Paradigm Shift in Manufacturing via Information Technology

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Abstract -- **Emergence and acceptance of digital technologies and convergence of Information Technology and Operational Technology (OT) are rapidly changing the face of manufacturing industry. Intense competition in global and domestic markets is continuously demanding manufacturers to produce products of higher quality with much less cost. The implication of this is that today's manufacturing systems need to be equipped with such functionalities as intelligence, efficiency and flexibility, necessitating a paradigm shift in manufacturing technology.**

Here five emerging trends are examined that are transforming manufacturing, namely Lean Manufacturing, Applications of Artificial Neuron Networks, Smart Factory, Additive Manufacturing and Advanced Robotics.

Keywords: Adaptive production system, Lean manufacturing, Cognitive computing, Machine learning, Artificial neuron networks, Smart factory, Additive manufacturing, Advanced robotics

I. INTRODUCTION

THE nature of today's manufacturing processes is changing and becomes highly sophisticated than ever due to rapid variations in their environments resulting from paradigm shift in customer demand and from reduced product life cycle.

One challenge due to this paradigm shift results in businesses overhauling the way they manage supply chains, inventory, production practices and staffing. Store owners do not order products unless the products can be sold quickly; manufacturers do not produce unless they have buyers lined up. This resulted in the manufacturing sector facing challenges what economists term a jobless recovery [1].

Emergence and acceptance of digital technologies and convergence of Information Technology (IT) and Operational Technology (OT) are rapidly changing the face of the manufacturing industry. The current intense competition in global and domestic markets is continuously demanding manufacturers to produce products of higher quality with much less cost. The implication of this is that today's manufacturing systems need to be equipped with such functionalities as intelligence, efficiency and flexibility, resulting in a new paradigm shift in manufacturing technology.

The capabilities of technologies have grown more sophisticated: Artificial Intelligence, cognitive computing, and machine learning have enabled systems to interpret, adjust to and learn from the data gathered from connected machines. This ability to evolve and adapt, coupled with powerful data processing and storage capabilities, allows manufacturers to move beyond task automation toward more complex, connected processes.

As manufacturing has grown increasingly global, production has fragmented, with stages of production spread among multiple facilities and suppliers across multiple geographies. These shifts, coupled with the increased demand for regional, local, and even individual customization; strong demand fluctuation; and increasingly scarce resources, among other shifts, have made supply chains more complex. Due to these changes, manufacturers need to be agile, connected, and proactive to address ever-shifting priorities.

New approaches and techniques are continuously and rapidly introduced and adopted in today's manufacturing environment. Today's manufacturing industries have to become competitive for their survival. They require:

- High level of service to satisfy the costumers.
- High level of throughput to meet their revenues.
- Reduced delivery time at reasonable cost.
- Reduce WIP (work in process) inventory, to reduce the inventory holding cost hence the production cost.

It is very difficult to achieve the objectives by a manufacturing unit in real but can be aided by adopting a lean manufacturing system.

II. LEAN MANUFACTURING

Lean production supplies customers with exactly what the customer wants, when the customer wants, without waste, through continuous improvement. Lean aims to enhance productivity by simplifying the operational structure to understand, perform and manage the work environment [2].

Figure 1. Lean manufacturing, "waste" is defined as anything that doesn't add value to a product.

Lean implementation emphasizes the importance of optimizing work flow through strategic operational procedures while minimizing waste and being adaptable. Task of minimizing waste is achieved by what is termed, 'Just-in-Time'. It achieves streamlined production by reducing inventory.

Ministry of Micro, Small and Medium Enterprises announced a special Lean Manufacturing Competitive Scheme (LMCS) to bring manufacturing-competitiveness in the MSME Sector. The main objective of LMCS is to bring the manufacturing competitiveness in the MSME Sector [3]. Lean Manufacturing involves applying Lean Techniques (*e.g.* Total Productive Maintenance TPM), 5S, Visual control, Standard Operation Procedures, Just in Time, Kanban System, Cellular Layout, Poka Yoke, etc.) to identify and eliminate waste and streamline a system. The focus is on making the entire process flow, not improving only a few operations. Worker empowerment is also emphasized throughout the effort.

