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## Establishing the digital footprint in a Smart Factory

Nikhil Padhi

[nikhil.padhi@sunpower.com](mailto:nikhil.padhi@sunpower.com)

SunPower Corporation, San Jose, California

Prasanna Kumar Illa

[prasannakumar.illa@sunpowercorp.com](mailto:prasannakumar.illa@sunpowercorp.com)

SunPower Corporation, San Jose, California

### ABSTRACT

*Smart Factories have dominated discussions and conferences for the past few years. It is, in fact, a ground-breaking concept and has the capability of being a game changer, which can create a sustainable competitive advantage. They have the potential to address many challenges that the manufacturing world faces today. So much so that, sometimes they are projected as “panacea” to most of the problems. Experience of early adopters does suggest that they can help us solve many problems. However, companies face challenges in terms of structuring their smart factory journey into phases, identifying the pre-requisites, selecting the right vendor(s), justifying the ROI, forming the right teams, etc. This paper attempts to provide a high-level approach to set up a smart factory and tries to answer some of the questions raised.*

**Keywords**— Smart factory, Digital, IoT, Robotics, MES, ERP

### 1. INTRODUCTION

Manufacturing world has undergone multiple changes in the past decade. It had lost its “attractiveness” at the height of Information technology boom during the nineties and during the first decade of the twenty-first century. Ironically, the boom opened multiple vistas of innovation in manufacturing; robotics, IoT & analytics, augmented reality, 3D printing etc. As trade becomes global, companies are facing intense competition to retain and grow their market share. They are addressing this challenge through sustainable differentiation, cost leadership, focus on specific market segments & building a highly efficient supply chain network. For manufacturers, cost leadership and differentiation through innovation and product quality are the keys to success. It’s highly unlikely that they will achieve these twin objectives using the same techniques and processes that have been using for years. It’s imperative that they revisit their manufacturing ecosystem and make changes to face future challenges.

The next big question is, what does a factory of the future look like? In all likelihood, factories of the future are going to be “Smart” factories (some experts call it Industry 4.0!). They will have an optimum mix of man and machines (aka robots, TUGs, etc.). They will be able to make sense out of volumes of data generated on the shop floor and take corrective actions if required. They will have optimized process steps (e.g. 3D printing) and will adhere to the highest quality standards.

Most manufacturing-centric companies have embarked upon their journey to set up smart factories and, in most cases, willing to retrofit an existing plant to make it smart. However, one of the challenges they face is how to go ahead in setting up a smart factory. This paper will try and provide a high-level approach to set up a smart factory.

### 2. FACTORY THROUGH YEARS

Factories have undergone massive changes over the years. These changes have fundamentally altered the way factories operate. At a high level, this can be mapped using four dimensions; people, process, equipment, and systems. The following section briefly explains the changes in each dimension.

