

New Industrial Automation System Topologies made possible by the Industrial Internet of Things

by Peter G. Martin PhD

Executive summary

The emergence of the Industrial Internet of Things (IIoT) allows many traditional notions associated with industrial automation systems to be reconsidered. One of the traditional constructs requiring a new perspective is the topology of industrial automation systems. Traditional topologies were based on technological considerations and, as such, did not easily map to plant architectures. This paper analyses the benefits of new topologies that align perfectly with inherent industrial technologies, which are made possible through the adoption of IIoT.

Introduction

Starting with the introduction of digital computer technology as the delivery vehicle for process control systems in the 1960s and 1970s, industrial control system topologies have been designed for industrial operations based on the limitations and constraints of those digital technologies – not on the topology of the industrial businesses and operations. As a result, the physical and logical topologies of traditional industrial control systems have been fundamentally mismatched. Although these control systems worked and performed their functions, they were difficult to apply and maintain – at least in part due to the fact that their physical and logical topologies did not naturally align with industrial operational and business architectures.

The fundamental topology and functionality of automation systems are on the verge of undergoing a significant transformation due to technological advancements such as big and small data analytics, cloud computing, cyber-physical systems and the Internet of Things (IoT). The emerging automation systems will be based on natural industrial architectures (NIT) and defined by the asset architectures in the industrial plants and enterprises, not the technological constraints.

Traditional Asset-Centric or Process-Centric Topological Views

There are two competing perspectives for natural industrial topologies: asset-centric and process-centric. These two perspectives are based on the predominant topological view of an industrial operation. In an asset-centric model there are processes that are controlled within the context of assets. In a process-centric model assets are defined as nodes within the overall processes. Traditional machine controls through PLCs have taken an asset-centric perspective from inception because early PLCs were typically aligned to a specific equipment asset. Process controls were based on a process-centric perspective from inception.

The logical topologies of traditional DCS systems were more aligned to industrial processes than the assets due to their evolution from analog process control systems. This process-centric perspective served industry well for simple control loops up to process units. The problem with the process-centric perspective is that it tends to significantly increase in complexity as the process extends to entire units, process areas, plants, and enterprises. In fact, the complexity tends to increase exponentially (**Figure 1**). Although with considerable effort they could expand to the area, plant, fleet, enterprise and value chain levels, they seldom truly did because the complexity became such a significant barrier.

