Leveraging Digital Technologies in High-Tech

Strategies to Meet Growing Consumer Needs through Design and Manufacturing, Across the High-Tech Ecosystem

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We live in a digital world; every product is high tech. Semiconductors enable the computers we use, the cars we drive, the smartphones we carry - even the appliances we use in our kitchens. These modern appliances have transformed the way we live and interact with each other in our most basic daily routines.

Leading high-tech and semiconductor firms have found that quickly and effectively deploying digital technologies – including digital twins, smart connected operations (SCO) and product lifecycle intelligence (PLI) – drives sustainable competitive advantage.

This paper looks at these technologies and how they apply to the entire high-tech ecosystem, with semiconductors at the core. It will focus on pragmatic advice for the steps you can take to achieve rapid benefit regardless of where your organization is on the technology adoption curve.

Executive Summary

Semiconductor firms have operated in a fast-paced, complex, and structured environment for years, creating networks of homegrown systems to capture required information throughout design and manufacturing. However, the current expansion of the electronics ecosystem is unprecedented. As more industries are disrupted, and more products are empowered through global and local networks using the Internet of Things (IoT), semiconductor firms are brought closer to consumers and are required to meet new demands beyond traditional design and manufacturing. With the growing portfolio of products enabled by and reliant upon semiconductors to operate, traditional methods of managing the discover-create-make process are no longer enough.

Take, for example, a doorbell. Ten years ago, if someone arrived at a home and wanted to enter, they might have rung the doorbell, which would then ring inside the home and let whoever was inside know that someone was there. The homeowner would then need to go to the door and either look through a peephole or open the door to see who was there and decide if they wanted to let them in.

Today there are a variety of smart doorbells on the market that use motion sensors to detect when someone has arrived before they even ring the bell. The homeowner is notified via smartphone or other electronic device that someone is at the home, likely with video and even audio connectivity using a built-in camera and microphone. More advanced IoT-enabled doorbells may even be connected to the locking mechanism on the door, enabling the homeowner to let the guest in without going to the door, or without even being home.

So a simple function – ringing a doorbell – that previously had a shortened set of requirements, must now be able to able to integrate and perform multiple functions:

Previously: let the person inside the home know via audio signal that someone is at the door.

New additional demands: (1) let the homeowner know someone is at the door whether they are home or not, (2) let them access video and audio to see who it is, (3) alert them before the doorbell has even been rung, and (4) allow the homeowner to unlock the door and let the person in from their smartphone or other electronic device, whether or not they are home.

As the ecosystem continues to expand and the products, systems, processes, and data become more complex, high-tech and semiconductor firms need enhanced capabilities to meet these scaling demands. Digital twins, smart connected operations, and product lifecycle intelligence are three technologies that help companies continue to create value in this new environment.

This balance of this paper will examine the application of these tools and how they can be leveraged in the context of semiconductor design and manufacturing, as well as across the broader electronics ecosystem.

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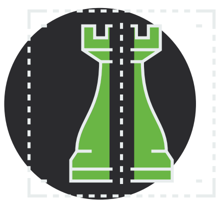
Definitions: Key Digital Enablers for High-Tech



Digital Twin

The digital twin allows enterprise users to simulate the entire supply chain, from requirements collection and design to factory layout, capacity, scheduling, processing, manufacturing and servicing in the field. The goal is to save time and learn through digital representations before committing physical assets to costly changes. The digital twin begins at the requirements stage, transitions through system and component design, factory layout, capacity analysis, process definition, manufacturing and beyond.

Smart Connected Operations

Smart connected operations (SCO) leverages disruptive technologies to facilitate more effective, efficient, customizable, automated and digitized systems that create new value and business models. With interconnected machines and connected workers, leading high-tech manufacturers achieve operational insights at scale. The desired business results and smart operations strategy are vital boundary layers to a successful outcome for SCO. Addressing these challenges enables companies to deliver innovative products and solutions that meet ever-increasing market demands.

