Smart Manufacturing for Energy Conservation and Savings

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Smart Manufacturing for Energy Conservation and Savings

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Introduction

Smart Manufacturing is a fabrication method that goes beyond the factory floor by implementing cyber-physical intelligent systems through a dynamic response time that allows the system to better adapt the manufacturing process to specific product and energy needs. It involves automated control, integrated manufacturing, and networked companies improving productivity through information sharing and informed decision-making. Smart Manufacturing provides the right information at the right time to the user in a manner that is understandable. There are the following levels to this integration of automation: Manual, Reactive, Programmable, Variable, and Intelligent Controls. At each concurrent level, there is more potential to save energy, and there may not be a direct reduction in energy cost. The greater potential stems from a greater ability to tune the system for higher efficiency.

The difference between traditional manufacturing and this smarter implementation is an integration vertically through the production line and horizontally across departments and systems. A Smart Phone enables functionality beyond that of a traditional phone by incorporating multiple functions in a single device. Similarly, Smart Manufacturing enables greater customization and optimization through the use of smarter processes to connect subsystems to a wider operational grid. "Through the implementation of smart manufacturing, the ultimate goal is to handle information only once, enabling optimization of assets, synchronization of enterprise resources, supply-chain resources, and automation of business processing response to customer demands." [1]

Overview

The concept of smarter manufacturing has recently been widely invested in by the USA, Korea, and Japan by dedicating a significant amount of funding into the developing field. With the many benefits that come with smart manufacturing implementation, numerous countries in Europe have seen significant savings by adopting "Industry 4.0." † Further adoption will revolutionize the current manufacturing field with changes in mass customization, waste reduction, and utility savings. The technologies that enable Smart Manufacturing are made up of the following components: intelligent automation, Internet of Things (IoT), additive manufacturing, augmented reality, big data analytics, automated simulations, and Cloud computing. The overarching concept of implementation is seamlessly combining these technologies and integrating them into a collaborative system.

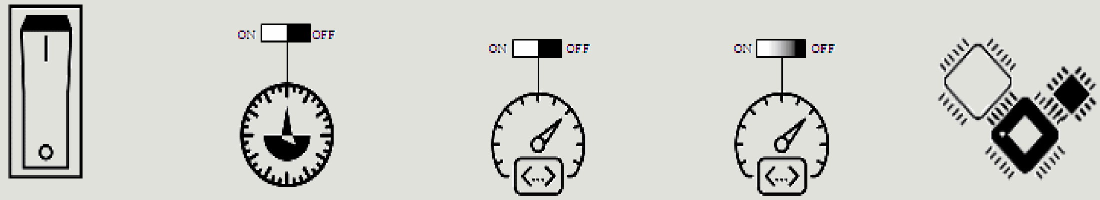
The goal of manufacturers is to reduce overhead costs without sacrificing product quality and production time. One of the most effective methods of overhead reduction is increasing system-wide energy efficiency. On average, 85% of the energy utilized in a manufacturing facility is not directly related to the production of the product.[2] It is also worth noting that the energy savings potential that stems from inefficient industrial consumption makes up a $47 billion-per-year possible savings in the U.S. alone.[3] These statistics demonstrate the availability of savings afforded to the manufacturing sector if energy efficiency is improved.

[1] "How Smart Manufacturing Saves Money" by E. A. Rogers is paraphrased and quoted for these statements.
[2] & [3] "Unlocking Energy Efficiency in the U.S. Economy" and "Energy Efficiency Management of an Integrated Serial Production Line and HVAC System" detail the energy savings potential that could be achieved through more efficient operation.
† Smart Manufacturing can also be referred to as "Industry 4.0." These terms both represent the cyber-physical system implementation in traditional manufacturing. Specifically, Industry 4.0 is a German initiative to implement smarter industry processes.