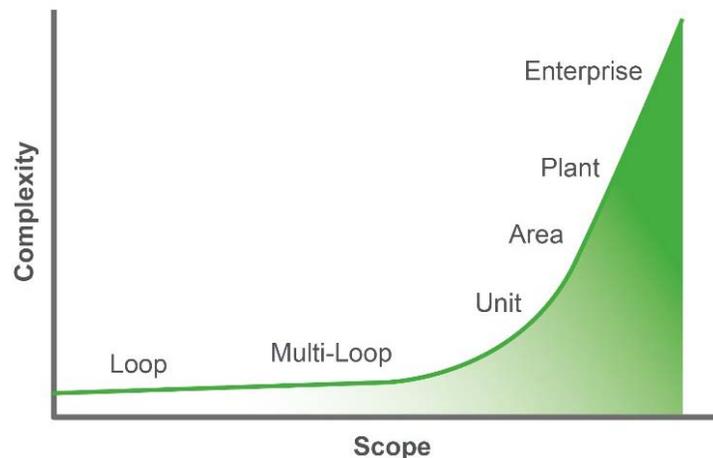


Figure 1

Exponential Growth in Complexity of Process-Centric Topologies

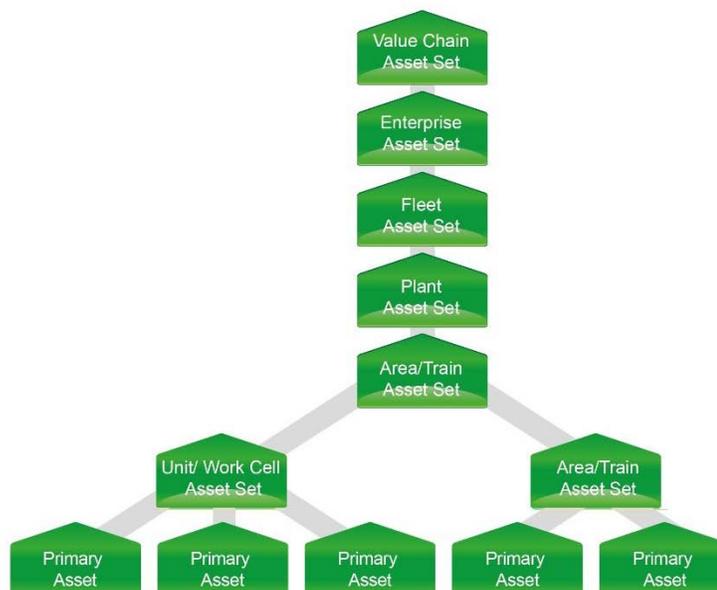
Asset-centric topologies partition the complexity of the processes into asset-aligned components. Resolving the control strategy for the processes within an asset is much simpler than trying to resolve an overall control strategy for an entire plant. This concept is similar to structured analysis techniques used to simplify highly complex IT systems by partitioning them into solvable components. An asset-centric perspective performs this partitioning naturally making the development of control strategies much simpler.

Asset-Centric Natural Industrial Topologies

Industrial businesses are designed to operate a system of industrial assets incorporating production and business processes to derive economic value. At the lowest level, plants are comprised of physical equipment assets - referred to herein as the primary assets of the operation. These primary assets convert materials and energy through the execution of embedded processes into value-added production. As such, the base-level operational architecture of industrial plants can be defined by the primary assets, the processes within those assets, and the processes that work across the primary assets to produce the desired output.

These assets and processes, along with the base sensors and actuators, are typically well documented in Piping & Instrument Diagrams (P&ID) of the operation. The primary assets are grouped into logical/physical entities called process units or work cells, which provide a functional subset of the overall production process. The units or work cells are typically further grouped into process areas that perform a larger functional subset of the overall production process. These areas are further grouped into plants. Plants are grouped into fleets. Fleets are grouped into Enterprises and Enterprises are grouped into Value Chains. **Figure 2** below shows an asset hierarchy that aligns with the industrial natural topology. Since this is the natural way industrial professionals think about and talk about their operations, the topology described is referred to as the Natural Industrial Topology (NIT) of the operation.

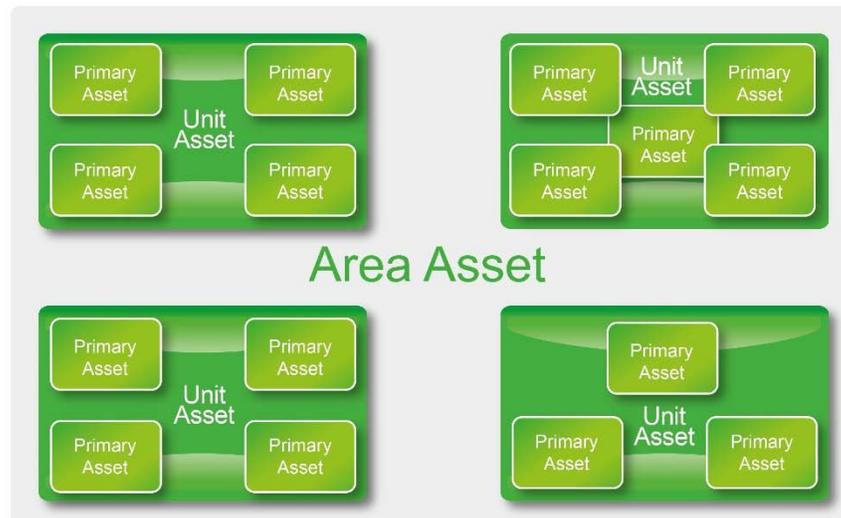
Figure 2
*The Natural Industrial
Topology*



Another perspective that can be useful in the evaluation of industrial operations is the embedded NIT view partially diagrammed in the **Figure 3** below. This view is intended to show the embedded nature of lower level assets and asset sets into the higher level asset sets. For example, a process unit is comprised of lower level primary assets and the unit level processes that enforce the unit level functions on the combined primary assets. The combination of the hierarchical and embedded views of the Natural Industrial Topologies appears sufficient for the analysis of the most relevant control system topology.