Product Lifecycle Intelligence

The data from SCO, PLM, ERP and other systems can quickly become overwhelming. PLI is an evolution of PLM that applies artificial intelligence and machine learning to help PLM users extract meaningful insights from product data, formulate predictions, recommend improvements, and automate actions within systems and processes. Deployed via a suite of user-centric apps, PLI addresses core business needs of PLM users, including data migration, new product development cycle times, change management, product quality, supplier management, manufacturability and regulatory compliance. Ultimately, PLI enables evidence-based decision making, reliable planning and forecasting, and continuous improvement of business results.

Overall Equipment Effectiveness

Although the term OEE was first coined in the 1960's[1], the growth of digital-enabled manufacturing has reinvigorated its importance. It is simple, insightful, and can be measured in real-time with the right systems in place. OEE tells you how well you are producing vs. a theoretically ideal situation, summarized by three parameters: equipment availability, process performance and product quality. The product of these parameters provides overall equipment effectiveness, where the gap between the actual score for a process and 100% represents the opportunity for potential improvement.

1 https://www.shmula.com/overall-equipment-effectiveness-oee-understand-measure-and-improve/26124/

Digital Strategy in Semiconductor Design

As we measure the value of digital twins, smart connected operations and product lifecycle intelligence in the design process, let's first consider the relationship these technologies have in the R&D stages of product development.

A digital twin enables the simulation of key performance characteristics without having to commit to the time and costs associated with their physical counterparts during design and development. SCO is the vehicle by which smart, connected assets provide feedback to R&D in early product development to achieve breakthrough solution development. PLI ties analytics into the equation, with the ability to leverage historical data and market responses to meet performance commitments, like cycle time, change frequency, design reuse, first pass yield, cost and quality.

Lay the Foundation with Digital Twins

In order to reap any of the R&D benefits described above, a rock-solid foundation of processes, systems and data must be in place. A digital twin, for example, is only as good as the CAD that models it, the meta data that describes it, and the processes that control it.

In this case, the semiconductor industry is likely in a better spot than most others. In chip design, the digital twin concept has been a standard way of working for design engineers for decades. With widespread use of CAD and PLM systems, the building blocks for a digital replica of a physical asset are already in place at most high-tech firms.

Despite the industry's relatively advanced position on the digital twin maturity curve, the question of whether or not semiconductor firms fully leverage these evolving capabilities is an entirely different one. **To realize the full benefits of a digital twin, semiconductor firms must apply simulation not just in isolated eCAD or mCAD instances, but across the myriad of complex processes and systems involved in design and manufacturing.**

Design engineers should ask themselves the following questions to identify if they are getting the most out of what is possible:

1. **Enterprise Data:** Is our data system structured, clean and well-governed to support meaningful simulation across our supply chain?
2. **Smart Connected Technology:** Are our sensors, devices and machines networked to enable feedback loops between design and manufacturing?
3. **Data Visualization:** Can our data be pulled into real-time views to enable rapid decision making?
4. **Machine Learning:** Can we leverage analytics to generate insights beyond those known today on key metrics like design for variability, design for testing, design for manufacturing and design for yield?
5. **Enterprise Integration:** Are we using all necessary tools such as a cloud system or our own enterprise architecture to reduce our data center footprint and storage costs?
6. **Cybersecurity:** Have we secured our systems to safeguard our data from malware, phishing and other cyberattacks?

Digital Strategy in Semiconductor Design

Answering yes to these questions yields obvious benefits. Without addressing these important aspects, manufacturers miss out on important opportunities.

Let's recall a smartphone provider that made the wrong kind of headlines in 2016[2] after releasing a product that was anticipated to have the latest must-have features and serve as major driver of revenue for the company.

