannot be configured by customers

- **Read-only access to automation systems:** All data acquisition drivers in the MindConnect Nano and MindConnect IoT2040 devices have read-only access to the data sources

- **Security-hardened software:** The MindConnect Nano and MindConnect IoT2040 software is based on a customized Linux operating system that is limited to a set of components and services as required by an original equipment manufacturer (OEM) customer

- **Firewall-friendly connectivity:** The MindConnect Nano and MindConnect IoT2040 devices communicate via firewall-friendly outbound internet traffic over HTTPS. Only a single outbound port (HTTPS port 443) and a fixed URL1 need to be open at the firewall. No inbound port is required to be open

- **Proxy support:** The MindConnect Nano and MindConnect IoT2040 devices support proxies for outbound traffic to the MindSphere platform. The proxy settings can be configured via the asset configuration tool in MindSphere

- **Off-boarding:** Off-boarding a MindConnect Nano or MindConnect IoT2040 device stops data collection and detaches the device from the MindSphere platform

Data ownership and access

At all times, MindSphere customers own their respective data, which is treated with maximum confidentiality. Customers have full control of access and authorization rights to their data. MindSphere was developed with data security as a top priority: access protection, tenant segmentation and encrypted communications make sure data is kept confidential and protected from manipulation by unauthorized external parties.

MindConnect add-ons

As an out-of-the-box solution, MindConnect provides all the connectivity elements needed to get started with IIoT. Add-on options and services include the following:

- **MindConnect IOT Extension:** MindConnect IoT Extension is a connectivity layer that expands the number of protocols that can communicate directly with MindSphere. Various field protocols are supported along with an increased range of hardware connectivity agents that create a direct connection to assets in the production environment. With a wide range of supported hardware connectivity agents and field protocols, MindConnect IoT Extension brings all production data into MindSphere in a cost-effective and flexible way

- **MindConnect Integration Services:** As part of the connectivity services, these services provide integration capabilities to both on-premise and cloud-based enterprise systems, databases and products. This includes connectors to industrial systems, historians, PLCs, SCADA, DCS, MES, manufacturing operations management (MOM), product lifecycle management (PLM), ERP systems and service platforms, such as Salesforce

  This category offers a wide range of cloud and enterprise connectors with more than 30 connectors to cloud platforms, such as Amazon S3, SNS, SQS, Apache Solr, Microsoft Dynamics, Salesforce and Google Suite. It also features more than 20 enterprise connectors to on-premise enterprise systems, such as JDBC, Oracle, PeopleSoft, SAP and others

- **Common Remote Service Platform (cRSP) Services:** These support remote access logging and encrypted transmission via multiple protocols, such as HTTP, HTTPS, ssh, sftp, Telnet, PuTTY, NetOp, WinVNC, TeraTermPro, Timbuktu, Tarantella, SCO-/Citrix-/MS Terminal Server, X.11, SNMP, while supporting VPN tunneling

MindConnect services provide the foundation for every industrial company to become a digital enterprise with IIoT. With these powerful connectivity capabilities, companies have an opportunity to provide unprecedented transparency across their entire operation to not only optimize processes, but also develop new business models to increase profitability.

MindSphere: An open, comprehensive, highly scalable microservices architecture

The MindSphere platform is focused on supporting the Industrial IoT. It is a cloud-based, open IoT operating system because it builds upon the typical PaaS to enable customers to develop, run and manage their applications without the cost or significant effort of building an infrastructure or managing complex, rapidly changing software stacks. Customers also gain much more flexibility and tailored functionality with modular applications, along with faster and more cost-efficient updates and agile development.

MindSphere is designed to be fault-tolerant and highly scalable, using a microservices architecture to provide application programming interfaces (APIs) that can be used in a wide variety of combinations to build applications and functionalities that address customer needs. These include Siemens applications, ecosystem partner applications, third-party integrations and applications that are locally built by MindSphere customers.

MindSphere provides out-of-the-box (OOTB) core components that are needed to start managing and visualizing collected data. These core components lay the foundation to get started. The MindSphere application framework and common application components offer APIs and add-ons that enable building the required structure. Figure 3 illustrates MindSphere as a series of layers, components and services.

Fleet Manager. Fleet Manager is a set of core components. The fleet concept in MindSphere is broadly defined as any collection of connected assets – it can be any combination of assets and asset types. It enables users to quickly get an overview of the data and status of all connected assets. Flexible search options help users to stay in control when managing a large number of assets from different customers – either distributed worldwide or located in one site.

