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Digital transformation in manufacturing industry – A comprehensive insight

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ABSTRACT

Digital disruption has upended the entire manufacturing industry across the world. Industry 4.0 has witnessed many opportunities from the advanced technologies to enhance efficiency in the existing manufacturing processes through automation, artificial intelligence and machine learning approaches. This article states the necessity of digital transformation (DX) in the manufacturing industry for improving quality and efficiency, reducing waste and cost reduction, adapting quickly to changes in the customer demands and market, and creating services and innovative products. The two most common types of DX in the manufacturing industry are process DX – digitizing the existing processes to improve the operational efficiency; product and service DX – creating new experiences and digital services for customers to improve customer satisfaction. This article also sets out to explore the challenges being faced by the manufacturing industry during the course of DX. The success factors of DX in the manufacturing industry could be associated with one of the three dimensions: organization, environment, and technology. The major steps for effective implementation of DX that a manufacturing company should consider are also discussed.

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1. Introduction

In the scenario of Industry 4.0, the volume of digital data being used is rising with enormous speed. The internet protocol traffic has reached 45,000 Gbps at global level in 2017 from about 100 Gb per day in 1992 and it is expected to reach 150,700 Gbps by 2022 [1] fuelled by many new users availing internet facility and by the growth of the internet of things (IoT). The covid-19 pandemic has issued a wakeup call to every-one including all kinds of industries. The serious societal disruption has led to the importance of disruptive organisational digital transformation simply called DT or DX [2]. Digital disruption has upended the entire manufacturing industry across the world. Thus DX has become a vital part of the stable growth of a company in recent periods. Industry 4.0 has witnessed many opportunities from the advanced technologies to enhance efficiency in the existing manufacturing processes through automation, artificial intelligence and machine learning approaches. Digital or smart factories are no longer fiction, but reality. Smart manufacturing has gained grip to increase effectiveness and efficiency in the existing manufacturing process and methods. Customers are now demanding quick delivery of quality products, while manufacturers endeavour to operate at minimal costs. Manufacturers are therefore trying to improve shop floor efficiency and need to look at factors such as availability and optimizing plant performance, minimizing maintenance costs and optimal utilization of resources. The attention is therefore shifted on increasing productivity and profitability with existing systems and infrastructure. DX facilitates the manufacturing industry to focus on reducing costs and improving operational efficiency; ensuring the quality of manufactured products; responding promptly to the changing market needs. Convergence of enhanced information technology and operational technology is also leading to the rise of intelligent factories using digital twins. Digital twins [3] serve as a significant element for implementing industrial autonomy initiatives to realize operation optimization and smart manufacturing, machine failure prediction and the reduction of process development lead time. Digital twins are considered as foundations of Industry 4.0 DX journey [4].

It has become important to pursue end to end DX inorder to realize objectives like improving quality and efficiency, reducing waste and costs, adapting quickly to changes in the customer

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demands and market, and creating services and innovative products. Mostly, DX in manufacturing unlocks many opportunities, including customization, efficiency, agility and automation. However, driving DX is not easy. While the benefits that DX offers are tremendous, there is no single approach to DX. Each industry journey is unique. Therefore, choosing a suitable DX technique that fits one's business is important. However, the following three guidelines will increase the chance of a successful initiative of DX; construct an initiative vision for the DX journey; create a holistic and realistic strategy; recognize the right industry expertise and collaborative partner required to bring in the change the industry needs.

DX in manufacturing means enhancing conventional manufacturing processes, products and workforce with digital technologies, such as automation, sensors, robots, artificial intelligence, IoT, eCommerce and more. However, any DX strategy should not lose track of changing times. The rapid technological development due to DX in the manufacturing industry leads to issues of its realization [5]. Every industry should always understand that DX should not be seen as a solution to any single area of manufacturing. Instead, it should be looked at as an on-going process of getting and staying at the top of the market. It is significant for the industries to learn what is essential for the successful realization of DX.

2. DX in manufacturing industry

DX is the need of the hour for any size of manufacturing industries. Companies must learn to be competitive and relevant in the new digital ecosystem. Fundamental advances such as cyber physical production systems, IoT [6], big data and cloud computing [7] and human–computer interaction constitute the principal technologies of DX in the manufacturing industry, heading to smart factories. With the support of innovative technologies and available massive data interfaces, machines can be entrenched in processes and stimulate the functions of machinery.