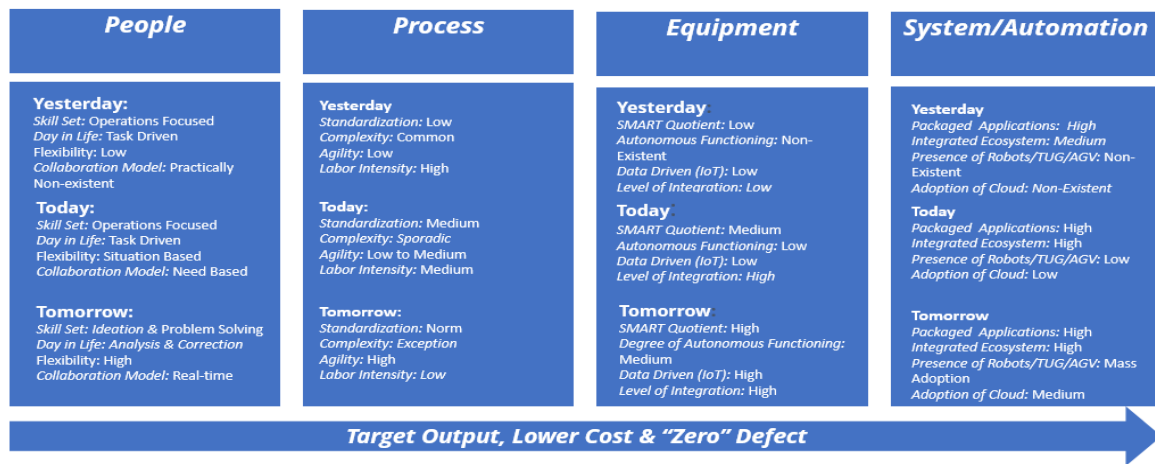
#### 2.1. People

**Skillset:** It used to be, and still to a large extent is “Operations Focused.” Personnel on the shop floor are primarily focused on performing highly repetitive steps in their respective process areas. In the coming years, they need to develop an attitude toward solving problems. Even an Operator needs to stay alert to identify an anomaly in the line and alert her supervisor immediately.

**Day in Life:** So far, it has been “Task Driven.” Going forward, there will be increased emphasis on analysis and course correction.

**Flexibility:** It must be higher in terms of learning new skills, working across different process area(s), relocating to a different geography etc.

**Collaboration Model:** It must be literally real-time among teams located in different geographies in different time zones.



## 2.2. Processes

**Standardization:** Standardization of manufacturing process steps will be the norm. However, plants should have the ability to churn out different product types to satisfy customers in different segments. At first glance, both these aspects look contradictory, however, on a closer look, we would realize that they complement each other. Normally, there are multiple common process steps irrespective of end products which can be standardized. For example, restaurants have scores of dishes, however, they standardize basic steps such as preparing sauce, keeping the core content such as rice and pasta ready. The same is true with automobile companies. They have a wide range of models, but the same basic steps such as gearbox assembly, fuel Injection system assembly can be standardized.

**Complexity:** Complexity will not be desirable.

**Agility:** Agility needs to be very high going forward; e.g. new products need to be launched within a very short interval targeting different geographies and different customer segments.

**Labor Intensity:** This will have a decreasing trend. This doesn't necessarily mean "job losses", rather less labor will be required to run a production line. Another part of the labor force can focus on more value-added activities such as root-cause analysis of issues, productivity improvement initiatives.

## 2.3. Equipment

**Smart Quotient:** Smart quotient will be increasingly higher with the passage of time. More and more machines will adhere to industry standard protocols such as SECS/GEM. Extraction of data captured by the machines will become streamlined.

**Autonomous Functioning** (aka machine learning): Currently machines require human intervention for their smooth functioning especially to address out of control (OOC) situation, to analyze defect, to implement the solution etc. Increasingly, they will leverage machine learning to take care of many of the situations mentioned above. This will help shop floor personnel focus on longer-term improvement areas.

**Data-driven:** Most equipment generates large volumes of data which mostly remain unexplored. Going forward with machine learning, IoT will be able to analyze these data and provide actionable plans to improve Overall Equipment Effectiveness (OEE), Yield etc.

**Level of integrations:** Integration of Programmed Logic Controllers (PLCs) with overall system architecture, commissioning of Robots will become the norm.

## 2.4. System/Automation

**Packaged Application:** Plants have been implementing "packaged ERP" (Enterprise Resource Planning (ERP) such as Oracle EBS, SAP, and Microsoft Dynamics as their back-end application to manage costing and financial reporting. They are going for "packaged MES" (Manufacturing Execution System). MES marketplace has many options for organizations to choose from. This trend will continue and most plants will embrace packaged applications.

**Integrated Eco-System:** Increasingly, plants will have an integrated ecosystem to drive automation and productivity. PLC will be integrated with shop floor execution system, which in turn will be integrated with Enterprise Resource Planning (ERP) system and Statistical Process Control system.

**Presence of Robots/TUGs/AGVs (Adoption of Robotic Automation):** Robotic automation is not a new concept. It has been around for decades now. Considering the pressure to reduce costs, to improve productivity and to improve OEE and yield, there will be an increase in robotic automation.

**Cloud Adoption:** Cloud adoption for manufacturing execution system may not be high in the future. This is because shop floor execution systems are really "high speed" application where thousands of transactions are logged every minute and there will be literally "zero" tolerance for latency. Connectivity must be super-fast, which may not be possible in geographies such as Asia and Latin America where manufacturing operations are concentrated.