By having quick access to all connected assets and current and historic data, it is possible to quickly turn data into actionable insights. For example, the MindSphere Visual Flow Creator provides the ability to transform incoming data in real time. It aggregates and integrates with in-line analytics services to generate actionable insights visible on dashboards and email notifications. This enables condition monitoring, preventive maintenance, asset performance optimization
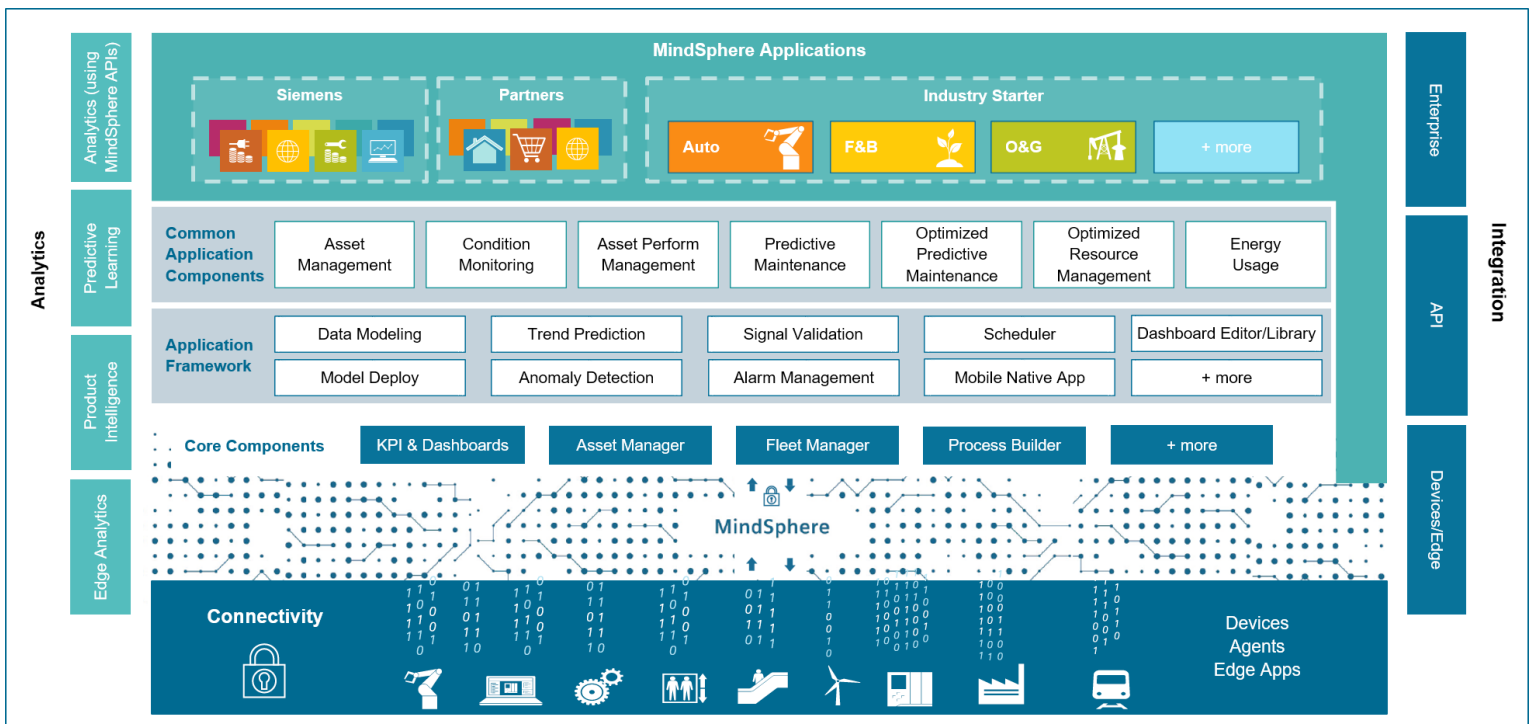

Figure 3: MindSphere architecture.

and similar use-case best practices to increase asset productivity, availability and utilization.

In addition, Fleet Manager provides dashboards and automated reports that are essential for daily operations in order to get an overview about fleet status, productivity, key performance indicators (KPIs) and much more.

Data management strategy

The MindSphere data management strategy is to provide cost-efficient IoT data management capabilities in every instance. To do this, MindSphere is focused on two specific areas. The first is workflow-based data acquisition, management and integration, which is supported by sophisticated but easy-to-use tools. The other is to provide a secure, raw data-access layer for integrated analytic applications. To accomplish this strategy, MindSphere provides the following:

- Seamless storage and archival of data, removing the need for partners and customers to worry about appropriate data management strategies

- Utilization and extension of the native components of any underlying infrastructure platform

- High performing and scalable solutions appropriate for specific use cases

- Integrated extract, transform, load (ETL) to facilitate data transformations from multiple sources and protocols to normalize data

- Flexible APIs that enable customers and partners to build powerful, data-centric applications

MindSphere has two differentiators in the area of data management:

- Integrated big data analytics with IoT data in a single platform

- Intelligent storage and aggregation algorithms that reduce the total cost of ownership (TCO) for data stored on the platform

Data management and data lake concepts

MindSphere uses a federated data lake concept for data management. Data lakes hold large amounts of raw data, from multiple sources and across federated systems, until needed. Applications or services can consume data and contextualize it with any other kind of data in the data lake.

In MindSphere tenants, data sets are organized into raw, staged and processed data and analytical results. The MindSphere platform provides separation for development, test, preproduction and production phases. The data lake can be used as a mechanism to share data across the platform for use in any authorized service or application.

Data security and access are controlled by internal authentication and authorization mechanisms managed by the identity and access management (IAM) solution. With these services, a user may choose what data to share with what applications and services on the platform. Data can be encrypted at-rest inside the data lake.

Application enablement and development

The MindSphere application enablement and management strategy is to empower developers with the APIs, services and support they need to quickly and easily build, test and deliver applications on the MindSphere platform using the tools of their choice.