The approach involves engagement of Lean Manufacturing Consultants (LMCs) to assess the existing manufacturing system of member units of the Mini Cluster(s) and stipulate detailed step-by-step procedures and schedules for implementing and achieving of lean techniques.

A Special Purpose Vehicle (SPV) drives each cluster. Once MSMEs experience the benefits and savings that accrue from LM techniques, they would themselves continue the Scheme from the second year onwards at their own expense. A three tier implementing structure is in place with a group of 10 or so MSMEs (SPV) at the lowest local-tier and a Lean Manufacturing Screening and Steering Committee (SSC) under DC (MSME) at the highest tier. The intermediate tier, National Monitoring and Implementing Unit (NMIU) is responsible for facilitating implementation and monitoring of the Scheme. For the Pilot phase of 100 Mini Clusters, it is envisaged that NPC (National Productivity Council) function as NMIU.

III. APPLICATION OF ARTIFICIAL NEURON NETWORKS TO MANUFACTURING

Recently, there has been an explosion of interest in applying artificial neural networks to manufacturing. Briefly, a neural network is a massively parallel distributed processor that has a natural propensity for storing experiential knowledge and making it available for use [4].

Neural networks are able to learn, adapt to changes, and can mimic human thought processes with little human interventions. They could be of great help for the present computer-integrated manufacturing and the future intelligent manufacturing systems.

Artificial neural networks have several advantages that are desired in manufacturing practice, including learning and adapting ability, parallel distributed computation, robustness, etc. There is an expectation that neural network techniques can lead to the realization of truly intelligent manufacturing systems.

The topic of artificial neural networks (ANN) received a great deal of attention among engineers as an alternative method of solving intractable problems. In the area of manufacturing, ANN have been applied to robot path planning, pattern recognition of data trends for use in analyzing production systems, vision systems, and recent attempts to use ANN for feature recognition to facilitate CAD/CAM. Neural networks are becoming a real powerful leading manufacturing technology to enter a new era for intelligent manufacturing.

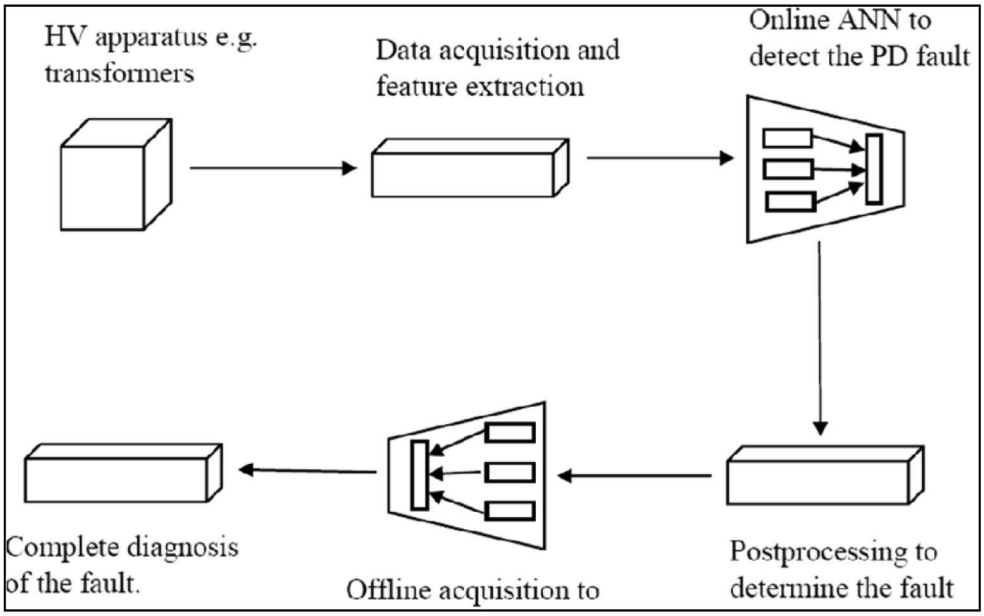

Figure 2. Example of Artificial Neural Network Application for Partial Discharge Recognition.