However, during the years factories will be focused on three key KPIs:

- Meeting Target output
- Lowering Cost per Unit
- "Zero" defects

Other factors such as OEE, Yield, throughput etc. directly or indirectly tied to one of these three parameters.

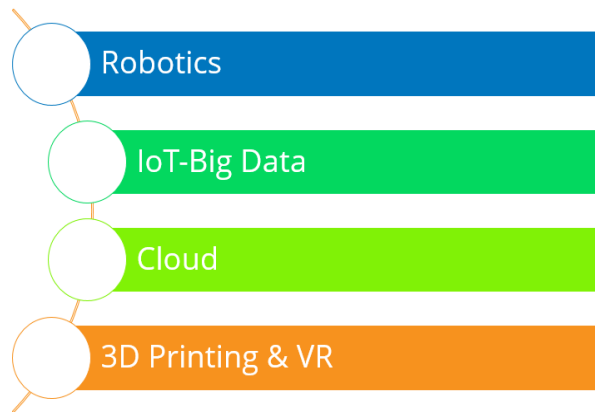
### 3. CURRENT CHALLENGES IN FACTORIES

Factories currently, face three key challenges:

- **Following an aggressive cost reduction Roadmap:** In most industry verticals, companies must stick to an aggressive cost reduction roadmap to retain their market share and to grow them. Every year, factories are required to meet the same or increased production target at a lower cost. This becomes more difficult to achieve due to increase in the cost of labor and raw materials over time.
- **Maintaining Traceability & Quality:** Companies must maintain traceability with a high level of accuracy to address customer complaints effectively. This also helps maintain a high level of quality with minimum, if possible “zero” defect. To achieve zero defect is really challenging, as there are complexities involved. For example, operators will make mistake or there will defect in one of the thousands of lots, which is difficult to detect.
- **Having Agility to launch new products at frequent intervals:** Organizations have to launch new products frequently to address new markets and new customer segments. Factories should be flexible enough to support this requirement, with minimal incremental investment and minimal disruption to existing operations.

Innovative system architecture and new disrupting technologies hold the promise to help achieve the above three objectives.

### 4. DIGITAL MANUFACTURING: DISRUPTING THE PRESENT TO BUILD THE FUTURE



**Robotic Automation:** Robotic automation in manufacturing facilities has existed for about three decades. The ability of robots to perform specialized tasks has increased significantly and they are now on the cusp of mass adoption

**IoT-Big Data:** They have empowered us to make sense out of tons of data generated by machines, which in turn helps us improve uptime, reduce defects and drive productivity.

**Cloud:** Provides a robust, relatively secure and scalable platform to host the entire application stack. It helps us focus on value-adding initiatives

**3D Printing & VR:** Another frontier in manufacturing and driving customer experience. Organizations are increasingly adopting them to drive productivity and customer satisfaction

The following section examines how each one of the above can help organizations address the challenges outlined in earlier sections.

### 5. ROBOTS: THE KEY DRIVER OF AUTOMATION

As mentioned in the previous section, robots have existed for decades. However, at present and in the future, they will play a significant role in addressing the challenges that factories face. The following illustration captures key information which will help decide if an organization should consider using robotic automation.