To facilitate application enablement and management, MindSphere provides a developer environment that includes:

- A wide variety of APIs to enable application development and reduce development costs on Cloud Foundry, AWS and Azure with supported programming languages on Cloud Foundry, such as Java, NodeJS, Python, PHP, .NET, Go and Ruby. Native infrastructure provider-based applications (for example, AWS and Azure) are able to use any available language

- Plug-ins for common development environments, such as IntelliJ and Eclipse, making it easier and faster to develop and integrate applications for MindSphere

The application enablement and management capabilities are characterized by two differentiators:

- The combination of capabilities provided by MindSphere APIs with cloud-native services

- The ability to develop and deploy software applications in hours or days instead of weeks and months

There are dozens of APIs available, such as asset management, event management, the data flow engine, notification services and context delivery service, including enhanced functionality. Examples of analytic APIs include trend predictor, signal validation, signal calculator, KPI calculator, anomaly detector and event analytics.

Additionally, there is a robust set of APIs available for developers to create customer-owned applications. These APIs, with re-usable supporting modules, are optimized for IIoT application development.

The application enablement and management strategy balances direct customer user engagement with a focus on Siemens' MindSphere partners developing applications. Partners developing commercial MindSphere applications may offer them in the MindSphere Store, which provides access to a significant installed base for targeting and selling applications. Siemens has a long-established network of solution partners that can help customers develop their own MindSphere applications.

Application development platform

Open source application development platforms provide a quick and easy way for developers to create new applications that can use and deploy the MindSphere platform APIs. For example:

- Backing services support basic services within the environment, including message queues, distributed caches, relational database management systems (RDBMS) and the document and file stores. For example, these services can easily be integrated into Cloud Foundry applications through APIs

- Development and production separation is a feature in the environment that distinguishes applications in development from released applications that are available for use. There are processes to support the promotion of the application from development to production, including validation checks that make sure applications comply with the platform policies for security and stability. Feature testing is the responsibility of the application developer

- Self-managed containers and virtual machines (VMs) enable customers with specific needs not supported by the MindSphere platform to create their own containers for deploying and integrating their code with MindSphere via its APIs. If containerization is not possible for an application, then the native code can be deployed through VMs and managed by customers. Some minimum requirements are necessary for integration into the MindSphere platform, such as IAM integration, which provides single sign-on and the security for the APIs

Locally developed applications

Locally developed applications that fit specific needs are supported by the MindSphere platform in several ways. The simplest way to develop and deploy an application is with one of two options:

- Cloud Foundry, for which tools in MindSphere support application development, deployment and validation

- Mendix cloud native low-code application development platform

Developed applications can be registered with the application manager and then accessed through the gateway. They can also be made available in the MindSphere Store.

Locally developed applications are supported by API access from an external application to the system. In this case, the external application is managed by the application provider and not directly by the MindSphere platform. This way, the application can exist anywhere and make use of whatever services and/or third-party tools are required to meet the needs of the application. However, the application can still access the platform APIs and provide single sign-on by integrating with the IAM services.

Services for MindSphere

Platform services
MindSphere platform services consist of two categories: core platform services and advanced services.

Core platform services support all functionality on the platform, such as:

• Tenant management

• User management

• Authentication and authorization (standards-based, including OAuth support)

• Master data services for data modeling and entity management

• Messaging

• Metering and usage tracking

Advanced services provide additional functionality to support IIoT services, applications, data management and integration support for third-party APIs. Examples include:

• Asset management, which assigns assets, such as different devices, a unique ID

• Property management, which supports mapping of locally extended properties or attributes with assets

• Event services, which provide event management and processing

Gateway services
MindSphere provides gateway services, specifically an API gateway, API management, service discovery and application registry services. These are protected by a web application firewall (WAF), combined with authentication and authorization services, for greater security to safeguard against standard web vulnerabilities and distributed denial of service (DDoS).

Gateway services are connected with the MindSphere platform's IAM services to secure APIs and applications. They also help control access using the platform's authentication and authorization services, which are provided as part of the platform services.

In addition, gateway services define scopes, which are associated with roles that are assigned to users. With this mechanism, the API gateway can provide access control to users for services. Fine-grained access control is managed further by gateway services if there are more fine-grained access rights within a service. One example is when a service restricts user access to specific data within that service.

IoT services
IoT services provide ingest, storage and query capabilities for IIoT time-series data. These services are designed to support high-throughput data ingestion from multiple types of devices, agents and connections, along with data lifecycle management and optimized storage practices.

For example, "hot data" typically consists of the most recent data, and is processed via a high-throughput, low-latency storage engine. In contrast, "warm" and "cold data" storage is normally managed internally through an automated tier process that moves hot data to warm or cold storage as it matures. Intermediate aggregates are provided to deliver faster query access as the data moves from hot to warm to cold storage. Storage formats for warm and cold data are optimized for analytic queries, too.

In addition to the default time-series data stored in MindSphere, locally developed parsers and storage for time-series data is achieved by building applications and integrating them into the IoT services. Locally developed parsers are used to support logic or customer-specific needs for data mapping to the IoT model or locally extended data structures, if needed to support applications.

Analytic services
Analytics provides basic analytics to derive insights from various plant data. For example, trend detection can provide the calculus for individual or multiple 1D time series, including basic algebra and statistics, such as mean, sum and variance. In addition, advanced analytic capabilities are available to execute more complex analytics and machine-learning techniques on data. These components can be combined to provide complex analytic pipelines.