Case Study/ Example: Monitoring and Control of an Induction Hardening Process. Induction Hardening Process uses heat generated by the resistance of the metal by passing high frequency induced electrical currents over the selected area to surface-harden the metal to provide a strong, hard, wear-resistant surface. It changes the microstructure of the steel by first transforming the outer layers of the part into austenite, occurring above 750° C. After reaching this state, the part is immediately quenched at a predetermined rate to further transform the austenite into martensite, which is a very brittle and hard state of steel. Then tempering, done to allow the structure to relax to an equilibrium state that is very strong and hard, but not as brittle.

The process uses a channel coil that is stationary, and parts move through that channel. As a part breaches the opening of the channel, the heating process begins; heating stops when the part clears the channel. The amount of time a part is in the channel determines the final part temperature.

A closed-loop artificial neural network system for automated control of an induction hardening process consists of two back propagation neural networks. The two variables that were found to be significant include motor speed and part temperature. These were the inputs into the prediction neural network while the output was predicted hardness. A part hardness target of 90 on the Rockwell HR15N hardness scale is specified for the induction hardening process.

Result: The prediction neural network was tested with 15 data sets from the original process data. Each data set contained two inputs, motor speed and part temperature, and an output hardness value was returned by the prediction neural network. The function of the feedback neural network was to determine the change in motor speed necessary to move the hardness value closer to the target (90 HR15N). The new motor speed and part temperature were entered into the prediction neural network. For example, at a motor speed of 0.5415 RPM and part temperature of 1718 °F, the neural network predicts a hardness of 88.591 HR15N. The deviation from target is 90-88.591 = 1.409 HR15N and the part temperature were used to determine the change in motor speed.

IV, ADDITIVE MANUFACTURING

Introduced in 1980s, Additive Manufacturing (AM) is the process of synthesizing an object by deposition or addition of material. Experts opine that it is the manufacturing-technology of the future as it features following compelling advantages:-

- It Saves on Energy Costs
- It Reduces Waste Production
- Affordable Cost of Entry (Attractive for start-ups)
- Easy to Change product specifications
- Training Programs are available.

The Process starts with a CAD file which is sliced into a number layers of equal thickness by the software. The machine then builds the parts by sequential addition of these layers over each other, until the part is complete. AM is about more than just creating a physical product, it is about bringing design and innovation to the forefront. In fact, having creative freedom without worrying about cost or time penalties is one of its primary advantages [5].

Still, some companies remain on the fence about AM and aren't convinced it is the future. AM reduces the amount of capital needed to scale up production without making major changes -- manufacturers can increase the speed and profitability of their business model.

In traditional manufacturing, modifying a design during production can lead to significant cost increases or time delays as tooling on a production line is altered. AM solves this problem by moving away from static designs and enabling engineers to produce multiple versions of a single design in a cost-effective manner.

Figure 3. Additive manufacturing brings quieter, lighter aircraft.

AM generates significantly less waste than traditional manufacturing methods. For example, a milling machine works by removing material from a block that is bigger than the product itself will be. The removed material is usually in the form of kindling or shavings that cannot be reused and therefore ends up as waste.

AM, instead of removing material, it "adds" material layer by layer so that only what is required gets used. In this way, additive manufacturing reduces material costs and waste by as much as 90 percent.

When compared with traditional manufacturing processes, AM significantly reduces energy usage by using less material and eliminating steps in the production process. Consider this example cited in a recent US report:

"LEAP jet engine from GE and Snecma incorporates fuel nozzles printed with laser sintering. Conventional manufacturing process welds 20 parts to produce the fuel nozzle, while AM produces a single piece that is 25% lighter, five times more durable, and reduces fuel burn by 15%".

Furthermore, re-manufacturing parts through AM can return end-of-life products to "like new" condition using only 2 to 25 percent of the energy that would be required to build a whole new part. The tooling industry will be a big arena where AM can play a substantial role. In 2016 around 4% of manufacturers were using AM printing process, whereas according to analysts, adoption in the tooling market continued to grow and reached 10% in 2019.