Robots: Key Driver of Automation	
Fact Check	Do I need them
<p><b>Robots are NOT panacea for Productivity Improvements</b>  <b>Key Drivers for Robots:</b> Productivity Improvements, Defect Prevention, Safety Improvements &amp; Precision Manufacturing</p> <p><b>Robotic Automation Vs Robotic Process Automation (RPA)</b>-Robotic Automation synonymous with Industrial Automation, RPA with Business Process Automation</p> <p><b>Robots don't come alone, they come with their Ecosystem:</b> Consists of Robot Providers, Gripper Designers and System Integrators to integrate the Robot with PLC and Shop Floor systems</p> <p><b>Robot Family:</b> Different Robots for different needs; Standard Robots, Mobile Robots and Co-Bots to choose from</p> <p><b>Robot Providers:</b> Highly fragmented market, however Kuka, ABB, Fanuc, Yaskawa &amp; Staubli are some of the known ones. They tie up with providers such as Applied Robotics and Robotiq for Gripper and different SI partners for commissioning (Integrating) the Robots</p>	<p><b>Answer: Yes as well No, driven by the Use Case and ROI</b>  <b>Forming the Right Team:</b> IT, Industrial Engineering, Manufacturing, Quality and Facility need to have close collaboration</p> <p><b>Mapping Processes:</b> Thorough Analysis of process Steps in terms of Precision Required, Overall Complexity, Space Constraints and Head Count required</p> <p><b>ROI, ROI &amp; ROI:</b> Gains in terms of Productivity Improvements, Safety Compliance and Defect Prevention to be stacked against Robot Cost (normally in \$50k-\$200k), Integration Cost (can be 3-5 times the Robot Cost) and cost associated with Down Time and Time to attain target through put. Normally, ROI looks very good for plants in EU and North America</p> <p><b>Risk Factors:</b> Failing to choose the right SI partner who is key to commissioning the Robots, Longer than expected time to reach desired Productivity level, Productivity Loss due to Shut Down during installation at times underestimated</p>



As can be seen from the above findings, Robots can't be a panacea for productivity improvements. They are effective agents to improve productivity when applied in the right geography, for the right use case, and with the right expectations. Last but not the least, ROI must be at least reasonable.

## 6. IOT & BIG DATA: ORACLE OF FACTORIES?

IoT & Big Data has caught a lot of attention in the last few years. Tons of data captured by machines on the shop floor, which otherwise went unnoticed, started to draw the attention of Data Scientists. Patterns could be identified and applied to improve operations on the shop floor. However, it takes a while to figure out how to leverage IoT and Big Data on the shop floor. The following section summarizes key points about IoT and Big Data.

### IoT & Big Data: Oracle of Factories

Fact Check	Can They help me
<p><b>Big Data, What are they?</b> Simply put, they are huge chunks of data generated by devices or processes</p> <p><b>IoT:</b> a Platform to extract, analyze, contextualize &amp; represent large chunk of data (Big Data) data analytics, machine learning, visualization, etc.</p> <p><b>IoT comes with an eco system:</b> Platform, Connectors, Solution providers, Data Scientists &amp; "IoT ready" machines (Secs Gen/PV2 compliant, Sensor Enabled etc)</p> <p><b>IoT Providers-</b> Can be Open Source or Proprietary. An example of Open Source IoT is Kaa, C3IoT, ThingWorx, Jasper, Ayla Networks are examples proprietary ones.</p> <p><b>Selecting the IoT Platform:</b> Factors such as Specialization in a vertical, Ability to build applications with less efforts, Ability to integrate in the ecosystem, Scalability and Security drive decision making. Need to decide whether On Premise or PaaS</p> <p><b>SIs include:</b> Known System Integrators such as Deloitte, Accenture, IBM, Wipro, TCS, Infosys etc.</p>	<p><b>The answer is in general Yes, but should justify bang for bucks</b></p> <p><b>Selecting the right Platform :</b> Can be difficult in a fragmented market. Factors such as, number of clients in same or similar domain, Number of Out of Box Use Cases, TCO &amp; IoT Ecosystem they have built drive the selection process</p> <p><b>Selecting the right Integration Partner:</b> This can be difficult as well. At this point, as IoT is still in early stages getting a SI partner with considerable experience can be challenging</p> <p><b>Choosing the Use Case:</b> Normally, in the Manufacturing World, Predictive Maintenance, Defect Analysis &amp; Prevention, Energy Optimization, Asset Management and Facility Management are common Use cases.</p> <p><b>ROI, ROI &amp; ROI:</b> Savings obtained through Productivity Gain, Defect Prevention and Optimization should offset upfront Cost for the Platform, Cost to develop the Use Case and Yearly maintenance Fee for the platform.</p>

This indicates IoT and Big Data hold a lot of promise for factories. However, we can unleash their true strength by choosing the right IoT platform, right SI partner, right Use Case and having a pool of bright Data Scientists. It may be called out that IoT and Big Data is relatively new areas, it's really challenging to find the right talent. The time required to reap benefits may be a bit longer as well.