Levels of Smart Manufacturing

- Level 0 – Manual Control
- Level 1 – Reactive Control
- Level 2 – Programmable Control
- Level 3 – Variable Control
- Level 4 – Intelligent/Anticipation Control

"In this hierarchy of control technologies, it is important to keep in mind that they connote increasing level of complexity and not higher levels of energy savings." [1]



Level 0	Level 1	Level 2	Level 3	Level 4
A control system that is manually actuated and only has ON/OFF states.	The feedback from a sensor or system of sensors actuates the system in either an ON or OFF state.	Programmed instructions can take multiple conditions and inputs into account to actuate the system in either an ON or OFF state.	The system has conditions other than ON or OFF and can operate in an in-between state.	Considers variables outside the operating system to make intelligent decisions.
A pump fan that has to be manually turned ON or OFF.	A pump fan that can take sensor information and turn ON or OFF based on the state of that sensor such as a pressure sensor indicating that the pump must be activated.	Through programming, the pump fan takes multiple sensor states into account. For example, a water level sensor indicates that the pump should turned ON, but another sensor states that there is enough system pressure to complete the shift, and therefore repressurization would be an unnecessary expense.	A pump fan that is attached with a VFD, Variable Frequency Drive, will allow the pump to operate at speeds other than ON or OFF. Through programming, the energy consumption can be tuned to a more specific need, and the Industrial Assessment Center has had significant savings with VFD implementation.	A pump fan that is connected to the rest of the system. An example would be if the business departments needed to reduce overhead. The VFDs could be programmed to reduce motor speed in order to meet the needs of another department.

[1] The levels are further detailed in "How Smart Manufacturing Saves Money" by E. A. Rogers with more examples for the specific levels of integration.

Levels of Smart Manufacturing

A Cyber-Physical System (CPS) is a method of assigning varying levels of complexity to the corresponding amount of necessary information. Similar to the previous levels, the first step in CPS is data collection. The system requires reliable readable data in order for any further complexity to be added. As the data is manipulated, interpreted, and utilized, the complexity and digital/physical integration are both improved. [4]

Examples

1 - Sensor connection as feedback
2 - Robotic operation utilizing sensor information
3 - Fleet of robots operates utilizing peer-to-peer monitoring
4 - Info graphics are displayed to the operator for all robotic systems
5 - Robotic operation continues without interference and rarely necessitates intervention

Correction — Level 1

Proper feedback data is necessary and relies on a sensor network.

Presentation — Level 2

The important portions of the information must be filtered from the noise for more complex applications such as monitoring system health.

Machine Network — Level 3

At this stage, the system is connected beyond the singular operation and is able to compare performance with other similar machines.

Data Analysis — Level 4

Information has been collected and processed, and at this stage it is displayed concisely to the operator for decision-making.

Data Collection — Level 5

Rather than an operator performing the decision-making, the system is self-adjusting and self-configuring with minimal supervisory control.

[4] The levels for the cyber portion of smart manufacturing integration are further detailed in "A Cyber-Physical Systems Architecture for Industry 4.0-based Manufacturing Systems" by Jay lee, Behrad Bagheri, and Hung-An Kao.

Pillars of Smart Manufacturing

Industry 4.0 was started in Germany, and case studies have been performed to analyze its impact on the field of manufacturing. It is estimated that over the course of the next 5 to 10 years German industrial component manufacturers might see productivity improvement between 20 to 30 percent, and automotive could increase by 10 to 20 percent. The increase in consumer demand is also estimated to increase revenue by 34.4 billion per year (approximately 1% of Germany's GDP). [5]

