Digital Transformation Value Indicators for a Sustainable and Circular Economy

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1 INTRODUCTION

Digital transformation is a megatrend in the manufacturing world. It is a caterpillar to butterfly journey that is focused on the application of digital technologies and the realignment of the organization to improve processes, resiliency and agility for the production floor.

Many companies over the past five years have been working to move their manufacturing organizations from a disconnected, paper based, operation to a connected factory floor through digital transformation. The journey begins by identifying the “pain points” of the operation, assessing current automation and IT infrastructure and planning to digitize data (paper-based data to digital data) and digitalize processes. The objective is to increase visibility and ultimately predictability for operations, equipment and material flow.

The quest for connected factories has evolved and it has become more apparent that not only does digital transformation improve business results, but it can also provide a path toward sustainability and lowering demand on resources and contribution to global climate change.

As resources have become increasingly more expensive, supply chains more dynamic and customers demanding for more environmentally manufactured goods there is an additional focus on many companies to incorporate sustainability and circular economy principles into their digital transformation strategies.

This article will explore the relationship between IoT systems, digital transformation and sustainability initiatives. It will also focus on the concepts of sustainability and circular economy that are delivered by smart factories and the impact that digital transformation plays in shaping value drivers and outcomes. Future articles will be shared on how smart operations (planning, logistics, product design and procurement) plays an important part in achieving greater sustainability and impact.

2 SUSTAINABILITY THROUGH DIGITAL TRANSFORMATION

2.1 ROLE OF DIGITAL TRANSFORMATION IN SUSTAINABILITY

To understand what part digital transformation and smart factories play in supporting sustainability, it is first best to identify the main digital capabilities and technologies that enable operational efficiency, agility and resiliency.

The Digital Transformation in Industry whitepaper [1] (section 2) published by the IIC in July 2020 has identified a number of key emerging and emergent technologies that underpin digital transformation in an industrial context. The diagram below illustrates some of these technologies and the vertical spaces that they impact, including manufacturing.

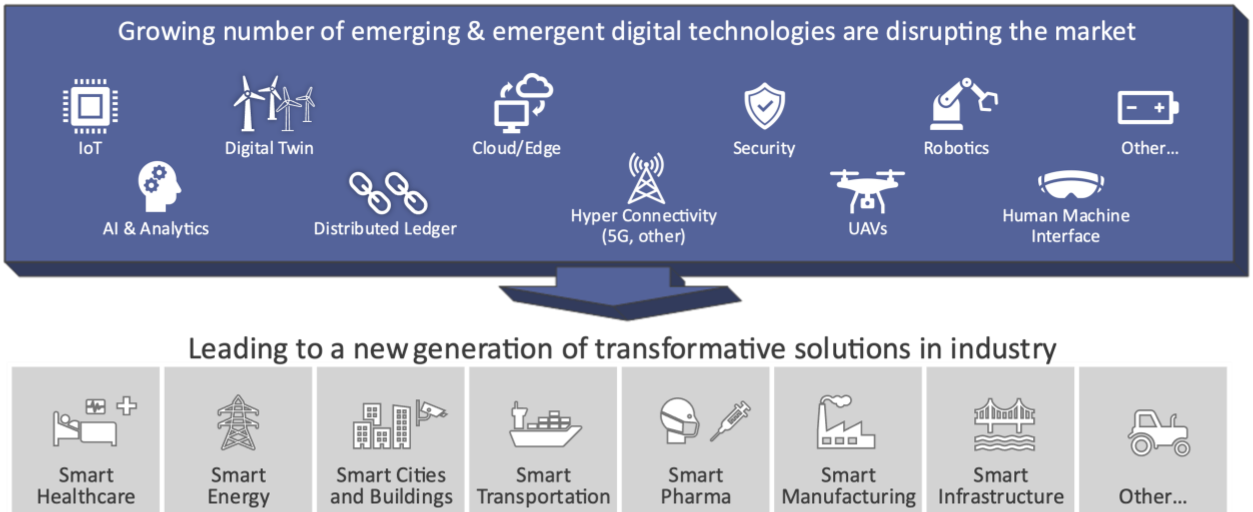

Figure 2-1: Emerging/emergent digital technologies leading to transformative solutions in industry. Source: IIC.