Figure 3

Natural Industrial Topology – Embedded View through Area Asset Set Level



Asset-Centric Control System Architectures

Automation and control systems are supporting assets (as compared with primary assets and asset sets) of industrial business designed to assist the primary assets to effectively execute their processes. The topologies of control systems have traditionally not been well-aligned with the natural topologies of industrial operations. Initial control system topologies were simple single computer architectures. As the cost and size of digital technologies declined, the architectures transitioned to more distributed, hierarchical architectures such as the distributed control systems (DCS) of today. Even though they became more physically and functionally distributed over the past three decades, their physical topologies never evolved to the point at which they matched the physical industrial asset topologies.

The key to a successful industrial operation is the effective control the processes within each asset and asset set in a manner that maximizes the efficiency and profitability of the asset while simultaneously minimizing the safety, environmental and security risks. To meet this need in the simplest and most effective manner, a control system should be aligned to each of the primary assets and asset sets in an industrial operation and business. The control strategies embedded in the control environment for each asset would be designed to provide real-time asset performance control by controlling the efficiency, profitability, reliability risk, security risk, safety risk, and environmental risk to optimize the asset's performance, leading to autonomous asset operation. The asset performance control approach would be implemented for the primary assets first. Then a unit

level asset performance control strategy can be developed to coordinate the control across the primary assets comprising that unit. The unit performance controls are executed based on the understanding and trust that the asset performance for each primary asset in the unit will execute correctly. This takes the complexity out of the unit performance control strategies because they can be focused on the processes at the unit level without concern for the details of the lower level assets which have already been resolved. The same concept can be applied all the way up through the control hierarchy to area, plant, fleet, enterprise, and value chain. In essence, this becomes a system of systems with each subsystem performing effective asset performance control for its target asset.

For control systems based on natural industrial topologies to work effectively, a software mechanism must be developed that is designed to enable the asset performance control for lower level assets to effectively merge into the higher level asset performance control strategy. This can be accomplished by designing each asset performance control strategy in an intelligent agent with the object oriented characteristics of encapsulation, polymorphism, inheritance, and late binding. These characteristics make such a topology feasible. Each intelligent agent is designed from inception to morph into the higher level intelligent agents resulting in control strategies optimized to single assets combining into the control strategies for the higher level assets.

Natural Industrial Topologies and the Internet of Things (IoT)

One technology-based initiative that has been gaining market attention over the past two years is the Internet of Things (IoT). In fact, IoT is the primary driving force called out by the Industry 4.0 initiative spearheaded out of Germany. The Industry 4.0 initiative believes IoT is triggering a fourth Industrial Revolution. There is considerable benefit behind the concepts associated with IoT and a fairly good match between IoT and natural industrial topologies. Much of the literature associated with IoT presents a fairly unwieldy concept of every “thing” working autonomously to perform the functions for which it was designed and being able to communicate with every other “thing”. As a result of this fairly loose description, much of the focus on IoT technologies is on providing the connectivity and communication bandwidth to enable every “thing” to communicate with every other “thing”. Although the terminology commonly associated with IoT is quite vague, there is a very close alignment between IoT concepts and industrial operations.

Industrial operations are comprised of a number of production assets (things) interconnected to enable the production of products. As was previously mentioned, the inherent architecture of industrial operations is largely defined by its assets. This is true for primary assets and asset sets. The concept of IoT is applied to industry from an asset-centric perspective through Natural Industrial Topologies.

In manufacturing and production operations there are physical assets and asset sets as well as business assets and asset sets. Business assets and asset sets can be treated in an equivalent manner to physical assets and asset sets. Therefore, industrial businesses and value chains can be defined as a hierarchy of assets from the primary physical assets through physical asset sets that define the operation of the business through business asset sets that define the business functionality.

Cyber-Physical Systems

One concept associated with the Industry 4.0 initiative that is particularly significant to the development of Natural Industrial Topologies is that of Cyber-Physical Systems (CPS). A CPS is a system aligned to an asset that includes the sensors and actuators necessary to provide effective control for that asset as well as the internal processes that make the asset work properly and the process control for those processes. A CPS aligned to a primary asset, or any asset set that incorporates complete asset performance control, results in an autonomous intelligent asset. In the future, equipment level CPS' may be provided with the equipment when sold, providing significant value-add from the equipment manufacturer.