## 7. CLOUD: NEW GAME CHANGER

Cloud has dominated the conversation in the recent past. There is so much jargon around cloud, SaaS, PaaS, DBaaS, IaaS etc. Then there is a "public cloud", "private cloud", "hybrid cloud," etc. It can be really confusing. Then, there are questions around if we want to move applications to the cloud or our infrastructure to cloud and so on. The following summary attempts to answer many of these questions and provides a broad direction for cloud transition.

### Cloud: New Game Changer

Fact Check	Do I move to Cloud
<p><b>Cloud :</b> Most common buzzword in the last 3-4 years, simply put it offers Infrastructure as well as applications for which we "pay as we go"</p> <p><b>Multiple Flavors:</b> SaaS (Software as a Service), IaaS (Infrastructure as a Service), DbaaS (Database as a Service), PaaS (Platform as a Service) etc</p> <p><b>Cloud Ecosystem:</b> In general, Consists of SaaS Providers (e.g. MES Providers, ERP Providers etc), DbaaS providers (e.g. Oracle, Microsoft), Cloud Providers (e.g. AWS, Microsoft Azure, Google etc) and System Integrators (e.g. Accenture, Infosys, Deloitte etc) who help migrate to Cloud and offer Ongoing support</p> <p><b>Key Drivers for Cloud "Movement":</b> Cost Savings, Ability to focus on Productivity Improvements, Process Improvements and improving Customer Experience</p> <p><b>Role of SI Integrators:</b> Help perform required assessment to move to cloud, help create a Roadmap &amp; Regression Testing</p>	<p><b>Answer is "Yes" as well as "No"</b></p> <p><b>Form the right Team:</b> It should consist of SMEs from Infrastructure team, applications team, security team, PMO and relevant Functional departments (e.g. Manufacturing)</p> <p><b>Big Bang Vs Phased Approach:</b> Whether to move applications en masse or in phases</p> <p><b>Are Mfg Apps Correct Use Case:</b> Mfg Apps may NOT be the right Use case on account of concerns around Uptime &amp; Latency</p> <p><b>Assess Infrastructure Readiness:</b> Assess if Network and Security architecture can support hosting Mfg apps on cloud.</p> <p><b>Assess Architecture Fit:</b> Assess if Customizations and Integrations will be supported in Cloud. It may be difficult to replicate Custom components on Cloud.</p> <p><b>TCO:</b> CapEx Vs OpEx conversation. Cloud requires less upfront CapEx but higher recurring OpEx (SaaS Fee, DbaaS Fee etc).</p>

A detailed due diligence needs to be undertaken to assess if manufacturing applications can be transitioned to cloud. Moving manufacturing applications to the cloud may not be the best solution, especially when plants are in Asia and in Latin America. This is primarily because connectivity may be an issue when thousands of transactions are logged real-time. Any latency would not be

*Padhi Nikhil, Illa Prasanna Kumar; International Journal of Advance Research, Ideas and Innovations in Technology* acceptable. While assessing the Total Cost of Ownership (TCO) for cloud transition, it's a CapEx Vs OpEx conversation. If an organization will like to pay for upfront higher CapEx and lower recurring OpEx or they will go for low or no initial CapEx, but a higher recurring OpEx.

### 8. 3D PRINTING & VR: EXTENDING THE DIGITAL KINGDOM

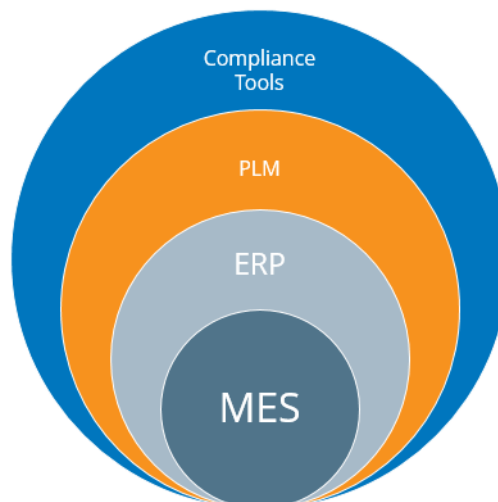
3D printing and Virtual Reality (VR) are another dimensions of the Digital Revolution. 3D printing, as a concept, has existed for decades. It has gained traction in the last few years.