In reality, the dual curved display, water resistance and expandable storage were quickly overshadowed by the device's most publicized (and very negative) feature – combustibility. After a recall within weeks of the initial release, defective phone replacements following that recall, and then a full inventory scrap after disaster struck on the replacement phones, guidance for the company's operating profit was adjusted down by 33%, and revenue forecasts were slashed by tens of billions of dollars.

Even worse, aviation officials in United States and Europe issued a complete flight ban on this smartphone and the company was severely criticized for their handling of the crisis. One survey revealed that 34% of current customers would not buy another phone from this company because of this incident.

The blame was widespread. For the first battery vendor, a design defect did not allow enough room for the heat seal around the battery and the internal battery components. This caused the electrodes in the battery to crimp and introduced the possibility of a short circuit.

For the second battery vendor, a manufacturing defect caused penetration between the positive and negative electrodes through the insulation tape and separator in the battery.

In both cases, the short circuit resulted in excess heat and eventually fire from the battery. So, whose fault was it?

Here, we are left with more questions than answers:

- **Was it a specification problem?** Was this failure mode anticipated? Was it missing from the specification and therefore not tested?
- **Was it a testing problem?** Were there relevant entries in the specs that should have been found in testing, but the battery vendors did not sufficiently cover these tests?
- **Was it a simulation problem?** Were models created, simulated and validated from the specs?

Whatever the root cause, this example highlights the importance of capabilities that sync up the physical and meta physical worlds. Had a digital twin been in place for the phone, virtual simulations could have caught the lack of design margin for the system before it entered manufacturing and most importantly, the market.

Tip: Begin with the end in mind: expand the digital twin to look at interactions between components to get in front of failures before they occur.

2 https://www.nbcnews.com/tech/tech-news/samsung-finally-explains-galaxy-note-7-exploding-battery-mess-n710581

Digital Strategy in Semiconductor Design

Design Processes that Leverage a Systems of Systems Approach

Overall, legacy design processes are being stretched. Solutions are no longer just a chip or a piece of software – they are a set of sub-systems that must all work together, or the entire solution will fail. A system engineering approach is the next step in strategically uniting all these constructs together, addressing the complexity of this system of systems and enabling successful delivery of higher quality solutions to market.

A successful approach for developing these systems involves focusing on customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design, validation, verification and release throughout the production/manufacturing lifecycle.

The V Model can offer a helpful framework to develop this approach.

V Model Basis for Quality/Testing Plan

Testing Types

Validation

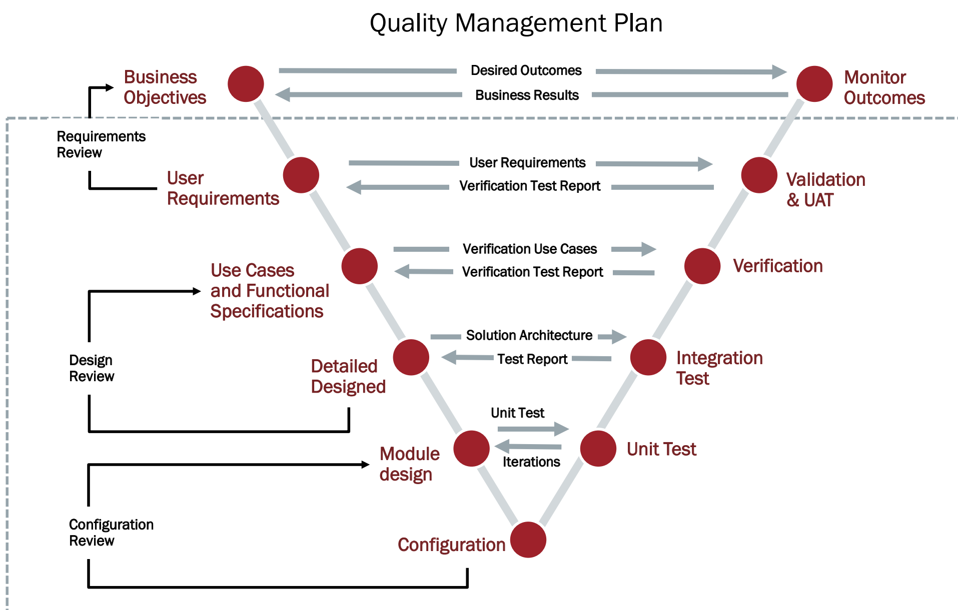
- Installation Qualification (IQ)
- Operational Qualification (OQ)
- Performance Qualification (PQ)
- Part 11 Compliance