The Control Functions for the Processes of Industrial Assets

In summary, the basic physical and logical topologies of NIT based control systems are in alignment with each other and with the natural asset architecture of industrial operations and businesses. What is left to resolve is the control functionality that must be performed for each asset in the architecture to meet the overall operational and business control objectives and to develop intelligent and autonomous assets. **Figure 4** below provides a clear and concise model for the asset performance control functions.

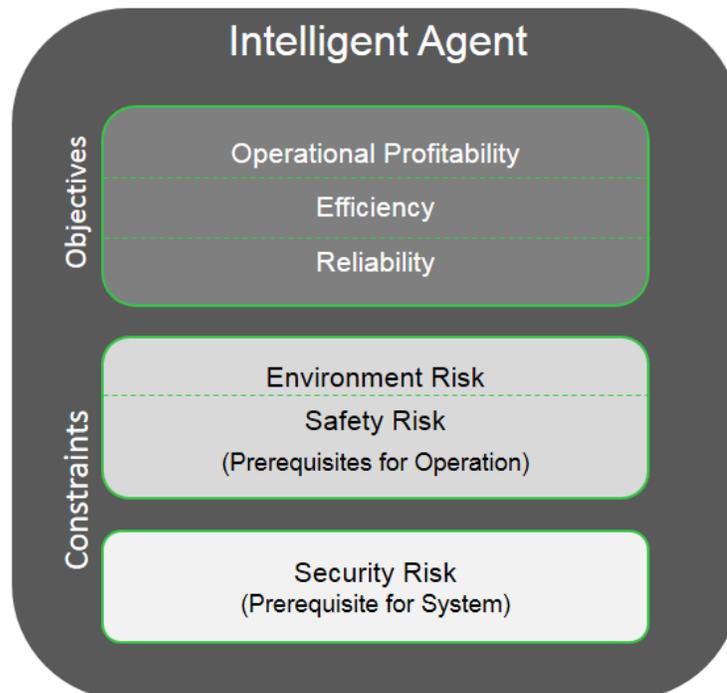


Figure 4

Extended Real-Time Control creating autonomous Intelligent Assets

The first area in this diagram is Security Control. This includes cybersecurity and any other security issues associated with the use of this asset. Effective Security Control should be considered an absolute prerequisite for any control architecture. By embedding Security Control into the intelligent agent associated with each industrial asset, the security risk of the system as a whole will decrease significantly.

The two categories of industrial risk that need real-time control are safety risk and environmental risk. Control strategies based on the appropriate measurement of safety and environmental risks should be developed for each asset and asset set. Since environmental and safety risks present the primary constraints on driving increased efficiency and profitability from each asset, proper control of these three risks is essential for increasing efficiency and profitability.

The third major area is for the control strategies associated with the ultimate objectives for the asset in the production process. The objectives here are to maximize reliability, efficiency, and profitability of the asset. Asset reliability has traditionally been handled as an operational risk that is dealt with by the maintenance department. But with more in depth knowledge of the actual working of each asset, asset reliability can be viewed as a real-time control opportunity. There are two aspects to asset reliability that require real-time control, the maintained state of the asset and the probability of asset failure. Both of these can be measured in real time at the primary asset level through deep asset knowledge. Once they are measured, the appropriate control strategy can be applied.

The primary objectives for each asset are maximizing efficiency and profitability. Most traditional process control strategies are to maximize operational efficiency. For higher level assets, both efficiency and profitability need to be controlled in real time and the appropriate strategy is a cascade control strategy with profitability cascaded to efficiency.