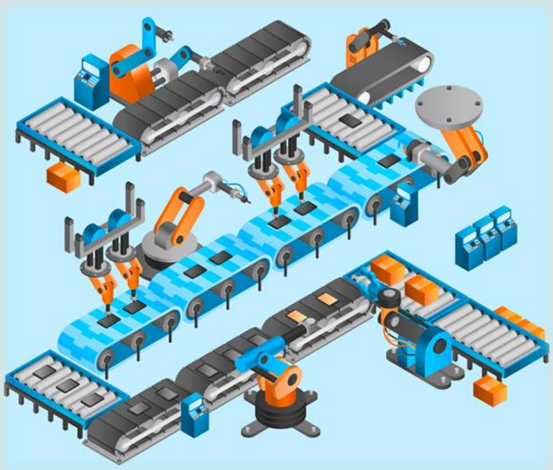
Using Germany's implementation of Smart Manufacturing as a case study for American manufacturing potential, there is a vast largely untapped pool of savings awaiting U.S. adoption of smarter manufacturing processes. The levels of Smart Manufacturing detailed on page 5 give general implementation guidelines for a variety of applications. The CPS levels on page 6 directly serve as a cyber-physical data integration guideline. Smart Manufacturing is composed of Augmented Reality, Intelligent Robotics, Cloud Connections, Internet of Things, Additive Manufacturing, and Data Analytics. The description and energy saving methods for each of these categorizes will be detailed below.

[5] "Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries" details topics beyond what are mentioned here such as employment and investments. It detailed specific costs such as labor, depreciation, materials, and overhead and how they are affected by the implementation of Industry 4.0.

Intelligent Robots/ Automated Solutions

A requirement for smart manufacturing autonomous production is that robotic operators must complete tasks without the need for isolation. Smart manufacturing encompasses a wide range of topics and the emergence of new robotic technologies that are perfect for the new industrial revolution.

Robots are the physical manifestation of the Cyber-Physical Systems (CPS), as mentioned previously. The introduction of robots into the manufacturing setting has propelled production far beyond what was previously achievable. To compare the 1990s to 2014 markets, the three largest companies had a market share of $36 billion to $1.09 trillion with 1.06 million fewer employees. These were the three largest companies in Detroit (1990s) and the three largest companies in Silicon Valley (2014). The widespread introduction of robotics resulted in a necessary workforce that is 90% smaller. By connecting the robots system-wide, the results in Germany suggest another financial and productivity boost for the U.S. manufacturing industry by following similar methods. [6]



"Lights-Out" Factories - These facilities will continue working without lights or heat, greatly reducing overall costs and allowing for reallocation of human workers to higher priority tasks.

Collaborative Robots – Robot-to-robot or robot-to-human interaction that extends the system complexity beyond that of an isolated system.

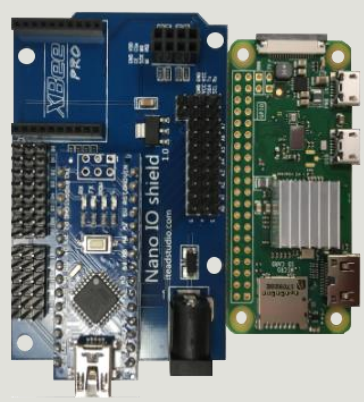
Mass Communication – Fleets of robots communicating with each other or other parts of the facility system to better improve efficiency.

[6] "Industry 4.0: A review on industrial automation and robotic" goes into further detail regarding impacts that complex robotic systems have had on German manufacturing as well as listing commercially available robots.

IoT/Data Analytics

Micro-controllers and micro-computers are far more cost efficient with the normalization of the Internet of Things (IoT) and general widespread popular appeal. The IoT is an open platform that has allowed the development of many widespread networking technologies. By simply reading sensor data and communicating that across the network, a vast collection of data can be gathered to improve overall system efficiency. Each subsection of the system can be connected via these micro-computer systems, allowing for far greater customization of the manufacturing process.

- Micro-controllers and micro-computers connect subsystems.
- Sensor data is collected and processed into usable information.
- Sensor data after being processed is either given to an operator to make an informed decision or utilized by the system to make its own decision.
- Through the collection and processing of large amounts of data, the system can be tuned to fit specific needs at specific times rather than operating at a maximum value.