IoT and a number of other digital technologies play a key role in a wide range of transformative solutions in smart manufacturing, such as:

- Plant performance optimization
- Production quality assessment and control
- Asset condition monitoring
- Predictive maintenance
- Energy consumption optimization
- Environmental monitoring
- Goods condition monitoring during transportation

Several other articles and papers in the industry highlight a very similar set of technologies as enablers of digital transformation.

A white paper published by the International Organization for Standardization (ISO) Smart Manufacturing Committee (Aug. 2021) [2] took great strides and effort to identify current technologies and capabilities that are enablers and those that enhance digital transformation and manufacturing sites. Figure 2-2 shows a sampling of these technologies.

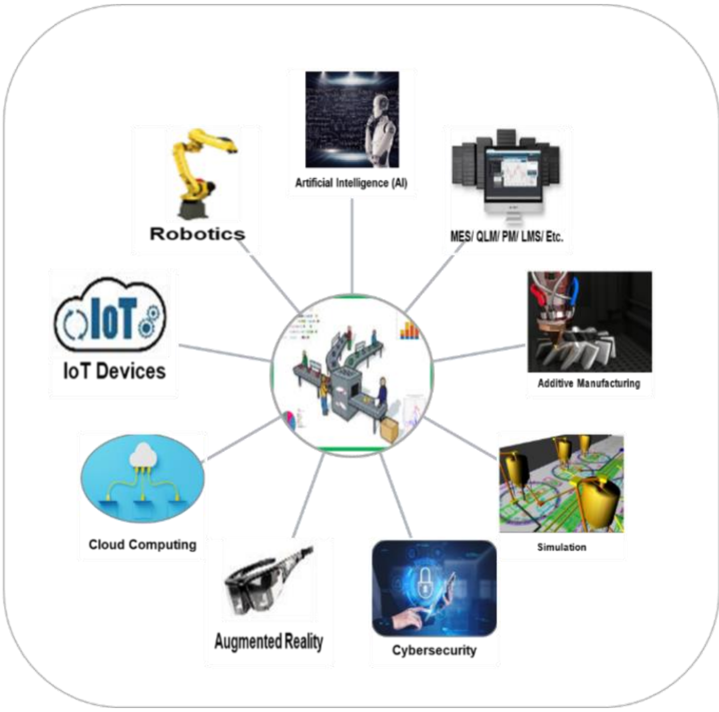

Figure 2-2: Enablers of digital transformation in smart manufacturing. Source: IIC.

Many organizations are adopting such technologies to transform manufacturing production systems from paper to digital and implement solutions such as predictive maintenance, asset performance management, process control, operator training and spare parts inventory reduction to name a few.

In addition to enabling digital transformation in manufacturing, here are a few examples of how IoT can have a direct impact on the efforts of manufacturers to reduce their carbon footprint:

Industrial automation-based process control: IoT can help reduce the carbon footprint by optimizing the manufacturing processes and reducing the energy consumption and waste generated by inefficient or faulty operations [3][4].

Quality control: IoT can help reduce the carbon footprint by detecting defects or anomalies in real-time and preventing defective products from being produced or shipped, which would otherwise require rework or disposal and consume more resources and energy [3][4].

Condition-based maintenance: IoT can help reduce the carbon footprint by monitoring equipment health and performance and scheduling maintenance based on actual condition rather than fixed intervals, which would avoid unnecessary or excessive maintenance activities that consume more resources and energy [3][4].

Smart metering: IoT can help reduce the carbon footprint by monitoring and managing energy consumption and costs across different machines, departments, or facilities, which would reduce waste and improve efficiency and enable better energy management [5][6].