Fact Check	Do I adopt 3D Printing & VR
<p><b>3D Printing</b> : an innovative method to “print” three dimensional objects</p> <p><b>VR:</b> Creates a virtual environment with the feel of real-objects. This is really helpful in enhancing overall customer experience and can be useful to fix minute defects</p> <p><b>3D Ecosystem:</b> In general, Consists of SMEs/Service Providers to generate “Digital Replica”, and put the key components together, Hardware Providers for 3D Scanners, Camera and Software Providers for CAD , Photogrammetry software etc</p> <p><b>VR Eco-System:</b> Hardware providers for TFT Display, VR Head Mounted Display, Speaker, Touchpad etc. Software Providers for Kernel which includes Graphic Subsystem, Audio Subsystem etc and SMEs to put these pieces together for the tight Use Case</p> <p><b>Key Drivers for 3D Printing &amp; VR:</b> Cost Savings, Improve Product Development Process and create a better Customer experience</p>	<p><b>Answer is “Yes” as well as “No”</b>  <b>Form the right Team:</b> It should consist of SMEs from IT, Industrial Engineering, Manufacturing, Quality etc. This should be a cross-functional effort.</p> <p><b>Identify the Right Use Case:</b> Appropriate Use Case needs to be identified for these two technologies. VR may be appropriate to simulate Assembly Lines to identify Bottlenecks, identify gaps during new product development. 3D Printing can be useful to build key sub-assemblies, building prototypes etc</p> <p><b>Assess Architecture Fit:</b> Careful analysis needs to be done to assess how these technologies fit into the overall architecture. In many cases these technologies fail as they don't gel well into the overall system landscape</p> <p><b>TCO:</b> At the end of the TCO and Pay back period are really important before going for these technologies. Calculations must include the savings on account of productivity improvements and other gains vis a vis initial CapEx, recurring OpEx and ramp up time to reach target productivity level</p>

Initially, these two technologies were relevant for very specific use cases. As mentioned in the above summary, they are now applied to a variety of use cases across industries. Organizations should start looking at them more as mainstream technologies rather than looking at them as technologies which are niche.

Before the Digital journey, organizations need to ensure that they have the required system architecture in place which to facilitate such a journey. Creating such a System architecture is a two-step process, getting the “Base” ready and then creating a “seamlessly” integrated ecosystem on top of the base. The following two sections describe these two steps in detail.

### 9. SECURE THE BASE



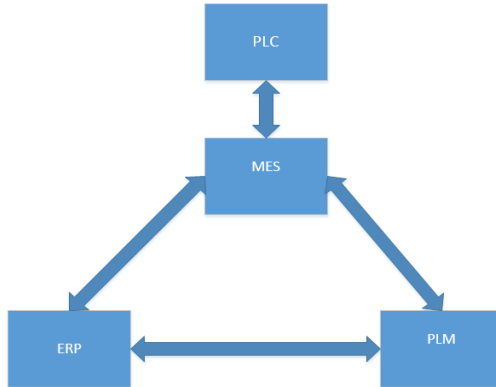
Three KPIs drive system architecture in factories:

- Efficient Transaction Processing, which drives productivity and target output (Efficient= minimum number of clicks/transaction, the minimum number of data entry/transaction & minimum latency to commit a transaction)
- Total Cost of Ownership (TCO), which drives lower cost/unit
- Lower defects and traceability

Three pillars are to create a strong base:

- MES - Which supports efficient transaction processing, provides strong traceability, supports equipment integration, helps defect prevention, has attractive TCO and is scalable
- EBS - Which provides a platform for costing, consolidation, planning, financial & statutory reporting
- PLM - SKU creation and management

**10. CREATE SEAMLESSLY INTEGRATED ECOSYSTEM**



Create an integrated eco-system. The secure base integrated with industrial control systems to drive productivity improvements

- Automated transaction processing for multiple process steps
- Little or no data entry for the process steps automated
- Automated equipment status monitoring
- Automated product classification

Finally, it's important to keep in mind that quality is of utmost importance. The following section outlines the quality framework which will complement the Digital Architecture.