Benefits of Control Systems based on Natural Industrial Topologies

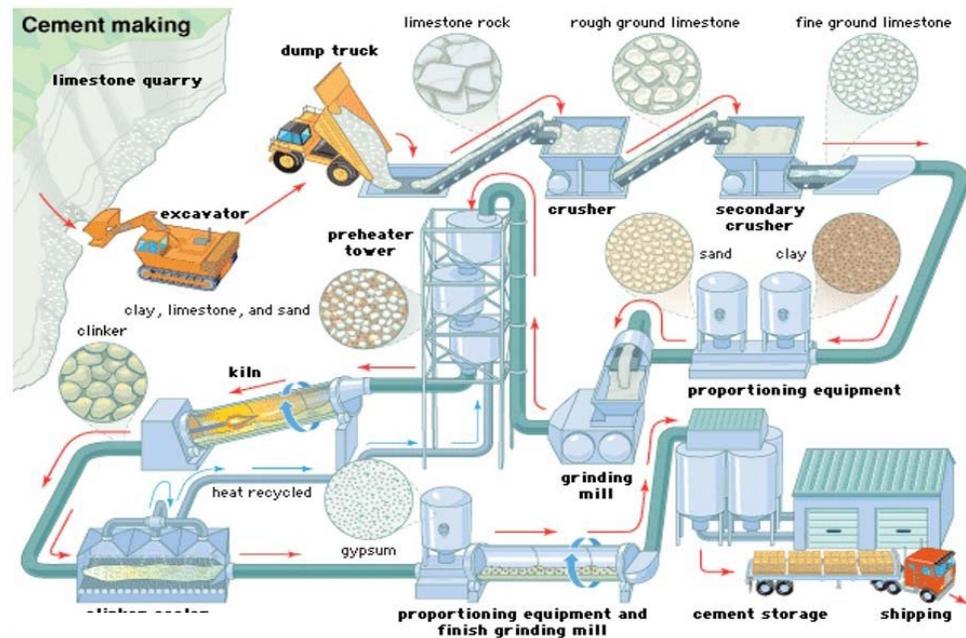
There are a number of obvious, and perhaps not so obvious benefits of control systems designed to align with natural industrial topologies. First, the user of these systems will inherently understand the system architecture because it is a match to the plant architecture. This will simplify the engineering task and reduce the amount of system knowledge required to effectively use the system. Also, since each node in the architecture is designed to operate autonomously in a cyber-physical system environment, the initial configuration process will be inherently simpler because it will partition into well-defined and natural components based on assets and asset sets. Additionally, any application or system update to a single control system associated with an asset will only impact that system. The remainder of the system should continue as set up.

The single asset integrity characteristic should result in significant savings in both hardware and software as the need for redundancy will be significantly reduced. Finally, the extended control will provide a significant improvement in the security, safety, environmental integrity, reliability, efficiency and profitability of each asset and asset set all the way up to the enterprise level. The bottom-line improvements will provide higher levels of ROI as well as continuously improving cash flow to industrial operation for decades.

Industrial Example – The Cement Value Chain

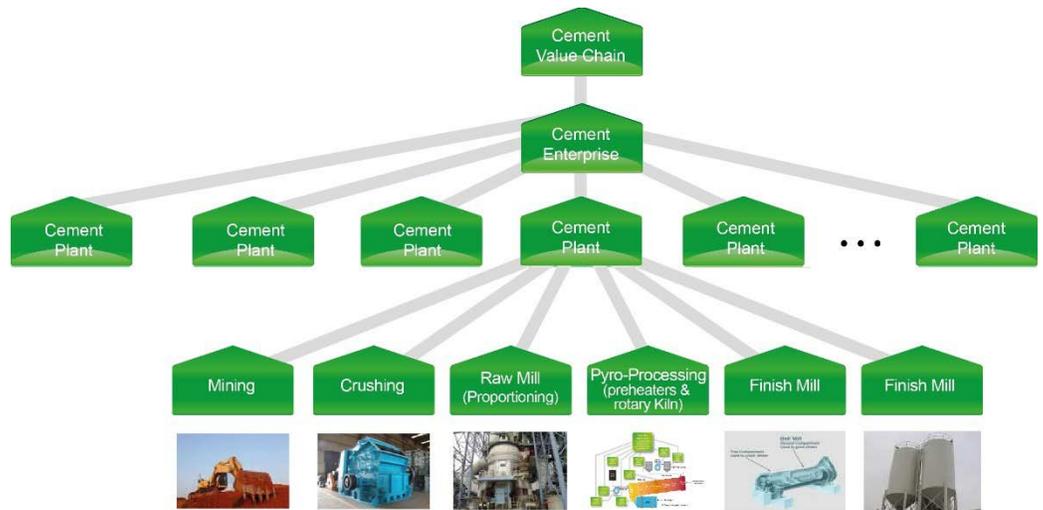
To illustrate how a system based on a natural industrial topology would be deployed in an industrial operation, an example of such a system for cement value chain follows. **Figure 5**, borrowed from Encyclopedia Britannica, presents a nice depiction of Cement Processing from the mining of the limestone through the shipping of the finished product.