Smart manufacturing execution system (MES): IoT can help reduce the carbon footprint by collecting and analyzing data from various sources such as machines, workers, or materials, which would improve production planning, scheduling, tracking, or reporting and enable better resource utilization and optimization [6][7].

An effective and well thought digital strategy and roadmap can bring valuable benefits and insights to reducing waste, increasing process visibility, decreasing cost, improving quality and building a more effective and efficient workforce. In this article we present two examples to illustrate how IoT systems combined with an effective digital transformation strategy and program can support and augment an organization's ability to achieve its sustainability goals.

This article will focus on one particular sustainability goal and measure which is the reduction of harmful greenhouse gases, namely CO_2 [8]. The majority of the carbon footprint calculations in this paper are based on the US Environmental Protection Agency [9] and the US Energy Information Administration [10].

2.1.1 IoT Devices and Asset Performance Management

The explosion of IoT devices and connected factory floor has provided many organizations with direct visibility to operations, equipment performance, process performance, equipment reliability and more. A good business and IoT strategy have proven and driven efficiency improvements as high as 20-30% in some cases and significant ROI savings.

However, as this technology has advanced many organizations have been aligning these projects with sustainability goals.

A simple example of how IoT devices impact a sustainability goal is to look at a typical three-phase, 20-HP motor operating 24 hours a day. Online sensors that monitor motor temperature and electrical power can detect when a motor is not running as efficiently and wasting energy. A 20-HP motor with a power unbalance between phases of 2.5% will result in a motor winding temperature increase of 12.5%. Correcting the power unbalance from 2.5% to a recommended 1.0% results in 1311 Kw/h savings equivalent to 0.57 Tons CO_2 per year [9]. The accumulative savings of CO_2 would greatly increase by the number of motors operating in a typical plant and motor horsepower.

However, an average factory in the US uses about 95.1 kWh of electricity per square foot annually with almost 70% of the power consumed by electrical motors [9]. Expanding the example case above to an average manufacturing plant could result in a reduction as high as 106,010 kWh or 45.9 Tons CO_2 per 100,000 square foot facility.

2.1.2 Simulation /Digital Twin

Adoption of simulation and digital twin has been increasing each year and across many industries since 2010. The advent and improvement in high performance computing and software has allowed many organizations to use simulation to advance and improve product designs (Finite

Element Analysis FEA), simulate, and improve process operations (Computational Fluid Dynamics - CFD and Discrete Element Models – DEM) and increasing manufacturing operations (Discrete Event Modeling). Many organizations have been able to demonstrate shorter product development times, design for manufacturability, increase in product quality and increase in equipment/workforce utilization.

An example, from a confidential company, illustrates how process operations can be improved using simulation and computational fluid dynamics (CFD) for industrial mixing operations. The simulation demonstrated that the manufacturing cycle time could be reduced between 15-20% per batch. The first reaction is cost savings, capacity constraint reduction and overall equipment effectiveness (OEE) increase. However, in this case, reducing the cycle time also provides additional benefit and helps achieve sustainability goals as well. In this case, the manufacturing site was able to save nearly 1000 hours of cycle time in one mixing vessel. This reduction in time saved 14,910 kWh, or 6.46 Tons CO_2 annually for this one operation alone.

2.1.3 Augmented Reality (AR)

Augmented Reality (AR) provides maintenance and training organizations with the opportunity to reduce equipment downtime, travel, improve operator effectiveness to troubleshoot and pinpoint equipment malfunction.

A situation where AR can play an integral part in decreasing energy consumption in addition to production downtime and overtime, vendor on site travel and support is around a typical packaging line (filling, capping, labeling, heat sealing, primary/secondary packaging and inspection systems).

Let's consider a hypothetical plant and packaging line located in Chicago. The filling equipment is not functioning as needed, reducing the fill speed and overall line efficiency (OEE) by 25%. The local engineering and maintenance team is not able to determine what the issue is and what part(s) are needed. The OEM manufacturer for the filling equipment is located in New Jersey.