Verification

- Boundary Conditions
- Pressure Testing
- Security
- Scalability

User Acceptance

- Solution Workshops
- Directed (UAT)



As organizations develop a system of systems approach, which stretches from desired business outcomes to the measurement of outcomes, they should do so with the following questions in mind:

- **Impact Assessment:** How might we ensure maximum traceability between different levels of requirements, solution development and testing?
- **Change Control:** Do we have a common change control process applied across system definition, creation and realization?
- **Concurrent Changes:** Are we equipped to handle changes against a product that are happening simultaneously?

Digital Strategy in Semiconductor Design

Evolve your Approach to Analytics

Demand for increasingly sophisticated product lifecycle management (PLM) tools has been a byproduct of increasingly complex consumer demands, as well as product and design development requirements. As PLM has evolved from basic data storage to a discipline that ties together a product's development lifecycle and digital twin, the need for better PLM measurement tools has also evolved. Drawing from a Peter Drucker quote, "That which cannot be measured cannot be managed."

In R&D, engineering and product development leaders must uphold performance commitments like system adoption, cycle time, change frequency, design reuse, first pass yield, cost and quality. In semiconductor design, this could mean measuring the effects of a decision made by a design engineer on downstream operations, or measuring improvements to business performance based on a potential chip material replacement, tolerance adjustment or attribute change. With product lifecycle intelligence, these insights can be built right in to a user interface, making them readily available to engineering roles (as opposed to data scientists), so informed design decisions can be made on the fly.

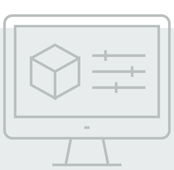
Quicker, data-driven decisions lead to improved cycle times, better resource planning and deeper risk analysis that improves downstream operations and business performance. This is increasingly important for a fast-paced industry governed by Moore's Law, where the imperative for rapid design of continually faster processing speeds, smarter features, and zero defects – all within the same delivery timeline – is unmatched.

Digital Strategy in Semiconductor Manufacturing

A wafer may go through over 1,000 steps as it goes from ingot to ship; a process ripe with possible points of failure, rework, downgrades and missed information. Many semiconductor firms have home grown systems – with varying amounts of structure – documenting the life of a wafer as it moves through the fab. While these systems capture the data needed for specific isolated teams, the root of the problem is that they are isolated. This isolation limits decision making, since it is optimized for a specific team or a local process rather than global production.

Simulate Activity between Design and Manufacturing with a Digital Twin

The use of a digital twin in semiconductor manufacturing means having a full, simulated model of the physical product, including the processes and associated data, which allows the fab to determine the optimal process with an understanding of the downstream impacts before implementing. **This full visibility enables global manufacturing optimization based on the fab or a line rather than local optimization of a tool.**



Take yield as an example. Maximizing yield is the single most important goal in wafer manufacturing. By definition, a higher yield means a lower scrap rate which impacts the total cost of wafer processing. There are many variables in determining yield; for example, incoming material quality, processing times, deposition rates, wafer location in batch process tools, and anneal temperatures.

Today these are optimized on a step or tool basis by running a design of experiments (DOE) and determining coefficients and relationships. This data is managed in offline Excel™ calculators, and manually analyzed to make lot adjustments and corrections between tool maintenance cycles.