Arduino (left) and Raspberry Pi Zero (right) are widely used open-source microcontrollers and microcomputers

The Kentucky Toyota facility utilizes Rockwell's smart software, which allows for real-time error corrections by connecting subsystems to a larger network. This implementation has minimized the production of waste with fewer reworks. [7]

A research group out of Madrid, Spain, referred to these IoT-based factories as "smart factories." The main benefit for these facilities is simply control where the entire system can be modified to meet the current needs. Specifically, HVAC systems can be integrated with production, power meters, and environmental controls to avoid operation at peak time and minimize unnecessary expenditures. [8]

[7] "How Will the Internet of Things Help Manufacturing?" is a magazine article detailing the discussions that occur during the Cisco's Internet of Thing World Forum in Barcelona. Many of the previously made statements are from CEO of Rockwell Automation Keith Nosbussch.
[8] "Smart Factories in Industry 4.0: A Review of the Concept and of Energy Management Approached in Production Based on the Internet of Things Paradigm" details how IoT, specifically, affects the operation of manufacturing facilities.

IoT/Data Analytics

Cloud Manufacturing, as detailed in [9], refers to more than a facility communication system, but rather entire manufacturing sites communicating with each other on a vast network. Having interconnected industrial sites allows for greater customization and allocation of resources. Specifically, the Tennessee Valley Authority utilizes live data collection from many energy generation facilities in order to properly allocate power to different areas at different times.[9]

Siemens, the largest industrial manufacturing company in Europe, has a few different software packages available in the area of integrated engineering. Their COMOS and PCS programs provide the user with a continuous data flow and "assimilate planning and operating environments." [10]

It is estimated that over the next 20 years, Smart Manufacturing could generate savings upward of 10 to 15 trillion dollars. Areas of significant potential savings are as follows: Steam, Process Heating, Compressed Air, Pumps, and Fans. These systems are high energy consuming but, with the correct control schemes, can be effectively be tuned. [11]

[9] "Cloud manufacturing: Strategic vision and state-of-the-art" elaborates on the largely unexplored field of cloud manufacturing.
[10] COMOS is a data platform intended for easy plant wide management.
[11] "Smart Manufacturing Technologies and Data Analytics for Improving Energy Efficiency in Industrial Energy Systems" presents simulations on various smart manufacturing methods in differing manufacturing environments.

Additive Manufacturing

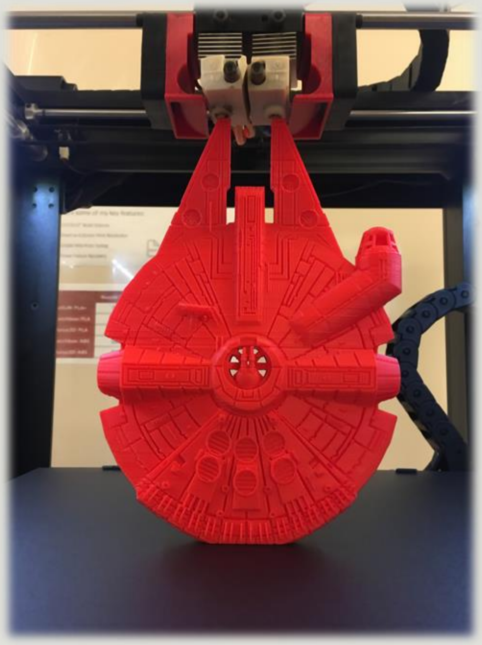
The Additive Manufacturing fabrication method, often called "rapid prototyping," is the depositing of polymers layer-by-layer to create a 3D part. 3D Printers are able to quickly produce complex physical models within a relatively short time, and the systems themselves are simpler and safer to operate than most traditional fabrication equipment.

Rapid Prototyping – Rather than creating a faulty part out of expensive material, manufacturing a simpler and quicker prototype in which to test can greatly minimize waste.

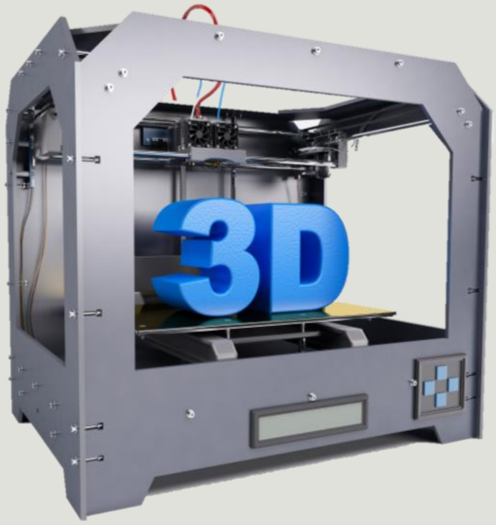
Cost Savings – The aforementioned waste can be costly in not only material expenses, but for some applications, it can save energy expenses. For high-energy applications such as forging or casting, printing a test model before the finished part provides many benefits.