In the past, the factory would contact the OEM vendor, arrange a site visit, while continuing to operate at the reduced line speed. This type of situation can historically take up to 2-3 days to resolve and in some instances longer. In this example, the line is running at a reduced efficiency (25%), requiring additional shifts and equipment operating time. If we assume his line uses between 200-250kW and the line requires three additional shifts (8 hours), the facility will consume an additional 4800-6000 kWh and will generate 0.97 Ton/kWh CO_2 [10] (4100-5300 Tons CO_2). Adding CO_2 impact from travel and onsite OEM support, approximately 1-2 Tons CO_2.

In this example, the OEM service technician guides the end user factory mechanic/electrician by means of smart glasses enabling "see what I see." The remote OEM technician provides verbal instructions through the audio of the smart glasses by means of the images transmitted, incorporating AR into a factory digital transformation as described:

- Reduces between 4000-5000 Tons of CO_2 per service incident
- Decreases the need for an OEM technician's travel
- Reduces the duration of sub-optimal line operation
- Eliminates additional labor costs
- Potentially avoids customer order fulfillment issues.

2.1.4 Additional Capabilities and Considerations

Other considerations and capabilities such as additive manufacturing can reduce dependence on spare parts and inventory reducing carbon footprint for conditioned storage space, shipping, manufacturing and packaging. Artificial Intelligence (AI) provides insight to operational efficiency that directly relates to reduction in energy, improved supply chain value streams, logistics and inventory control, and preventing the equipment from being brought down or working sub-optimally.

2.2 Challenges for Sustainability and Digital Transformation

As with many transformations and change in manufacturing, engineering teams are often asked to demonstrate how investments, some significant, can deliver the desired return-on-investment (ROI). This can be challenging at times as transformation and change requires investments that may not produce immediate benefits, but are foundational, to allow enablers as described above to function.

Many engineers and IT partners who have been tasked with transformation efforts have encountered automation and IT systems that are running on old operating systems, PLC controllers and communication protocols. Building enabling digital capabilities on top and access to data often requires long term financial planning and a digital transformation strategy and program that is scalable across the entire manufacturing footprint of an organization and not just a "unicorn" site project.

Antiquated or inefficient network designs negatively contribute to sustainability and carbon reduction. Two examples and impact are described here.

2.2.1 Cloud and Data Retention

First, the cloud and stored data comes at a cost. It is simple to assess the first and ongoing cost of storage ($/terabyte). As factories move through the digital transformation journey, process, equipment, safety and quality data is accessible from IoT, manufacturing production and ERP systems are being added at an amazingly fast pace.

However, before thinking, just collect everything, it is important to consider the process, equipment, or quality attribute of interest and what is required to measure, control, or predict the process. It is also important to understand that there are business, compliance and legal upsides and downsides to the retention of all IoT data. IoT data may have a business and compliance value that extends beyond the immediate operational needs of the manufacturing process and thus may need to be retained for a much longer period of time. On the other hand, unnecessarily retaining IoT beyond its compliance and useful lifecycle may represent a significant cost, legal and environmental burden.

Process, operations, quality, data scientists and other stakeholders must work together to ensure that IT/OT needs are effectively built around sound principles and process need versus taking all that which is available and then addressing what is important. This approach is not always in the forefront of thinking about data and cloud. The cloud is not without having some infrastructure, is finite (unless additional servers are added) and is costly to maintain.

As part of a digital transformation, consider the amount of data to be accumulated and stored on a typical packaging line per day and three shifts. Considering that a packaging line would consist of IoT sensors, vision systems and automation, an estimate would be that each packaging line collects nearly 1-2 Terabytes of data per day. Although in most cases not all data is stored or used, it would be more appropriate to estimate a total of 150-200 GB per day (35,000-50,000GB/yr./line).