Using a digital twin, these parameters can be varied and simulated to optimize yield with more accurate results because the source data is a central, continuously updated database. This means companies can understand, for example, that method A is better than method B to reach a target yield, or that method A has a better chance of consistently reaching a higher yield than method B. **So instead of being based on optimization around a specific tool or process, results are based on key parameters across teams throughout the fab, which reduces insular thinking and localized decision making.**

Tip: Establish a solid data foundation of end-to-end data across the product development process to maximize the full benefits of a digital twin.

Digital Strategy in Semiconductor Manufacturing

Predict and Prescribe Optimized Manufacturing Results

While the digital twin empowers globally optimized decision making, PLI leverages advanced analytics to gain actionable manufacturing insights at scale. Semiconductor manufacturers have no shortage of data and collect very specific information for reporting key metrics on the health of the fab, but much of the data goes unused or is underutilized.

PLI makes this data actionable by determining correlations between data points to explain historical issues, predict future performance and even prescribe actions to prevent future problems.

Let's examine cycle time as an example.[3] The amount of time it takes to manufacture a lot of wafers from start to finish determines the overall capacity of the fab and is critical for forecasting. As the technical specification requirements for ICs increase, technology becomes increasingly complex, which can require additional masks, depositions, resist layers and metrology steps in the process.

A production manager seeking to reduce cycle time could use PLI to uncover the correlations and discover that one of them relates to the variability and overall queue time for one of the metrology steps. While the actual processing time is relatively quick, the variability for wafers waiting to be processed is high. PLI might determine that this variability comes from a quick ramp of a new part type in the fab that is not yet mature, predict that the queue times will continue to be both long and highly variable, and that the cycle time will continue to increase until the part type becomes more stable as it matures.

PLI can then prescribe process improvements such as dedicating a tool or adjusting the production mix when the new part type is introduced so it doesn't hit metrology at the same time as other more mature parts, potentially reducing both variability and queue time.

Tip: Use PLI to determine correlations and reduce variability for key manufacturing KPIs, like cycle time.

3 https://semiengineering.com/battling-fab-cycle-times/

Digital Strategy in Semiconductor Manufacturing

Track, Mantain and Improve Operations with Smart, Connected Technology

Smart connected operations leverages connected technology and assets to facilitate more effective, efficient, customizable, automated and digitized systems that create new value and business models. These interconnected machines and connected workers provide additional operational insights.

The complexity of semiconductor manufacturing continues to increase with evolving and expanding user requirements and integration points across the electronics ecosystem. The table below provides examples of SCO use cases and benefits.

Improve Machine Availability	Use real-time alerts, notifications and tracking of machine problems to avoid unplanned stops (breakdowns) during scheduled production time
Real-time Monitoring of Operational KPIs	Leverage dashboards for real-time monitoring of critical indicators and operational metrics to enable quicker response times to potential problems
Improve Machine Performance	Use smart connected equipment to operate most effectively and deliver greater performance rates
Inventory and Material Tracking	Collect and transmit data on inventory, die banks and raw material to provide greater access to data and enable reordering, logistics optimization and inventory maintenance
Improve Machine Output Quality	Use real-time connectivity of industrial assets to improve the quality of output when the product/equipment is in operation and to flag possible excursions for further review
Predictive Analytics of Machine Health	Collect historical data from IoT sensors on machines, apply algorithms to uncover warning signs of costly failures, and proactively schedule maintenance prior to malfunctions
Worker Health and Safety	Digitally map geo-fenced boundaries that use IoT sensors to send notifications to employees when hazardous zones or equimpent are nearby
Track Worker Efficiency	Input project data planning to forecast the operational timeline for facility projects, automatically time employee work time by sensor tech and report against expected project timeline
Asset Finding	Manage a dashboard console view of all locations of machinery, assets and workers: improve worker efficiency with auto-guidance and notifications of asset locations related to current tasks
Workplace Safety Planning	Track safety procedures, compliance and incident reports throughout worker performance data, project data, machine variations and maintenance, and location-based data in the facility to improve safety

Tip: Use SCO to reduce unplanned tool downtime by receiving real-time alerts and notifications.