Customization – The benefit of additive instead of subtractive manufacturing is being able to create previously unachievable shapes.

[12]



Metal 3D Printing – The field of metal 3D printing is new but offers more benefits for applications that require metal.



AM's main benefits are customization and waste reduction. However, it is worth noting that the energy consumption on traditional Fused Deposition Modeling 3D printers is greater than that of traditional methods. For prototyping, this energy difference can be easily compensated through waste reduction. This does mean that functional non-prototype parts are only valid, from an energy standpoint, in lightweight applications such as aerospace. [13]

[12] "Additive Manufacturing and Sustainability: An Exploratory Study of the Advantages and Challenges" explores the sustainability of additive manufacturing with an in-depth summary describing the advantages, challenges, and AM as a business model.

[13] "Environmental Impact of Additive Manufacturing Process: Does AM Contribute to a More Sustainable Way of Part Manufacturing?" details the energy consumed per unit mass to validate the energy efficiency of the AM process.

Augmented Reality

Augmented Reality, in manufacturing applications, introduces a layer of digital feedback to the user in which to convey more information. This form of information relay is most often utilized during assembly setup or maintenance operations, where an operator with minimal training can complete the necessary task with the assistance of a digital visualization.

- Simulation – Dangerous functional equipment can be simulated rather than operated during troubleshooting. This allows for faster turnover periods and improved safety.

- Real-Time Feedback – While the machine is running, live sensor data can be overlaid to assist a user in operating or troubleshooting the device with less required training.

- Digitized Workflow – Through the use of augmented reality, live data can be processed into operational data that will allow operators to "see" the manufacturing workflow.

It should be noted that Augmented Reality does not require the use of a head-mounted display. In fact, a feasibility study showed that HMDs were the least effective method of interaction. The most feasible method of interfacing was through a handheld device such as a tablet. This proved to be the simplest, cheapest, and lightest way for companies to adopt AR. [14]

The main benefit of Smart Manufacturing with AR is the natural interaction that the digital display affords the user. Opportunities that were previously not visible could be apparent when presented in a different manner. In a manufacturing setting, low training maintenance and preventative maintenance would be the major sources of energy savings. Data indicating that a system is not failing, but soon might, when overlaid with the device may reveal issues worth fixing.

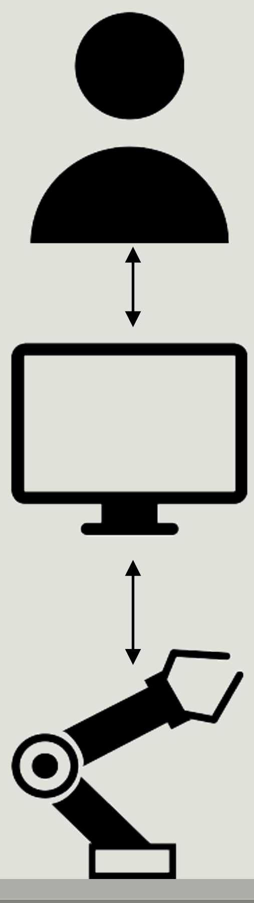
[14] In "Evaluating the Application of Augmented Reality Devices in Manufacturing from a Process Point of View: An AHP Based Model" an in-depth analysis was performed to determine the realistic challenges for adopting one of four Augmented Reality interface mediums.

Traditional vs. Smart Manufacturing

Traditional manufacturing primarily considers systems independent of one another and is built in a vertical fashion centering on the product line. Smart Manufacturing is built in a horizontal manner extending across the facility from business to maintenance.