Shiwangi et al [8] explored the antecedents of DX and its influence on company performance in the manufacturing industry. They highlighted in their report, the six important antecedents, namely cognitive readiness, organization culture, organization mindfulness, competitive pressure, strategic alignment, and information technology (IT) readiness. Haijia et al [9] investigated a digital innovation model for the traditional manufacturing industry and the core measures adopted to promote intelligent manufacturing. In the age of the digital economy, old-fashioned manufacturing companies hinge on advanced technologies to improve themselves. They should actively incorporate themselves into the list of DX. Introduction of advanced technologies and technological innovations has been an approach that every manufacturing industry should undertake to ensure their survival in the competitive environment. Two digital technologies widely mentioned by many researchers while discussing DX are the digital ecosystem and the digital platform [10].

There are two most common types of DX in the manufacturing industry, namely process DX – digitizing the existing processes to improve the operational efficiency, and product and service DX – creating new experiences and digital services for customers to improve customer satisfaction. Choosing the one among these two to focus on is an important starting point for any manufacturing industry.

Process DX is critical for industries to choose between heritage paper based systems and digital systems. Without DX support, there are certainly inefficiencies, such as duplicative efforts, manual processes, etc. This results in restricted access to information for employees, impeding their productivity. In the process of process DX, first changing and enhancing general operational processes into digital work-flows can deliver instant results, such as unifying emails, calendars and messaging. Empowering employees more access to actionable information facilitates them to do their jobs more efficiently such as analytics driven decision support systems and digital field service processes. For example, advanced analytics paired with remote device monitoring can analyse a wide range of systems and predict when maintenance will be required before a machine fails and causes disruption. Digital is not just adding speed and a new level of reliability to the existing processes and systems; it also implies attaining more accurate, real-time information about the performance of the industry.

Product and service DX [11] is about using digital technologies to provide innovative services and experiences, which transform into new business and hence revenue potential. This involves the digitalization of entire product platforms and utilization of data driven services. Some manufacturers are providing these services for a while, but without the agility, speed and analytic capabilities which are offered by today's cloud computing technologies. Products of any kind are becoming gradually smart or computerized. Smart products are now built with a software platform that makes them more dynamic. For example, a smart power generator-set can examine historical data to learn when demand will be lower and reduce its fuel consumption automatically; a smart heating furnace automatically can identify when it requires maintenance and prompts to schedule a maintenance service time and date; a hydraulic pump can carry out real-time fault diagnosis of its operation to prevent breakdown and perilous conditions [12].

3. Challenges of DX in manufacturing industry

The Covid-19 pandemic has not only influenced both routine operations of companies dramatically, but also the initiatives and tasks of the DX of the company [13]. Despite the need of DX in manufacturing industry, there are some challenges [14,15] for the manufacturers to overcome which include:

Capital expenditure: Companies of any size tend to focus on return on investment (RoI) and the strategy for successful attainment of RoI is always different for different sized companies. Many companies combat the upfront cost, but the opportunity cost of not implementing DX may be greater or even disastrous. Using inexpensive cloud based software and worthwhile hardware; companies may work out incremental plans that focus on a critical area at the foremost such as idle time, with added plans to enrich the system as outcomes pay for them through improved production. Financial management lays down a wholesome foundation for the DX of any manufacturing industry. So while the current technology is updated, the financial management technology also needs to be integrated [16].

Skillsets: With the implementation of digital technology, the industries need less number of workers. However, they need workers with varied skill sets. Many manufacturing processes have been mechanized. Usage of machine sensors for collecting qualitative data has become quite normal in the manufacturing industry. Industries now require workers with top technology skill sets. They need workers who are capable in analytical skills and mathematics to use the innovative technologies effectively. The desire for trainable-workforce that was encompassed some time back is slowly dwindling as innovation has become more predominant. However, an advance in virtual reality coupled with augmented reality makes it effortless for the industries to train the workers on the job and cut down the training costs. Many industrial automation platforms commonly run with the technology of artificial intelligence and machine learning algorithms. Also, some of

the industries using digital twins in manufacturing and 3D printing require employees with new skill-sets which are in high demand.