This means that the environmental impact of each packaging line in terms of CO_2 created annually is approximately 66-110 Tons of CO_2 annually. In a recent publication in the Journal of Business [11], the authors note that approximately 30-40% of all data generated is not used and is considered as "Dark Data." An effective digital transformation plan and design using trained neural algorithms and data sets can reduce data needs by 30-40% in the example above, or approximately 19-44 Tons of CO_2 per year.

2.2.2 IoT Infrastructure

Second, when building the digital IT infrastructure to support the IoT devices and communications for the factory floor, consideration should be given to new technologies that can combine many necessary features (routers, firewalls, WAN devices, etc.)

Advancements are being made each day in IoT infrastructure that are superior to currently installed technologies in terms of impact and reducing carbon footprint. As part of the IT foundational assessment process of the digital transformation, consideration should be given to the obsolescence of current infrastructures, the amount of "black box" connections and framework that is required to connect current automation systems, local storage devices and IT systems, with new IoT and edge devices and communications infrastructure to manage and support. Employing an IT infrastructure strategy can avoid unnecessary complexity of operations and ongoing maintenance but can also support sustainability objects as fewer devices can reduce the amount of electrification needed.

Some recent examples of new technology have indicated reduced electricity consumption of 130 watts when compared to the average electricity use of a router, firewall and WAN accelerator. As an example, if a business used 3,500 networking devices to perform the functions previously performed by three devices, annual energy savings would be an estimated four million kWh, generating 2,200 metric tons of CO_2 emissions.

3 SETTING SUSTAINABILITY GOALS AND KEY PERFORMANCE METRICS

The challenge in setting sustainability goals within a digital transformation strategy is to understand the total cost of ownership as well as the carbon-burdens [12][13] related to the manufacturing, operation and data transmission (energy consumption), end-of-life disposal and future upgrades and replacements of the added IoT components. In section 2.1 of this article, the examples given provided ways of enhancing the ROI for the business, while also demonstrating the additional savings and measurable impact from CO_2 reduction. However, as with any project and implementation, total cost must play a decision in the way the technology is implemented. Taking into consideration costs such as data retention and cloud, plus design and infrastructure efficiencies can negatively offset the project ROI if not considered up front.

To achieve the above, a framework that organizes information and guides actions is needed. This article does not define such a framework, but it can list some of the elements:

- Assess the scope and objectives of the digital transformation initiative vis-à-vis the sustainability goals and associated political, economic, social, technological, regulatory, legal and environmental factors, Requirements should represent a clear understanding of manufacturing and business objectives and the part OPEX and lean play in identifying key pain points and how digital transformation and digital capabilities are defined and help accelerate from manual to automated, reactive to predictive.
- Identify the key stakeholders and their needs, expectations and interests.
- Establish specific, measurable, achievable, relevant, time-bound goals for both business outcomes and sustainability impacts.
- Develop a digital transformation roadmap (best options, best cost-benefit ratio) and an implementation plan.
- Monitor the progress (metrics),

To achieve these goals, the organization must implement innovative processes that will aid in developing strategies to overcome the challenges associated with IT/OT convergence in IoT systems, integrate business operations with digital transformation, reduce internal organizational and procedural frictions during the transformation journey, and expand the scope of the transformation initiative to incorporate sustainability goals. An upcoming IIC BIDX framework document will address these innovative transformation processes.

4 CONCLUSION

Digital Transformation and its benefits for solving ever increasing demands upon manufacturing to remain agile, resilient and efficient is well known, providing substantial savings and should be the goal of every industry. The ability to use digital transformation as a mechanism to achieve lower demands upon resources, recycling of resources, lowering carbon footprints and providing a better environment to our communities is just as important and built into the organization's strategy.

One last item to consider as part of a good transformation project is the people involved. Digital Transformation should include all functions, engineering, operations, quality, human resources, laboratory, IT, Environmental Health & Safety (Sustainability) and key external partners to assure the project will meet all objectives.

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