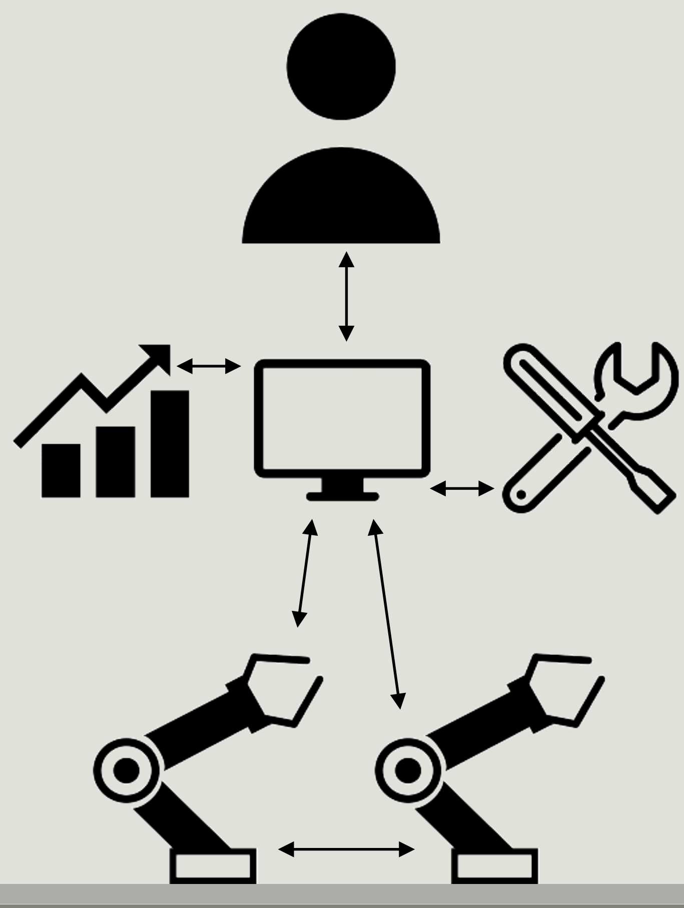
Traditional

- System is unaware of surroundings.
- Isolated optimized cells perform same task.
- Cells are unable to respond to dynamic changes in production.



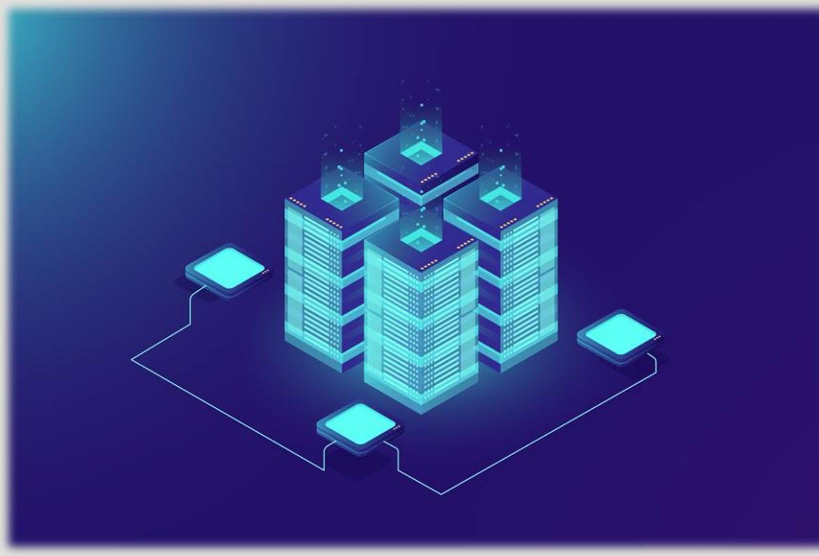
Smart Manufacturing

- Subsystems communicate with one another, allowing adaptive responses to changes in manufacturing.
- Communication networks can extend beyond the manufacturing floor to other departments to allow for greater flexibility.



Savings Realization

Data processing is a method of saving energy that relies on taking the data received and implementing it for an application. If the data suggests that there is potential savings in one department, but nothing is applied, then no savings will be made. Big Data Analytics requires software infrastructure as well as action.