As the need to obtain parts quickly continues to rise, AM processes will continue to become more and more relevant in future. AM equipment manufacturers are predicting that as more companies begin to adopt these technologies, it is only a matter of time before the future of manufacturing is completely transformed.

V. SMART MANUFACTURING AND SMART FACTORY

Smart manufacturing is the process that employs computer controls, modeling, big data and other automation to improve manufacturing efficiencies. Formally, it is defined as systems that are "fully-integrated, collaborative manufacturing systems responding in real time to meet changing demands and conditions in the factory, in the supply network, and in customer needs" [6].

Smart Manufacturing is being predicted as the next Industrial Revolution or Industry 4.0. And, as with many other advances throughout recent years, it all has to do with technology connectivity and the advances in the contextualization of data.

It is a broad category of manufacturing with the goal of optimizing the manufacturing process. Smart manufacturing aims to take advantage of advanced information and manufacturing technologies to enable flexibility in physical processes to address a dynamic and global market.

Smart factories go beyond simple automation: the term, 'Smart Factory' describes an environment where machinery and equipment are able to improve processes through automation and self-optimization. The smart factory represents a leap forward from more traditional automation to a fully connected and flexible system—one that can use a constant stream of data from connected operations and production systems to learn and adapt to new demands.

Central to the smart factory is the technology that makes data collection possible. These include the intelligent sensors, motors, and robotics present on production and assembly lines that the smart factory puts to use. Sensors make it possible to monitor specific processes throughout the factory which increases awareness about what's happening on multiple levels. For example, vibration sensing can provide a warning when motors, bearings, or other equipment need to be maintained. These types of subtle warnings become alerts for preventative maintenance or other actions that head off larger production problems if left unattended.

Similarly, sensing technology on Self-Driving Vehicles used for material handling improves efficiency and safety as product is moved around the factory. These types of robotics have the ability to sense and avoid people, as well as unexpected obstructions in the course of doing its work. The ability to automatically avoid these common disruptions is a powerful advantage that keeps production running optimally.

The concept of adopting and implementing a smart factory solution can feel complicated, even insurmountable. However, rapid technology changes and trends have made the shift toward a more flexible, adaptive production system almost an imperative for manufacturers who wish to either remain competitive or disrupt their competition. By thinking big and considering the possibilities, starting small with manageable components, and scaling quickly to grow the operations, the promise and benefits of the smart factory can be realized.

Ultimately, it's the application of intelligence at the factory level that creates a dynamic production environment and the desired results - reducing costs while improving quality and reliability. Consider how smart equipment makes it possible to automate much of what's required to accommodate product variation and smaller-sized production runs during the manufacturing process. The future of manufacturing is for more customization, so by minimizing downtime for retooling and resetting equipment, manufacturers can operate efficiently while staying flexible.

The true power of the smart factory lies in its ability to evolve and grow along with the changing needs of the organization -- whether they be shifting customer demand, expansion into new markets, development of new products or services, more predictive and responsive approaches to operations and maintenance, incorporation of new processes or technologies, or near-real-time changes to production.

The Impact on Jobs: As the smart factory slowly emerges, the roles that people take on will evolve from what they are currently doing in today's factories. People will take on more complex roles while automation will conquer the tasks that are repeatable, mundane or currently impacted by labor shortage [7]. Studies indicate that technology, overall, does not eliminate jobs. As factories get more technologically advanced, the number of indirect jobs needed to support them will increase proportionately. In turn, new suppliers in new industries will emerge, fuelling the advancements from outside the smart factory.

Multiple talent-related challenges--including an aging workforce, an increasingly competitive job market, and a dearth of younger workers interested in or trained for manufacturing roles--mean that many traditional manufacturers have found themselves struggling to find both skilled and unskilled labor to keep their operations running. Many companies are making investments in smart factory capabilities to mitigate the risk associated with this possibly pervasive labor shortage. However, this move can create a new set of talent-related consequences, as automated assets typically require highly skilled personnel to operate and maintain; even the location of manufacturing facilities would need to take into account factors such as this.