Figure 5
Cement Processing



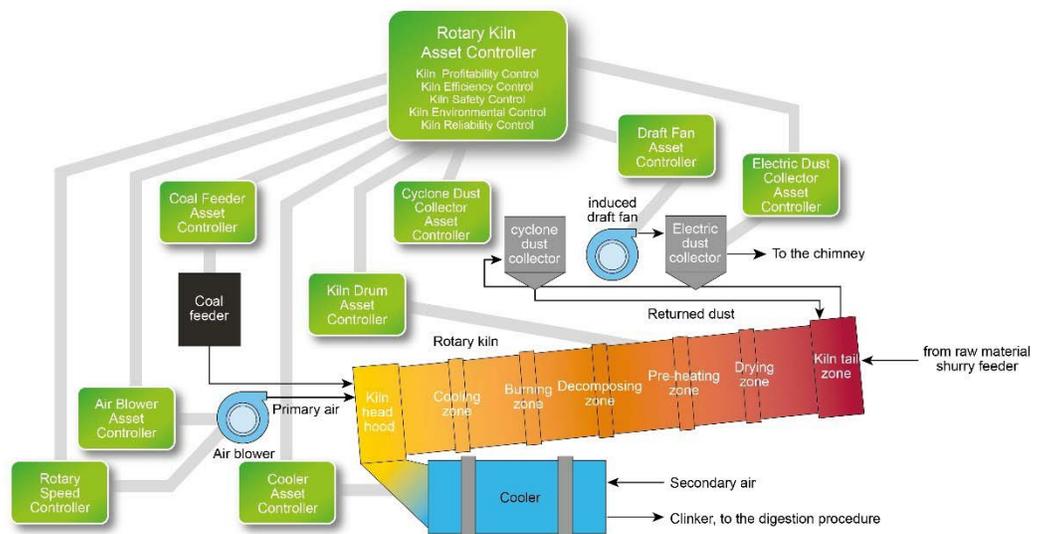
The process begins at a limestone quarry in which excavators dig the limestone and load it into dump trucks which transport it to the processing facility. The limestone is processed through crushers to reduce it to fine ground limestone. The limestone is then mixed with clay and sand in proportions determined by the recipe for the cement product being produced. This mixture then travels through a grinding mill which further grinds and combines the mix. The clay, sand and limestone mix is then moved through the pyro-processing unit in which it is preheated and transported through a rotary kiln in which the mix chemically combines into an intermediate called clinker. The clinker is cooled, mixed with gypsum and the mix is ground through a grinding mill to its finished composition and size and transported into storage silos for shipping. An overview of the high-level NIT is displayed in **Figure 6**.

Figure 6
The Natural Industrial Topology of a Cement Process



For purposes of this example, a single process unit, the kiln, will be utilized to demonstrate how a natural architecture aligns with plant equipment assets. The Rotary Kiln (**Figure 7**) appears to be a fairly simple asset set on first inspection, but there are a number of primary assets that comprise the Rotary Kiln. In this example, a CPS would be associated with each of the primary assets. Each CPS would include the sensors, actuators and control strategies for the asset. In this case there would be a CPS for the Air Blower, Rotary Speed, Cooler, Coal Feeder, Kiln Drum, Cyclone Dust Collector, Draft Fan, and Electric Dust Collector primary assets of the Rotary Kiln sub-unit.