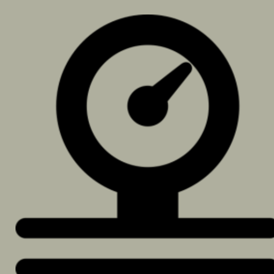
Toyota is a company that has found savings utilizing data processing in both its Kentucky and Alabama facilities. The software (Rockwell) that was used allows them to improve overall troubleshooting capabilities as well as operate more efficiently. Specifically, the location in Alabama sees a savings of approximately $550,000 per year from the implementation of smart processes. [7]

The Siemens COMOS program is an example of a data-processing software that allows for feedback into the system. [10] COMOS can show live data simulations of the operating facility and allow the user to make informed decisions. The software handles the processing and visualization so energy savings can be determined without skimming through spreadsheets. COMOS is not the only available software; Rockwell is another alternative that also provides the user with easier-to-interpret data. The more accessible data also allows for more seamless integration for potential savings.

Savings Realization

Smart Manufacturing savings are not limited to complicated technological devices such as robots. Oftentimes, the largest savings can come from older equipment such as pumps, furnaces, and HVAC systems. By simply adjusting the control scheme on older equipment, devices can be brought into the field of Smart Manufacturing.

Variable Frequency Drives (VFD) are a control system for motors that allows the operating speed to be dialed into any gradient state between on and off. Pump fans are often run at max speed and throttled to maintain system pressure. For most applications, this is a very inefficient method of operation, and simply installing a VFD can result in significant savings. A study in “Renewable and Sustainable Energy Reviews” showed that simply installing a VFD on the primary and transfer pumps resulted in a 500,000 kWh/month savings. The total savings from the test case was $860,000 simply by changing the control scheme.[15] The Industrial Assessment Center generally has a payback period of two to three years on large-throttled pumps. VFDs are a prime example as to how older equipment can be integrated into a smart system. By having the speed controlled based on system-wide data, the pump can be tuned to operate more effectively.



Conveyor systems are no longer an afterthought in the manufacturing process and need to have systems that allow smarter integration into the system as a whole. Traditional conveyors have been mechanical and pneumatic with little to no feedback. New systems make use of electric motors with feedback to track, sort, and adapt. On top of the "Smart systems," energy can be saved by utilizing this method as electric motors use far less energy than pneumatics and can be "tuned" for optimal efficiency. [16]

[15] “Applications of Variable Speed Drive (VSD) in Electrical Motors Energy Savings” expands on the savings potential that the VFD control method affords companies.

[16] “Industry 4.0 Drives Conveyor Technology: New Products Feature Flexibility and Energy Efficiency” discusses the process of machining and how Smart Manufacturing can be considered in all avenues of manufacturing.

Savings Realization

Through the use of Smart Manufacturing data processing, Kurtz Ersa, a forging company, was able to modernize and increase production. All foundry processes are centrally monitored, which allows the operator to make informed decisions to better manage the facility. Emissions and heat production are major concerns specifically for foundry applications. By utilizing smart processes, it is estimated that Kurtz Ersa was able to double productivity while increasing overall system efficiency. [17]

Kraussmaffei is a company that has developed a timer to inject ion molding machines. This timer coordinates the preheating time to the actuation, minimizing delay. This coordination considers factors outside of the isolated system such as other machines and the effect ambient temperature has on the preheating time. This simple timer device can result in an annual savings of $515 per machine. [18]

[17] "Smart Foundry - The Industry 4.0 Foundry" is a publication by the Kurtz Ersa company that explains how they implemented smart devices into foundry operations to operate more effectively.

[18] "New Energy Saving Production Timer is Industry 4.0 in Action, says Kraussmaffei Publication" discusses how the Kraussmaffei company developed a simple timer device in order to save energy.