IT issues: Expensive fibre optics, high-end servers and lengthy cable-runs must now let the cloud based technology [17] with different necessities. IT is also assigned with the major responsibility in transferring data, ensuring security and accessibility, and a horde of other responsibilities that are either unfamiliar or are conflicting to what industries have been doing customarily.

Data Security: One of the prerequisites in the successful execution of DX is the company's data security [18]. Since most of the systems used in industries enabled with DX, work on cloud based technology and depend on the internet. They use wireless or cellular connectivity and Ethernet systems to connect conventional machines to the shop floor. Though these IoT security challenges bear a threat, it can be moderated to lesser the risks of DX. With the growing number of cyber-attacks every day, cyber security becomes important in any company today [19]. With the highly technical risks of hacks, many industries are concerned if such an event could stop the entire manufacturing processes completely. In the case of a critical manufacturing industry such as a pharmaceutical company, these events could be life-threatening. Though these challenges are critical, security protocols are also increasing and will continue to care on stiffened security as implementation of DX speeds up over the period.

Corporate culture issues: All existing industries are already flooded with predominantly manual employees. Many innovative skills and training are necessary to be given to these manual employees to convert them into technology skilled employees. Many industries find it difficult to change the mind-set of existing employees for the change required to adapt to the new digital technology. A cultural change is important to facilitate an active manufacturing environment [20]. DX involves not only the installation of technologies but also requires the existing employees and organizations to change their mind-sets [21].

4. Critical success factors of digitalization in manufacturing industry

Customer expectations are the main drivers for the DX in the manufacturing industry and manufacturers cannot simply ignore them in their transformation initiatives. The success factors (SFs) of DX in the manufacturing industry could be associated with one of the three dimensions: organisation, environment and technology. These dimensions are the basics for the realization of DX. Organisation includes the factors: customer needs, autonomy, employee qualification, culture, management support, big-data use, and readiness for future while environment includes the factors: connectivity, transparency, collaboration, and standards. Eventually, the technology includes the factors: infrastructure, reliability, relevance, adaptability, security, completeness, availability, and real-time data.

The critical SFs can be separated into three groups in a conventional way; factors that are associated to the country level (political, economic and social issues), to the industry level (strengths and weaknesses) and to the company level (stakeholders) [22]. The drivers of DX in the manufacturing industry include: workplace improvement, process improvement, management support, vertical integration, horizontal integration, customer needs, cost reduction, innovation push, supply chain, market pressure, government regulations, and employee support.

The major steps the companies should consider for effective implementation of DX include:

Align technology and strategy: Adopting a holistic approach to technology and business strategy from the start is important, since it results in a huge difference in the cost of implementation, time-frame and results of a DX effort. In contrast, adopting a strategy independent of technology considerations poses needless risk. When a company is developing its business strategy without realizing the full potential of available advanced technology, it is common to see a huge gap between the technology and strategy. For example, a strategy may seem favourable, but may eventually not be fully realised if it is not aligned with the suitable technology. A cohesive approach that integrates both technology and strategy reduces the risk to the maximum possible extent [23] discuss in their model DIGITAL analysis, a conceptual understanding of criteria to learn where to apply digital technologies in a company involved in the process of DX to the greatest effect.

Choose an agile approach: Agility is another critical SF, since it eventually aids companies recognize more value from DX initiatives. Even if industrial experts are supporting the effective implementation of DX in the company, the result would be futile without agility. Instead, it is more meaningful to chalk out an overall policy at a macro level, and then fragment it into individual projects. This facilitates a dedicated initial scope that can be further expanded as adoption accelerates. Eventually, the success of DX depends on how process changes and technology functions under real manufacturing conditions. Therefore it is critical to emphasize on the initial project as a proof of concept to backing rapid learning. Using a proof of concept to demonstrate, refining objectives is a swift foundational approach that makes it promising to realize outcomes in a short time-frame and construct a road map further. It also offers the opening to augment the plan as required to build long term change. Capability maturity model originally developed by Carnegie Mellon University supports the company to carry out the gap analysis in the current DX capability and to develop a comprehensive roadmap for further improvement in a structured manner [24]. This model is used to refine the software development process once DX takes a shape in the industry.