Digital Strategy in Semiconductor Manufacturing

Create Visible Value with Overall Equipment Effectiveness (OEE) Metrics

Previously, we explored an example of high variability and generally long queue times for a given metrology step. Companies cannot afford these types of operational variances or sub-optimal manufacturing performance.

One metric gaining traction with executives and fab engineers alike is overall equipment effectiveness. Although OEE has been around for over 50 years, current digital trends have reinvigorated its importance. Viewed by many as the gold standard for measuring continuous improvement by showing potential for improvement, OEE measures availability, performance and quality. The key to using OEE to improve performance is to use it as an internal metric. For example, improving OEE within a tool or plant over time, rather than across tools or plants.

Using the previous metrology example, an operations manager can compare the current OEE of the tool to the OEE of the tool prior to introducing a new part type and see that it has decreased. With further examination, the OEE decline might be attributed to increased tool down time because the new part type requires more frequent tool servicing. This reduces both tool availability and performance. Monitoring the OEE of the metrology tool may provide similar recommendations: dedicating the tool (if the volume is high enough), waiting for higher batch sizes of the new part type before processing, or adjusting the production schedule so the new part type arrives at the metrology step during lower volume periods. All of these reduce changeover frequency and improve OEE.

Tip: Use OEE to gain insights on planning and optimum tool performance levels for the fab (which are lower than 100%).

Digital Strategy in the Electronics Ecosystem

While the previous two sections have explored the application of digital twins, SCO and PLI to semiconductor design and manufacturing, the entire electronics ecosystem can benefit from these digital game-changers.

Meet Increasing Demands with Scalable Simulation

We've already explored some benefits of a digital twin, like a full simulated model of the physical product activity, real time feedback loops between design and manufacturing, and global manufacturing optimization. As high-tech products become more connected, these feedback loops have transitioned from a luxury to a necessity.

A digital clone of the physical product provides the structure and insights necessary to deal with increasing consumer demands.

Traditional product development processes will no longer meet the demands of increasingly complex products that require robust testing, faster cycle times and increased manufacturing flexibility.

For example, NASA uses the concept of a digital twin to aid in repairs and maintenance of spacecraft. The end goal is to have the digital twin meet all the requirements of the physical build so it then contains all the information that can be gained from inspecting the physical copy.[4]

"The ultimate vision for the digital twin is to create, test and build our equipment in a virtual environment. Only when we get it to where it performs to our requirements do we physically manufacture it." - John Vickers, NASA

This is a complex example, but simplified digital twins are gaining traction in industries like retail and consumer products to model certain parameters and make adjustments before mass production. For example, a clothing company might use a digital twin to model the fit of different fabrics and how they lay, then make adjustments to the design prior to ordering all of the fabric, creating the pattern, and mass producing a dress shirt. This is not an isolated example – IDC reports that by 2020, 30% of G2000 companies will be using data from digital twins of IoT connected products and assets to improve product innovation success rates and organizational productivity, achieving gains up to 25%.[5]

4 https://blog.g2crowd.com/blog/trends/internet-of-things/2018-iot/digital-twins/

5 https://www.i-scoop.eu/digital-twin-technology-benefits-usage-predictions/

Digital Strategy in the Electronics Ecosystem

Asses and Invest in SCO Opportunities

Many companies and industries across the electronics ecosystem make SCO investments to facilitate end-to-end asset traceability, improve cross-organizational visibility, minimize maintenance costs and maximize human capital. In the 2019 edition of the Manufacturing Report, 79% of manufacturers said they believe smart factories will improve their supply chain relationships, 89% said smart factories will enable their staff to work smarter, and 91% and said smart factories will increase productivity levels per headcount.