Figure 7
The Rotary Kiln Asset Control

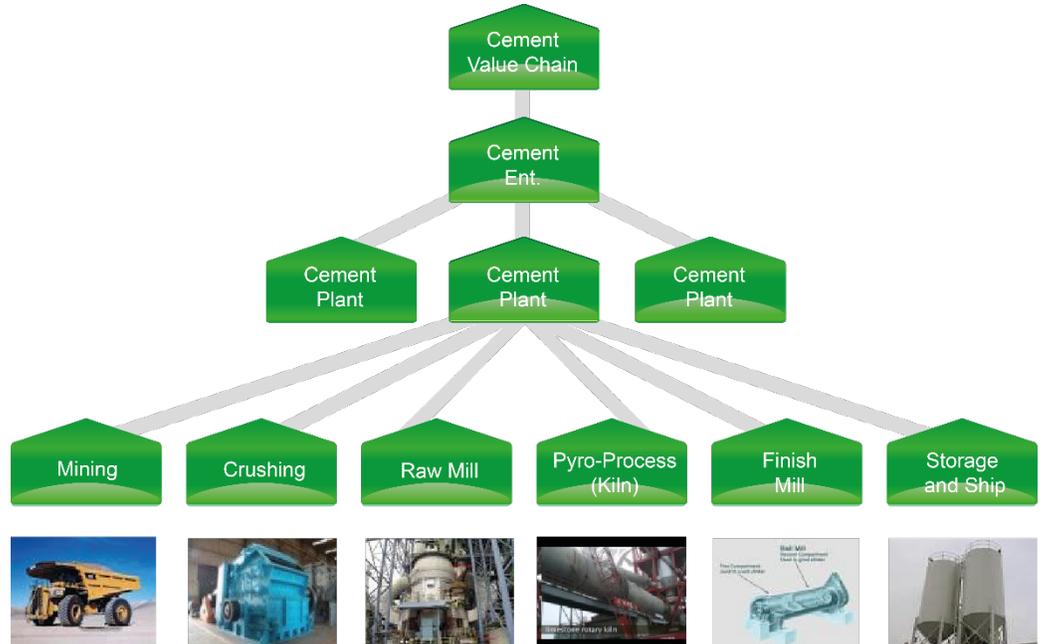


Once the control strategies for each primary asset are implemented within the associated CPSs for each asset, an overall Rotary Kiln asset performance control strategy can be implemented incorporating all of the control systems for the primary assets associated with the Rotary Kiln. In this way the control strategies for the Rotary Kiln Asset Performance Control System will not need to deal with the details of the primary assets.

This simplified example may serve to highlight the natural architecture approach utilized in Asset Performance Control System architectures.

The overall cement enterprise architecture based on its Natural Industrial Topology would look similar to the enterprise architecture in **Figure 8** below. This architecture represents exactly the architecture that the plant engineering, maintenance and operations teams perceive when they consider their plant and enterprise architectures. It may look fairly complex as compared to a traditional DCS architecture, but it covers much more scope than the DCSs of the past ever did. The programming and configuration of each node in the architecture is much simpler than with traditional systems due to the fact that each node represents a single asset or asset set and the configuration of a higher-level node can be done with the understanding that the lower level assets are optimally controlled.

Figure 8
Natural Architecture
(Internet of Assets)



Conclusion

Technology has progressed to the point at which technological constraints no longer provide barriers to the agility needed to move toward automation systems based on Natural Industrial Topologies. These emerging systems, powered by the Internet of Things, will enable industrial companies to develop intelligent and autonomous assets across their operations that can naturally converge into overall systems of systems that will optimize the performance of each asset, asset set and entire industrial enterprises. The result will be now and higher levels of industrial performance than ever before. Designing control systems to align with natural industrial topologies is the first step along a path of unprecedented industrial security, safety, efficiency and profitability.



About the author

Peter G. Martin, Ph.D., Vice President Business Value Consulting, Schneider Electric

Dr. Martin has over 35 years in industrial control and automation. He has authored numerous articles, technical papers, and books. He holds multiple patents. Fortune named Dr. Martin a Hero of U.S. Manufacturing. He was also named as one of the 50 Most Influential Innovators of All Time by Intech, and received the Life Achievement Award by the International Society of Automation (ISA). In 2013 Dr. Martin was elected to the Process Automation Hall of Fame, and was selected as a Fellow of the International Society of Automation. He holds BA and MS degrees in Mathematics and an MA degree in Administration and Management, a Master of Biblical Studies degree, a PhD in Industrial Engineering, and a PhD in Biblical Studies.



Acknowledgements

Special thanks to Don Clark, Rick Linscott, Todd Snide, Alex Johnson and Chris Lyden for their contributions to this white paper.



Resources

-  [Improving the Profitability of Industrial Operations: Realizing the True Potential](#)
-  [Dynamic Performance Measures: The Need to Measure Industrial Business in Real Time](#)
-  [Real-Time Strategic Empowerment for Improved Profitability](#)