In addition, analytics services offers the following APIs:

- **KPI calculation:** The KPI calculation API is an easy way to provide various calculations for KPIs based on sensor data. Depending on availability of data sources, a specific computational procedure can be applied. Procedures work for both the off-line batch analysis and the on-line analysis of new data

- **Anomaly detection:** The anomaly detection API detects unexpected behavior of processes and assets. Furthermore, clustering-based anomaly detection techniques allow human interaction and integration of domain knowledge (for example, by labeling of new clusters and/or anomalies). Developers can build applications for process and condition monitoring, early warning functionality and detection of fault conditions without explicit definition

- **Event analytics:** The event analytics API provides statistical analysis for visualizing the top 10 failures of the assets that are used to identify potential problems

- **Signal calculation:** The signal calculation API offers commonly used missing value handling strategies, such as removal and interpolation. The API calculates a descriptive summary of a sequence of signal values, and if required, derives new signal values by shifting, smoothing and transforming the original ones

- **Signal validation:** The signal validation API provides functions required to detect the most common issues in time-series data. Some of the functions include: range check, spike alert, step alert, noise alert and bias alert. The API can also be used for optimizing data quality

- **Trend prediction:** The trend prediction API is a forecasting framework that has many useful applications in the area of process and condition monitoring. Also, seasonality and trend removal is an essential task of data analytics preprocessing. With linear and polynomial regression, this API can be used to detect if a component's service lifetime will be reached in the near term or for process monitoring to predict the remaining time to prevent unwanted process states

Edge and analytic services
Customers wanting to benefit from both cloud and on-premise technology innovations can extend MindSphere by deploying software on edge devices and gateways by using the MindConnect LIB and MindConnect API. This provides advanced analytics and performance intelligence in secure proximity to plant equipment for faster processing in near real time, minimizing latency. It can enable a variety of use cases for descriptive, diagnostic, predictive and prescriptive analytics. It does so by leveraging cloud connectivity in combination with edge applications from Siemens or third parties in an integrated hardware/software environment.

The MindSphere industrial edge approach consists of cloud-based edge services and the modular edge runtime. Edge services and the modular edge runtime need to operate in synchronization from both engineering and runtime perspectives. This industrial edge approach is the transparent integration of cloud services with field automation platforms. It enables the seamless extensibility of an installed base of device assets, such as Siemens' SIMATIC IT automation controls, SINUMERIK machine controls, SIPROTEC smart grid components and Climatix heating, ventilation and air conditioning (HVAC) controllers, with an ecosystem of edge-oriented MindSphere applications operating at the field level but managed through MindSphere.

MindConnect edge services
These services provide connectivity across edge, IoT services and storage domains. The service APIs enable data to be sent from edge devices and agents to the MindSphere platform.

Edge services support devices and analytics, and provide the ability to manage devices, including updates for edge software. Edge applications can be downloaded and executed on edge systems, including edge analytics. The Siemens edge management strategy is to enable the transparent integration of cloud services with any device, asset or plant facility, allowing for seamless extensibility of a heterogeneous device and asset ecosystem.

The following MindSphere features are differentiators:

• Cloud-based edge services

• Modular edge runtime that is deployable to a wide variety of edge devices

• Ability to leverage cloud connectivity in combination with edge apps from Siemens or third parties in integrated hardware/software environments

Key capabilities include:

• Deployment of software on edge devices with the use of the MindConnect Library and API

• Integration of advanced analytics and performance intelligence in edge runtime

• Highly secure interactions with diverse edge devices, enabling multiple use cases for descriptive, diagnostic, predictive and prescriptive analytics

• Integrated capabilities provided by Siemens so customers can manage edge devices themselves, helping to provide a seamless user experience

Vendors are embedding cloud-enabled edge and device management capabilities into their hardware products for even better performance. These devices are supported by the MindSphere open-edge strategy and related connectivity and processing services.

Developer and partner services
These services deliver the functionality that customers and third parties need to build applications, deploy them to the MindSphere platform and integrate them with the platform services. The services include the developer cockpit, a single workspace to help developers manage the applications they are building, and an operator cockpit to offer applications to their customers.

Exchange services
Exchange services give developers the ability to sell their applications or make them available to customers by providing an interface to a shared marketplace for the MindSphere community called the MindSphere Store. Access control rules can be used to provide privacy for specific applications that are intended for use only by certain organizations.

Operations management services

These services are a toolkit to support MindSphere application solutions and all their internal development processes. They provide full automation throughout the development process using a continuous integration and continuous delivery (CI/CD) pipeline that adheres to modern DevOps principles. Examples include:

- Automated infrastructure is provided via extensive scripting

- Automated security validation is provided via code verification that confirms services deployed to the MindSphere platform through the CI/CD pipeline adhere to its security requirements. If a service does not conform to the security requirements, its deployment can be stopped

- Monitoring tools keep watch on the system, enabling escalations to trigger alerts if a service becomes unavailable or a problem is detected

- Logging and log analysis tools are available on the MindSphere platform to support incident tracking, troubleshooting and forensics capabilities

- A support ticketing system is available on the MindSphere platform that leverages the Siemens Global Technical Access Center (GTAC) system in Siemens PLM Software. Support tickets are integrated directly into the systems development lifecycle (SDLC). This provides immediate feedback from the customer to the Siemens development teams that own the particular service or services on the MindSphere platform. This way the development teams can respond more quickly to customer requests

Integration and connectivity

In MindSphere, applications are seamlessly integrated with operational data throughout the value chain, closing the loop through product ideation, realization and utilization lifecycle stages. Integrations can involve either or both enterprise applications and cloud platforms, operating either on-premise, in the cloud, or some hybrid of the two.