Return on Investments

Energy Efficiency

After 1994, a non-profit government organization LEED (Leadership in Energy and Environmental Design) was initiated to encourage the development of energy-efficient buildings. This program classifies companies based on the environmental impact that the manufacturing process incurs.[19]

Volkswagen was the first automotive company in the world to achieve the Platinum certification. The upfront costs for these green facilities is greater; however, studies suggest an initial investment of 2% will yield over ten times the return over the life cycle of the build through reduced consumption.[20]

Smart Manufacturing is not a condition to achieve LEED accreditation. However, the greater efficiency afforded to the companies that utilize it will assist in the application process. Companies like Volkswagen have used LEED not only to boost public perception but also to minimize the operational overhead.

[19] "LEED certification update: Fourth quarter 2018" explains what LEED is and the various levels of certification. An alternative for more information would be the LEED website (www.usgbc.org).

[20] The study conducted in the "Green Building Costs and Financial Benefits" paper described the return that companies could see with more energy-efficient investments.

Return on Investments

Customization

Smart Manufacturing is utilized in the field of ship design due to the one-off nature of these products. They are specifically tailored to particular-use cases, and smart processes can reduce energy and material costs. Specifically through the use of computational integration, highly customized products can be manufactured more effectively by involving the customer in the overall design process. These smart control systems can provide feedback to the operators or the computer itself to allow for a "smart management system."[21]

The highly integrated Smart Manufacturing network lends itself to be effective for customized parts. Integrated communication within each subsystem allows for adaptive controls, opening up the door for tailor-made parts. [4]

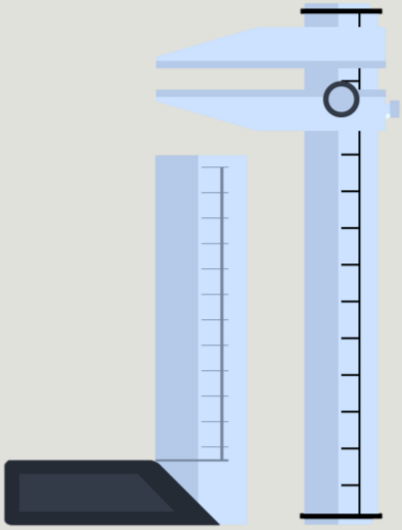
By involving the consumer or marketing department within the manufacturing framework, products can be produced to better fit the customer's needs while operating more efficiently.

[21] "Energy-Efficient Through-Life Smart Design, Manufacturing and Operation of Ships in an Industry 4.0 Environment" details how the involvement of Smart Manufacturing in one-off products can great improve overall product quality and efficiency.

Return on Investments

Superior Part Quality/Predictive Maintenance

The International Organization for Standardization sets the ISO part standards. With each new standard, manufacturing to tighter constraints becomes more of a challenge. It is suggested in [22] that the utilization of Smart Manufacturing techniques can achieve superior part quality. Smart Manufacturing acts as an enabler for many subsystems one of which is model-based methods. This approach to design enables 3D model-based engineering which is utilized to achieve the ISO standard.[22]



Data management systems like the aforementioned COMOS allow for tighter control over the work space.[10] With a large-enough dataset, predictive maintenance could be applied by analyzing varying levels of tolerancing during operation.

When exploring the concept of predictive maintenance, the increase in information is not limited to an isolated system. Like robotic systems, this concept results in the greatest savings when simultaneously implemented at the system and component level. It was found that the multi-level predictive maintenance system was able to operate with greater flexibility in applications of complex decision making, leading to significant savings.[23]

[22] “A Portrait of an ISO STEP Tolerancing Standard as an Enabler of Smart Manufacturing Systems” explores the ever-increasing complexity of part standards and discusses the use of Smart Manufacturing as a means for achieving future standards.

[23] “Multi-level predictive maintenance for multi-component systems” details a method of preventive maintenance as well as its importance in complex systems.

Conclusion

Smart Manufacturing is first and foremost an opportunity to better connect and operate the systems in which the facility needs in order to function. Through this superior connection, the overall plant-wide efficiency can be fine-tuned for minimum cost and maximum production. Utilizing the methods discussed here, manufacturing can be revitalized like it has been for the aforementioned companies.

Further Reading

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