Cybersecurity risk presents a greater concern in the smart factory than in the traditional manufacturing facility and should be addressed as part of the overall smart factory architecture. In a fully connected environment, cyberattacks can have a more widespread impact and may be more difficult to protect against, given the multitude of connection points [8]. Cybersecurity risk seems to only grow more pronounced as the smart factory scales and potentially moves beyond the four walls of the factory to include suppliers, customers, and other manufacturing facilities.

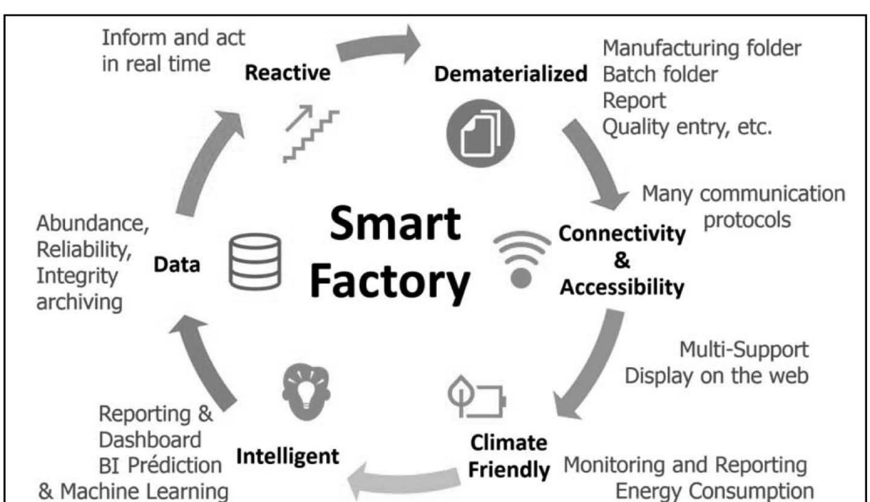

Figure 4. Smart Factory is a plant marked by a perfect knowledge of the context related to men and machines throughout the production process. This is established on a system operating in background to collect information from the context and make them available thereafter.

Manufacturers should make cybersecurity a priority in their smart factory strategy from the outset.

In the end, the investment of building a smart factory benefits manufacturers by creating a safer and more reliable plant. The demands on the manufacturing industry will continue thanks to the trend for more on-demand production and ever present drive to reduce costs. The smart factory is a direct way for manufacturers to excel in a competitive and dynamic marketplace.

VI. ADVANCED ROBOTICS

World over, automotive industry is the largest user of robotics and automation. Top 8 countries with the highest number of industrial robots for every 10,000 people employed in manufacturing are:

- South Korea, 347.
- Japan, 339.
- Germany, 261.
- Italy, 159.
- Sweden, 157.
- Denmark, 145.
- United States, 135.
- Spain, 131.

Industrial robot has seen improvements in areas such as computing capabilities and operational degrees of freedom. However, these robots are limited to operating in highly structured environments and exhibit low levels of autonomy. They are essentially the tools of long production runs and large volume manufacturers (*i.e.*, have a focus on mass production rather than on mass customization) and are considered components that perform essentially single operations in manufacturing.

Advanced robots, also known as smart machines operate autonomously and can communicate directly with manufacturing systems. By evaluating sensory input and distinguishing between different product configurations, these machines are able to solve problems and make decisions independent of people [9].

These robots are able to complete work beyond what they were initially programmed to do and have artificial intelligence that allows them to learn from experience. These machines have the flexibility to be reconfigured and re-purposed. This gives them the ability to respond rapidly to design changes and innovation, which is a competitive advantage over more traditional manufacturing processes.

An area of concern surrounding advanced robotics is the safety and well-being of the human workers who interact with robotic systems. Traditionally, measures have been taken to segregate robots from the human workforce, but advances in robotic cognitive ability have opened up opportunities, such as cobots, for robots to work collaboratively with people.

Advanced robotics refers to special design features and capabilities. Specifically, advanced robots are envisioned to be

- Mobile (*i.e.*, no longer bolted to the floor);
- Operate in unstructured, or uncertain, environments (*i.e.*, autonomous);
- Designed to manipulate or physically interact with their environment;
- Capable of achieving desired outcomes without needing a fully pre-programmed precise set of actions for achieving those outcomes; and
- Able to safely perform tasks in intimate operation with humans or in extremely hazardous environments.