In turn, these integrations can provide application developers with the ability to compare simulations and test results with real-world observations so they can continually improve the quality and responsiveness of their applications. They also gain the capability to connect to both on-premise and cloud-based enterprise systems, databases and products. In addition, PLM services can be integrated into the platform, providing

real-time and accumulated data on performance for input to high-fidelity, closed-loop digital twins of product, production and performance.

Compared to other IIoT PaaS alternatives, the MindSphere integration differentiators include:

- Big data analytics integrated with IoT data in a single platform

- Connectivity to the broadest possible portfolio of assets and systems with connectors to industrial and enterprise systems, historians, SCADA, DCS, MES, MOM, PLM, ERP, quality management (QM), supply chain management (SCM) and other systems and service platforms

- Connectivity to an open ecosystem of industrial devices, including manufacturers other than Siemens

- Integration with an asset's complete holistic digital twin, including the product, the production process by which it was made, and the performance of that product

Powerful applications and digital services

To optimize and customize the capabilities of a MindSphere instance, Siemens has created a rich application- and management-enablement ecosystem. Siemens engineers are actively developing analytic and industry specific applications, which enable companies to transform and visualize their data in game-changing ways. Beyond Siemens engineers, any developer can get access to the application- and management-enablement technologies to design and launch applications.

MindSphere applications by Siemens industry experts

Product Intelligence
Product Intelligence provides the ability to search and analyze billions of contextualized supplier, manufacturer and customer field data events in seconds, giving users a complete view of their entire value chain.

Product Intelligence was developed with manufacturing industry expertise from Siemens PLM Software. It automates insight from product performance data to create actionable intelligence. The MindSphere application connects a company's products with a worldwide value chain by unifying all of its big-data sources – such as PLM, ERP systems, MES, quality management systems

(QMS), customer relationship management (CRM) systems, and the IoT – into one easily accessible hub.

The Product Intelligence MindSphere application features four offerings:

- **Data Quality** enables users to clean, maintain and analyze big data integrity at the source

- **Performance Analytics** enables users to monitor data across the entire supply chain, even the customer experience, while quickly analyzing billions of data combinations in seconds. This can significantly reduce the cost, time and resources needed for big data analysis. It includes three key tools

  - Discovery allows companies to ask the questions they did not know they should ask by analyzing billions of data combinations to create big data insights

  - Monitoring enables users to track and observe trends for all their big data sources in a single hub for comprehensive analysis

  - Parametric data analytics is enabled by capturing multiple sources in a supply chain, including product testing during new product introduction (NPI), manufacturing during production and the IoT during field operations

- **Advanced Data Visualization** integrates Tableau® software and is used to create simple, clear charts and graphs from layers of complex dataset KPIs

- **Contextual Search** enables users to view and search all of their unified big data in one place for quick drill downs and investigation of the source of value chain issues

Manage MyMachines
Manage MyMachines provides visibility into machine utilization and performance, which allows users to reduce costs and improve service and maintenance.

Manage MyMachines comes from the Siemens Digital Factory group. It monitors machine tools worldwide for their availability and productivity at small and large production sites. It also allows machine tool builders to start developing new digital services, making it especially well-suited for the customers of small- to medium-sized OEMs.

Manage MyMachines can connect the Siemens SINUMERIK 840D sl controls to MindSphere in a simple and intuitive way. Additional Siemens and third-party control systems are on the MindSphere development roadmap.

MindConnect Edge Analytics
Edge analytics provides asset monitoring and data visualization capabilities that enable early detection of damage or anomalous behavior in machinery. In effect, it can help operators optimize production efficiency, lower maintenance efforts and minimize unplanned outages by facilitating planned maintenance outages via predictive maintenance and root-cause analysis.

MindConnect Edge Analytics is a Siemens condition-monitoring system (CMS). It enables easy engineering for data analytics workflows and supports a wide range of assets for data acquisition, providing dynamic data intelligence in all industries. Additionally, it offers many opportunities to collect field signals in a CMS device in the production area. The data can be read cyclically in a frequency up to 192 kilohertz (kHz), then analyzed, compressed and stored. Afterwards, the preprocessed data can be sent to MindSphere.

Rail asset management
The mobility specific platform, Siemens Railigent®, helps to increase availability, improve efficiency, reduce operational risks and costs, and improve maintenance for the rail transport industry.

It includes remote monitoring, fast diagnostics and preventive failure prediction for both rolling stock and infrastructure. Examples include: visualization of vehicle health status and location; prediction of component failures for gearboxes, bearings, traction motors, doors and power transformers; operation support; analysis of error conditions of the European Train Control System (ETCS); prediction of point machine failures and throughput analysis for rail networks.