While the benefits of smart operations are largely undisputed, nearly a quarter of businesses investing in smart connected technology report that two primary things holding them back are understanding where to get started and the daunting task of changing current state business processes. Companies that lack clear goals, plans and value chain alignment will find it nearly impossible to realize value from digital investments.

Start with the following questions to assess current digital maturity and position for success:

1. **Desired Business Results:**
Have we identified our core business needs and potential opportunities?

2. **Smart Operations Strategy:**
Have we created a SCO strategy built around our business imperatives?

By addressing these questions early on, companies can avoid the dreaded pitfall of holding a hammer and thinking everything is a nail.

As an example, an aircraft manufacturer had significant costs associated with difficulty finding tools, keeping tool sets together, and restricting tools to areas of the manufacturing floor. The company also wanted to track large pieces of work in progress assemblies. By leveraging SCO capabilities, like deploying a real-time tool track system, enabling smart tools to configure tool settings based on location, and confirming when operations were carried out, the aircraft manufacturer was able to reduce tool loss by 25% and tool search time by 15%.[6]

6 Based on Kalypso experience

Digital Strategy in the Electronics Ecosystem

Transform with an Emphasis on Information Insights

As digital twins and SCO frameworks are increasingly applied across the electronics ecosystem, designing systems for insight with PLI is an essential step of a digital strategy. PLI goes beyond traditional business intelligence methods like descriptive and diagnostic analytics that only provide insights on what has happened in the past. PLI uses predictive and prescriptive analytics – in addition to the hindsight and insight provided by simply exploring and explaining what happened – to provide managers the foresight to make proactive, data-driven decisions. Much of the electronics ecosystem has little or no corporate memory, and PLI can ensure that every design or manufacturing experiment and every product launch contributes to the corporate body of knowledge.

Consider some of the challenges inherent to implementing product changes for discrete manufacturing companies. Engineering change managers have typically relied on tribal knowledge and guess work when creating change implementation plans after a design or process change. Increasingly complex products require simultaneous electrical, mechanical and software updates involving different departments and integrated systems, which means change manager guesses become less and less educated. This leads to highly variable cycle times, resource conflicts and increased product and regulatory risk. When combined with an enriched PLM data set, PLI provides change managers with real-time information and recommendations to make informed, data-driven decisions that improve outcomes.

Based on past changes made to similar product profiles, PLI can prescribe tasks that should be included on implementation plans with pre-defined completion time predictions, margins of error and confidence levels. Since PLI predictions are based on a combination of correlated factors like what needs to be done, when and by whom, change managers are provided a set of levers that can be adjusted to reduce cycle time before a plan is set in motion.

Conclusion

The semiconductor industry has traditionally led the way with the products, designs and factories of the future. But this position is in jeopardy with increasingly complex products, demands for shorter design cycle time, higher user standards, and less time to validate more information.

By using digital twins, PLI, and SCO technology enablers, high-tech companies can create a connected value stream of visualizations and information links throughout product development, order processing, and manufacturing.

Companies that lead the way see many benefits, including:

- Linking the digital and physical worlds through the manufacturing master data model and the common plant model to provide informational insights within and across systems
- Simulating operations before any physical assets are committed or involved
- Creating a nearly real-time digital twin of the product, process and resources using feedback from all relevant production execution systems
- Making decisions based on insights from data in real-time
- Creating the ability to analyze engineering simulation and emulation data along with manufacturing big data via a true machine learning model

The semiconductor industry led the first wave of the digital revolution. Is your firm doing everything it can to realize it's full digital potential?

About Kalypso

Kalypso is a professional services firm helping clients discover, create and make better products with digital.

We provide consulting, digital, technology, business process management and managed services across the innovation value chain.

We work with our industrial high tech clients throughout the product development lifecycle - from commercial and engineering to manufacturing and end-of-life - to enable a digital enterprise with integrated data that delivers innovative products and solutions.

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