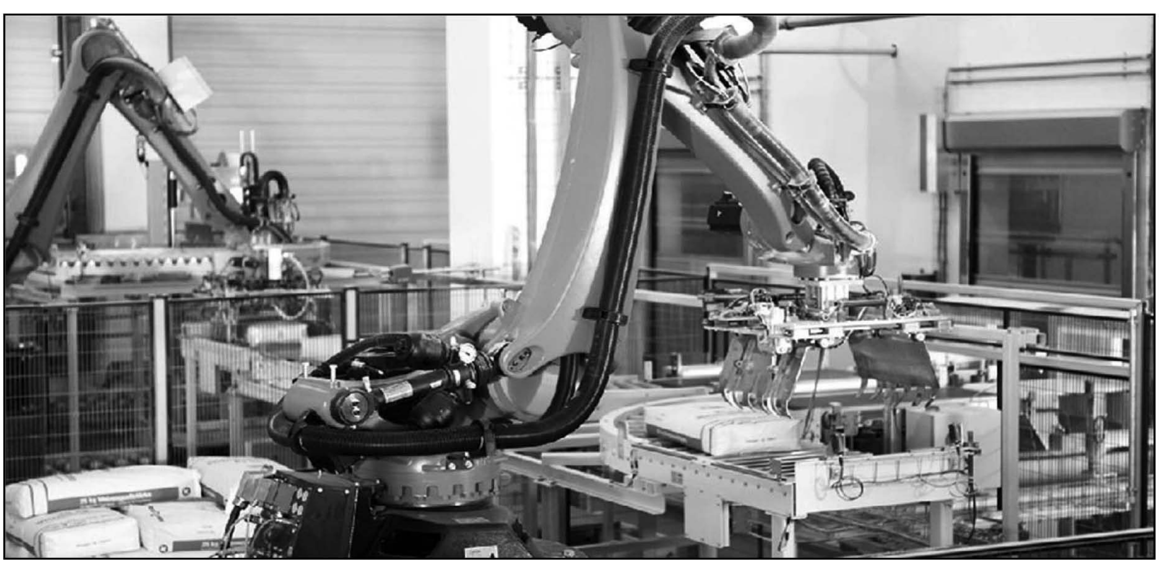

Figure 5. Advanced robots are able to complete work beyond what they were initially programmed to do and have artificial intelligence that allows them to learn from experience.

Intelligent automation could then build upon the new capabilities of these advanced robots to achieve increased levels of autonomy and flexibility that in turn would enable manufacturers to respond to changes in a more efficient and cost-effective way.

However, while the industrial robotics industry has been around since the 1960's, the advanced robotics industry is still in its infancy and will have trouble developing these highly desirable capabilities on its own. Support is needed that fosters collaboration and integrated, cross-disciplinary solutions if developments are to be achieved in a focused and timely manner.

The next generation of Advanced Robotics and Intelligent Automation systems would make possible new levels of speed, accuracy, precision, flexibility and agility, which in turn should provide manufacturers with greater competitiveness, profitability, and high quality employment opportunities. One needs to develop infrastructural solutions enabling Advanced Robotic and Intelligent Automation systems to seamlessly assist in, and perform more dangerous, dirty, dull, and difficult tasks leading to greater competitiveness through new levels of performance.

Technology Integration is challenging because robots are complex systems requiring simultaneous scientific and engineering advances in multiple areas. Developing integrated platform-independent scientific and engineering solutions requires cross-disciplinary teams. For example, new manipulators or motion systems also depend on advances in power and energy systems. Navigation depends on sensing systems, computing and mobility systems. And these components somehow must all work together reliably.

Advanced Robotics and Intelligent Automation require the development of infrastructural technologies that are broadly enabling and far-reaching, or next generation manufacturers will not have access to solutions that can provide needed new levels of precision, quality, agility, flexibility, and safety.

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- Big Data: Challenges and opportunities (Feb 2017)
- Smart Cities (April 2017)
- Lure of ISM Band (July 2017)
- Lithium Ion Batteries: Answer to Communications Energy Crunch (May 2018).

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