Features and capabilities include:

- Prescriptive maintenance enabling greater than 99 percent availability

- Optimized operation planning with up to 20 percent fewer delays

- Transparency in real time with the Global Positioning System (GPS) and hundreds of sensor readings per second for high-speed vehicles

- Root-cause analysis with reduction of complex fault resolution times by more than 20 percent

With Railigent connected to MindSphere, companies are able to improve their asset fleet along the entire life-cycle. For example, a rail operator will not only be able to improve rail vehicle availability, but also the operation of stations and optimization of energy consumption.

Energy management application suite
Siemens EnergyIP offers a broad range of applications for utility grids. The solution covers use cases like meter data management, decentralized energy management, market transaction management and customer engagement over portals and mobile devices. It can integrate and process data from millions of distributed assets, such as smart meters, remote terminal units and inverters. It can process meter data automatically, while also monitoring and controlling distributed energy resources and managing market participation for virtual power plants and demand response solutions.

Furthermore, EnergyIP offers an analytics environment based on state-of-the-art technology and advanced analytics applications to leverage more value from the existing data.

Features and capabilities of EnergyIP include:

- Manage data from millions of distributed assets in near real time

- Efficient IT-operational technology (OT) integration between IT applications and field devices

- Utility data model to interpret data from energy assets

- Bi-directional, closed-loop communication

In the future, the current functionalities of EnergyIP will be extended and gain significant value as its applications will be available as MindSphere applications. This will enable cross-vertical use cases, new business models and new service offerings to consumers.

Building performance and sustainability

Designed for managing the performance of commercial buildings and industrial facilities, Siemens' Navigator helps to turn data into actionable intelligence throughout the lifecycle of one asset or an entire portfolio of assets.

Navigator is designed to enhance the performance of building systems, achieve sustainability goals and reduce energy expenses while maximizing energy and operational efficiencies. With these capabilities, users gain greater visibility into the long-term performance of their buildings and facilities.

As a fully customizable, cloud-based platform, Navigator can be used to analyze a single building, a campus or an entire real estate portfolio. Built with powerful reporting and analytic capabilities, Navigator collects and analyzes large volumes of building performance data so users cannot only optimize efficiency and cost savings of their investments, but also generate actionable information to make informed decisions and improve business efficiency.

Control loop performance analytics

Control loop performance analytics adds a new layer of transparency to process data available in a DCS, supporting an efficient optimization process. Transparency is generated through automatic state detection and KPI calculation for different control states. This application gives users hierarchical plant overviews from management to a single control detail, allowing automated data analytics on a regular basis to support long-time process optimization and fine-tuning. Additional expert reports for critical control loops can be generated.

Drive-train analytics

Drive-train analytics provides the connectivity, analytics and visualization needed to enact cloud-enabled, condition-based maintenance (CBM) for drives, motors and gear units, while taking advantage of the knowledge of their manufacturers. A CBM model can provide early warnings of impending faults so remedial action can be taken before production disruptions occur. It also enables users to best match maintenance measures and planned production downtime.

DevOps environments for application development

To help Siemens' customers and partners build and integrate their software applications and services, MindSphere offers open APIs and development tools. MindSphere APIs draw upon Siemens' extensive knowledge of most major industries, as well as its familiarity with IoT and the key business drivers for moving to IoT solutions.

With these tools, customers can deploy software applications in hours or days versus weeks and months. It allows developers to refactor existing monolithic solutions into modular components/applications to offer customers much more flexibility and tailored functionality, as well as faster and more cost-efficient updates and agile development approaches. MindSphere provides developers with a wide variety of APIs, which can accelerate application development and considerably reduce its costs.

Plug-ins for common development environments, such as IntelliJ and Eclipse, make it easy and quick to develop and integrate applications for MindSphere. Additionally, developers can utilize re-usable services and components, from parsing, analytics and visualization to cloud-to-cloud integrations and data exchange to further accelerate time-to-deployment. Local debugging analysis and performance optimization also contribute to faster development timeframes.

In addition, application developers are able to draw on the resources of the MindSphere development community, such as a developer portal, developer conference, example demo applications, templates and more. For developers who offer their customers customized applications and services, the developer cockpit workspace helps them track the utilization of their services and manage their resources.

The MindSphere Store

The MindSphere Store provides a secure distribution platform for industrial applications and digital services hosted on MindSphere via direct downloads on a trial or fully paid basis, as determined by the application owners. Sources can include Siemens, from among its many business sectors, and third-party partners, such as ISVs and OEMs. All third-party applications available in the MindSphere Store are scanned and certified virus-free. Third-party providers are governed by a Siemens licensing agreement, including separate legal terms and conditions, and are fully responsible for their intellectual property. They are also responsible for providing sufficient levels of technical support.

Closed-loop innovation with end-to-end digital twins

Digitization is affecting every industry, making it possible, even necessary, for manufacturers to completely revolutionize the way they do business. The most innovative companies will not only reduce cycle times, increase yields and create new business opportunities, they will also dramatically improve their bottom line by implementing technology to improve their product throughout its entire lifecycle with insights gained using closed-loop digital twins from design through production and back again.

The idea of creating a digital approximation is not new. A digital twin is a cross-domain virtual model in software that accurately represents a product or production. But with the power of IIoT, it is now possible to take the digital twin concept further than it has previously been able to go.