Ensure relevance to your vertical: A strategy that reflects the industry vertical is vital for the DX process. Not all verticals have the same requirements when it comes to DX. For example, an aerospace industry may have specific challenges and opportunities, all of which may not be shared by other industry verticals. It is significant to be able to bring suitable expertise specific to the vertical to confirm that the company is taking benefit of all possible openings offered by DX. A vertical oriented approach will make the difference between transformation and a held up project. Irrespective of the kind of DX that the manufacturer is following, the likelihood of a successful initiative upswings when the manufacturer ponders holistically about technology and business strategy, applies a vertical specific approach.

5. Success stories of DX journey in manufacturing industry

DX has facilitated many manufacturing industries finding their competitive advantages in their niches. Implementing DX in the front-back office or on the shop floor improves the operational efficiencies of the industry and values to its customers during its product life cycle [25]. Following are a few success stories of DX journey in manufacturing industries showcasing how the companies have overcome their challenges in the operations and improved their efficiencies and thus customer satisfaction.

Saltworks, the largest salt manufacturer in the US, supplies artisan salts to food and beverage industries. The manufacturer initially had a challenge to manage the changing pricing schemes and rich content. After the company invested in costly add-ons to its eCommerce platform of OroCommerce, it could better meet over 80 % of Request for Proposal (RFP) of stakeholders. DX implementation in the back office of RFP enabled the company to

streamline the operations, save time and build customer satisfaction.

BAE Systems, the largest defence contractor in the UK, had a challenge in the assembly of complicated batteries in the manufacturing facility. The company was interested to use augmented reality (AR) technology to improve the speed in assembly operations with accuracy. The company purchased HoloLens smart glasses from Microsoft and used the software of Vuforia Studio, to convert the computer aided drawings and data obtained through internet of things, into training AR experiences to its production line workers. The designed software offered step-by-step instructions for correct assembly operations using colour codes. DX implemented in operations helped the workers assemble complex battery products and improved the speed and efficiency of battery assembly operations with minimum assembly errors. BAE systems adoption of AR could reduce assembly time by 50 % and training time to workers by over 50 %. Thus, the software solution supported the company to scale its operations.

ThyssenKrupp Materials Services, the largest material distributor in Germany wanted to use its data insights through algorithms in its operations such as optimizing its transportation costs, improving service levels, etc. However, it lacked the collection of right data, quality data, and the technology to store the data in proper format. The company introduced customized software 'Alfred', with the support of Microsoft's global Azure cloud platform. This self-learning data analytics solution provided recommendations on its stock levels, maintenance models, and best transport route to minimise shipping cost and time, allocation of materials to each industry, etc. DX in decision making processes facilitate the company improving its operational efficiency through simulation of the network setup at any given time for the given conditions.

Samuel Hubbard, the popular shoe manufacturer with its headquarters located in California, faced a challenge in automating its day-to-day operations to reduce the time spent in sending the competitive quotes to its prospective customers, generating leads, and engaging with customers. After the introduction of OroCommerce software in the front office, the company could better understand the customer journey, offer better customer support. DX of the company increased its sales of around $32,000 in B2B orders per month.

Titan Engineering and Automation Limited (TEAL), the leading assembly automation company in India, offers world class turnkey assembly and testing solutions in the area of transportation, consumer packaged goods, energy, etc. With the implementation of DX in its design operations, the company could make a considerable improvement in the delivery of its design solutions to its customers. Regardless of the complexity of the mechanical system, the back-front end software TEAL uses plays a vital role in achieving efficient operation and consistency in the manufacturing process.

6. Conclusion

DX and effective mechanisms of management can certainly provide for successful modernization of industry and for innovations. DX becomes an essential task inside any manufacturing company in today's exponential change towards digital technologies. Digital technologies, social networking, and cloud computing provide opportunities for integrating systems in manufacturing. This study has made remarkable contributions in the form of analysing key SFs in effecive implementation of DX in the manufacturing industry. It also explored the various challenges being faced by companies in the process of DX that is now receiving more attention from industry and academia. In the digital era, companies are enforced to refurbish policies and renovate their trade models through DX and achieve competitive leverage. This study also provides a complete plan of action for any manufacturing industry for effective attainment of DX.

Data availability

No data was used for the research described in the article.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Duraivelu K reports a relationship with SRM Institute of Science and Technology that includes: employment.

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