**11. CREATE A QUALITY FRAMEWORK FOR DIGITAL JOURNEY**

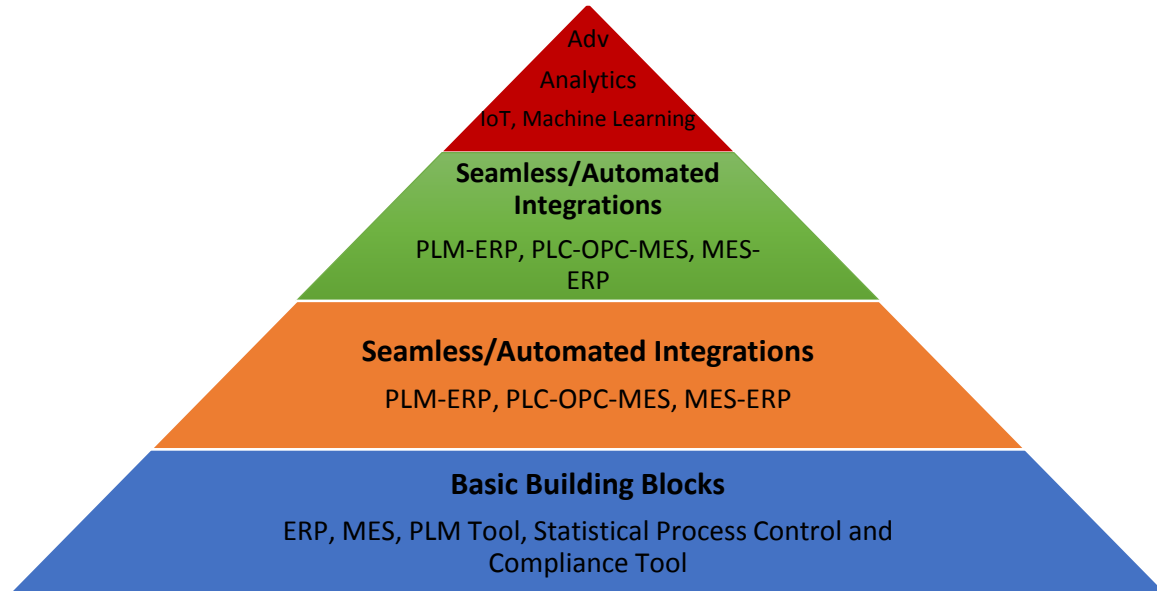


**Defect Analysis & Resolution:** Get to the root cause through 5 Whys, 8D, Fishbone diagrams etc., and apply a permanent fix. Organizations may consider a packaged quality module vis-a-vis a homegrown quality application

**Statistical Process Control:** Alerts occurrence of Out-of-Spec (OOS) or Out-of-Control (OOC) events to facilitate corrective actions. Organizations may leverage built-in SPC module that comes with MES a specialized SPC package.

**Defect Prevention & Continuous Improvements:** MES provides a platform to put in place checks and balance to prevent defects. Problem Solving is the key to continuous improvements

**12. PUTTING ALL THE PIECES TOGETHER**



The following paragraph summarizes a typical multi-phase approach for setting up a smart factory:

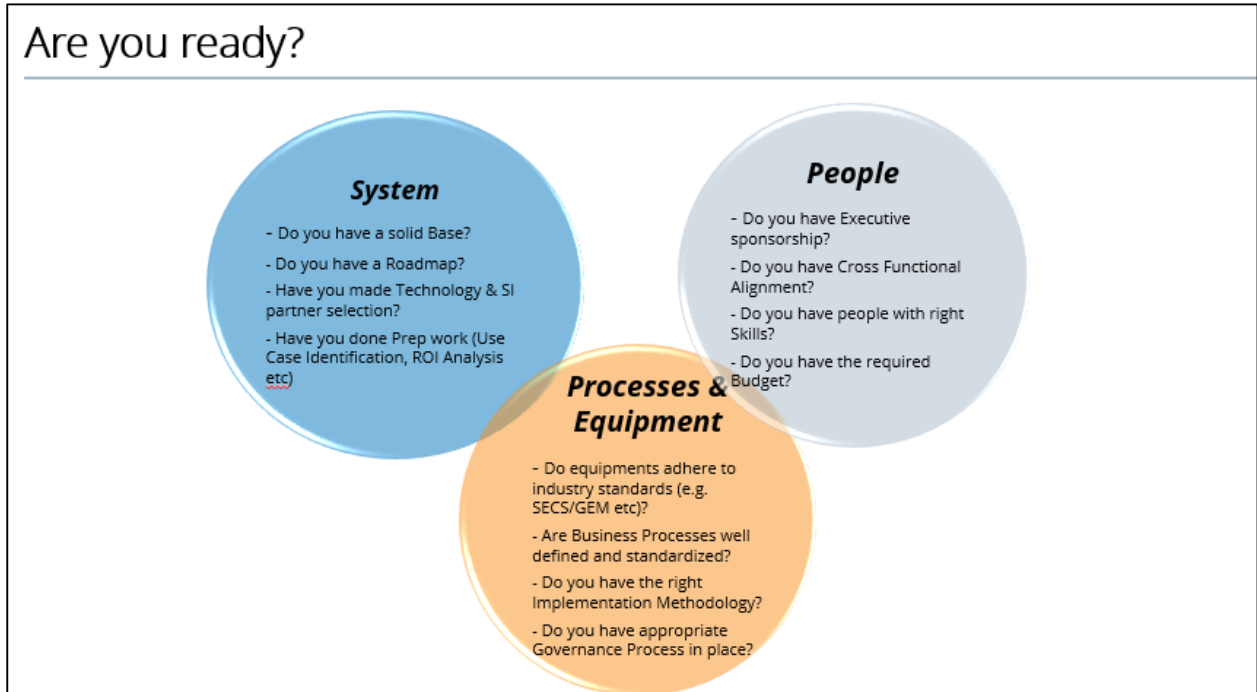
**Phase-I:** Secure the Base-Implement packaged Enterprise Resource Planning (ERP), Manufacturing Execution System (MES) & Product Lifecycle Management(PLM) product and build basic integrations.

**Phase-II:** Create a seamlessly integrated ecosystem with MES integrated with Industrial Control System-PLC on one hand and with ERP system on the other hand. PLM tool integrated with EBS

**Phase-III:** Introduce robots for process steps justifying ROI.

**Phase-IV:** Advanced analytics in terms of implementing use cases on IoT platform leveraging machine learning etc.

### 13. ARE YOU READY?



The following are essential considerations as an organization start their digital journey

#### 13.1 System

- Do you have a solid base?
- Do you have a roadmap?
- Have you made a technology & SI partner selection?
- Have you done prep work? (Use case identification, ROI analysis, etc.)

#### 13.2 People

- Do you have executive sponsorship?
- Do you have a cross-functional alignment?
- Do you have people with the right skills?
- Do you have the required budget?

#### 13.3 Processes & Equipment's

- Do equipment adheres to industry standards? (E.g. SECSGEM etc.)
- Are Business Processes well defined and standardized?
- Do you have the right Implementation methodology?
- Do you have an appropriate governance process in place?

### 14. CONCLUSION

Building a smart factory is a journey which can take years. There should be a clear vision, well laid out & phased approach and executive sponsorship to make this happen. There should also be an appetite to accept a longer wait period to see the results. All in all, it can be summarized using the saying “no one told you that it’s going to be an easy journey, but definitely it’s going to be worth your effort.”

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## **APPENDIX**

- ROI : Return on Investment
- MES : Manufacturing Execution System (Shop Floor Transactional system where the operators log the process steps, material consumption etc)
- ERP : Enterprise Resource Planning (OLTP-Online Transaction Processing system; Oracle, SAP etc)
- PLC : Programmed Logic Control (Industrial control system which controls the actions/movement of equipment through Ladder Programming)
- OPC : Open Platform Communications (Middle Layer between MES & PLC)
- PLM : Product Life Cycle Management (Item Hub)
- IoT : Internet of Things
- FG : Finished Goods
- WIP : Work in Process
- SKU : Stock Keeping Units
- BOM : Bill of Materials
- UAT : User Acceptance Test
- MW : Mega Watt (Measure of Energy generated)
- WO : Work Order