The data collected with IIoT platforms provides detailed insights into production operations. By taking this information and connecting it to high fidelity digital twin models, companies create a consistent digital thread that enables them to speed up development, optimize manufacturing processes and improve products for their next version or iteration with real-time insights (figure 4).

Siemens provides the complete digital twin with MindSphere

By combining MindSphere with Teamcenter® software, Siemens' product data management collaboration tool, the digital twin evolves and continuously updates to reflect any change to the physical counterpart throughout the lifecycle. This creates a closed-loop feedback in a virtual environment that offers companies detailed insights into the best possible design for their products and production processes.

For optimal results and the most accurate performance predictions, it is critical the digital twin has the highest degree of precision and fidelity. Siemens achieves this by incorporating multi-physics simulation capabilities. The digital twin can be a predictive analytics tool used to determine the performance characteristics of products and production systems. Products and production systems can be continuously optimized as the digital twin receives performance information from the field (the product) or the factory (the production system). Elements of the digital twin are integrated through a digital thread, which connects data and intelligent models throughout a product and production
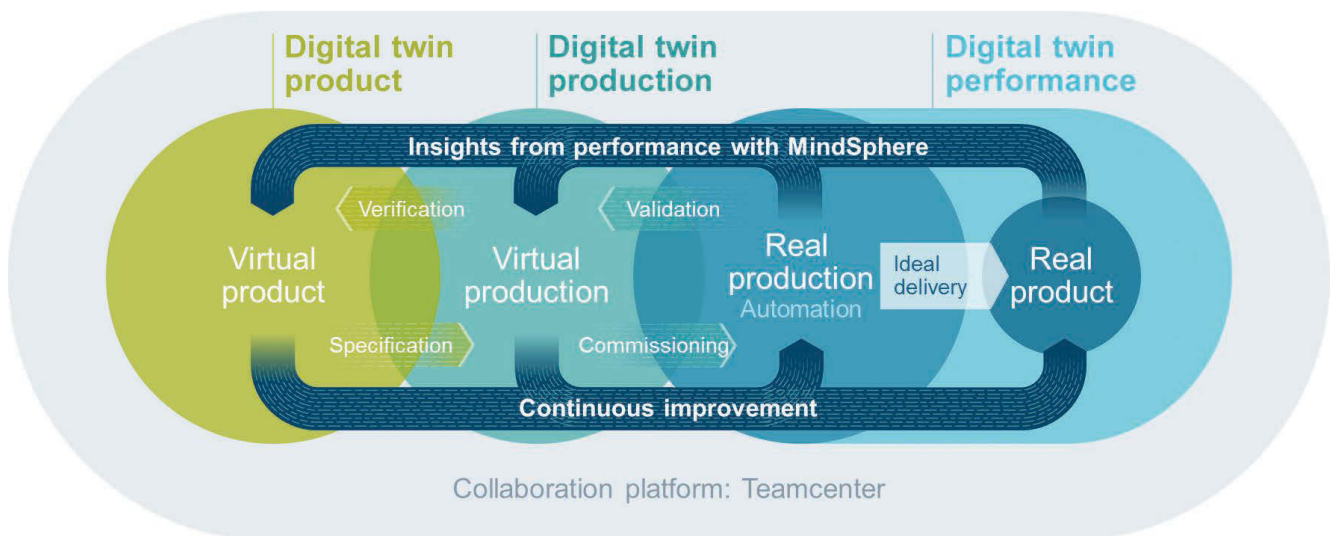

Figure 4: This picture shows how a digital twin can provide a virtual proxy for a product, production and performance.

equipment lifecycle to help companies understand why something is happening, and also reveal insights to make future design or production decisions faster.

Siemens believes in a holistic approach with intelligent models and a closed-loop digital thread, leading to insights that deliver actionable impact. The digital twin's end-to-end use can last through the design, manufacturing, operation, feedback and updates until the physical counterpart's end of life. The digital thread of the holistic digital twin interconnects a rich set of information created throughout the lifecycle, verifying past and supporting future actions.
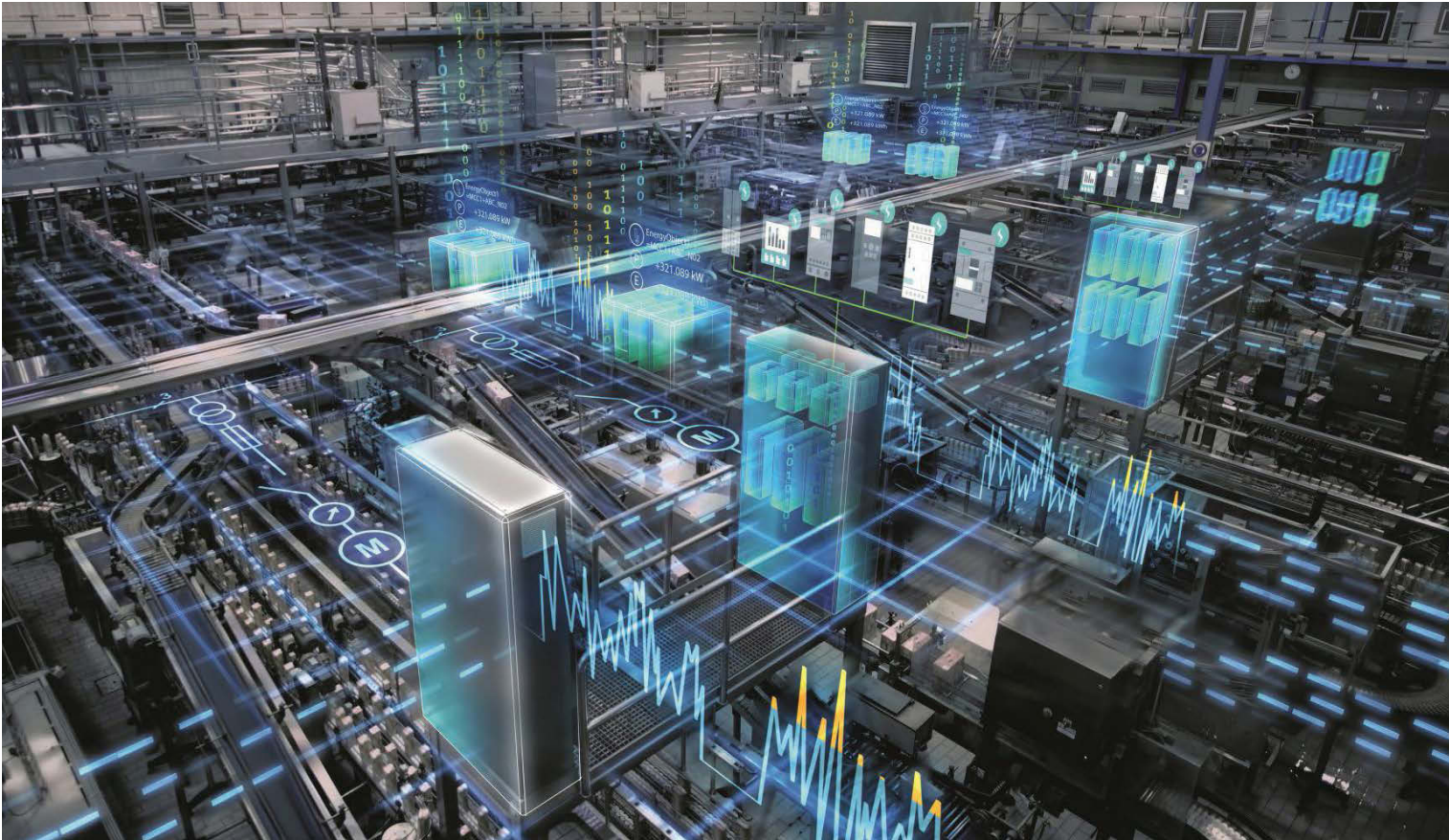
MindSphere partner ecosystem

Siemens actively cultivates a rich partner ecosystem by providing developers with an excellent opportunity to participate in the digital transformation of companies regardless of industry or size. With a global installed base of millions of devices, partner-developed, high-value applications are frequently released in partnership with Siemens.

Mindsphere offers a wide range of APIs to encourage development that provides a holistic set of IIoT solutions and services, precisely matching the specific requirements of customers. This provides partners with enormous opportunities to build and operate their own digital offerings around MindSphere.

Significant resources are focused on partner enablement to make sure the highest-quality solutions are developed and released in a secure environment. Partners receive support, such as training and consulting. All developed applications are tested by Siemens to meet strict security standards. The MindSphere partner program focuses on generating a win-win scenario for customers and partners. Partners can promote their MindSphere applications, while MindSphere customers benefit from numerous available applications and services that address their toughest challenges.

Simplifying digitalization with MindSphere

Acting now, at the forefront of Industry 4.0, will yield companies the biggest competitive advantage.

Today, digitalization is a key requirement for companies to remain competitive in an increasingly connected world. With Siemens' MindSphere, the digitalization journey can be accelerated with little disruptive risk. Connecting assets across the world to one platform does not require downtime or piecemealed connectivity solutions. And the insights gained from the resulting digitalization helps to lower costs, improve product quality, drive new efficiencies and performance levels, and shorten response times to customer requests and market demands. It can also open up new business opportunities and services.

MindSphere connects real things, including physical assets and web- and enterprise-based IT systems, to the digital world and enables high-value, industry based applications and digital services to drive business success. Its open PaaS capabilities enable a rich partner ecosystem that offers a wide range of innovative IIoT solutions. By seamlessly integrating operational data throughout the value chain, companies will not only drive greater operational transparency and performance, but will also be able to compare simulation and test results with real-world observations to boost performance, sharpen their competitive edge and realize much more profitability.

Your digitalization journey awaits. Contact a Siemens representative, your global partner or visit the Siemens MindSphere website to learn more.

Siemens

Headquarters
Granite Park One
5800 Granite Parkway
Suite 600
Plano, TX 75024
USA
+1 972 987 3000

Americas
Granite Park One
5800 Granite Parkway
Suite 600
Plano, TX 75024
USA
+1 314 264 8499

Europe
Stephenson House
Sir William Siemens Square
Frimley, Camberley
Surrey, GU16 8QD
+44 (0) 1276 413200

Asia-Pacific
Unit 901-902, 9/F
Tower B, Manulife Financial Centre
223-231 Wai Yip Street, Kwun Tong
Kowloon, Hong Kong
+852 2230 3308

www.siemens.com/mindsphere