Industry 4.0 - Way Forward for Integrated Manufacturing

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Abstract

Developments in technology and understanding of how things work have revolutionized industry across many parts of the world. To the extent that the first machine—the steam engine—is all but obsolete now. Over three stages, three industrial revolutions have taken place, and we are at the beginning of the fourth, called Industry 4.0. This paper describes the overall scenarios that have come and gone in industry, how industry has sought to improve cost, quality, and speed by improving methods of production. "Integrated Manufacturing" and "Integrated Organizations" have been promoted by the likes of the Malcolm Baldrige performance excellence models, which have made many Fortune 500 organizations achieve the TBL (triple bottom line) objectives, which promote sustainability. The paper describes is some details the core concepts of an "integrated organization," and how IOT, AI, ML etc. will further drive "integration," so that the achievements of TBL objectives of companies will become faster and reach very high levels.

Introduction

Since the early 1800s industrial way of life has occupied the thoughts and energies of countries. Inventors, scientists, businessmen, and politicians have been involved in developing methods to promote industrial production whose primary purpose was to mass-produce goods so that they can reach larger and larger markets and consumers. In the process, an economy largely dependent on the wealth generated by such activities provided for the appearance of the "welfare state." Countries in the west led the creation of wealth through industry, and ensured that large parts of their population could improve their standards of living. Over the years, cost pressures, new technologies, new products together have created an enormous explosion in the types and numbers of goods produced, and the ways in which these have been put into the market. We have seen three "industrial revolutions" already, including the computer age, followed by the latest, "Industry 4.0" which is defining the new rules for integrated manufacturing. Together with Internet of Things, Artificial Intelligence, Machine Learning, and advancements in production technologies, the world is now at the cusp of the next "industrial revolution." This will create the "integrated manufacturing" units of tomorrow, which will provide a platform for sustainable development, which is the ultimate goal.

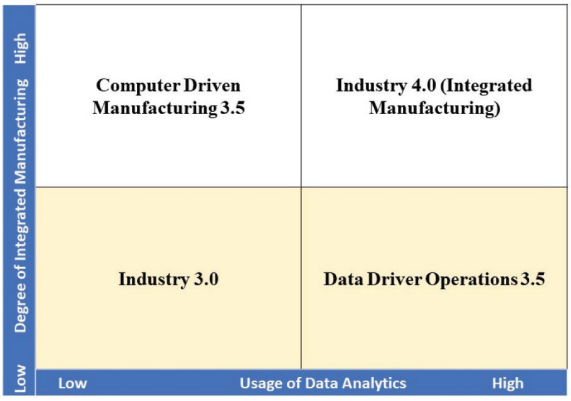
The four quadrants of progress

Industry 4.0 is arriving soon in India. The initial signs are beginning to blossom. Global industry has moved from 1.0 to 3.0 in about 250 years, and now, from 3.0 to 4.0 is set to happen. While Industry 1.0 lasted for about 150 years, Industry 2.0 lasted 70 years, and Industry 3.0 has lasted all of 50 years, till date. However, Industry 3.0 has already become Industry 3.5, due to the increasing role played by internet, cell phones, telecom interconnectivity, and data transmission and processing/analysis. Big Data and Data Analytics have started to shake the foundations of Industry 3.0, to advance it to Industry 3.5, and now, these and other progressives will propel us forward into the next era (see Figure 1).

Industry 3.0 was dominated by Information Technology (IT). While Industry 2.0 was the engineers delight, Industry 3.0 became the computer engineers fiefdom, with advancements in IT leading to growth, productivity, new products, improved market interactions, speedy feedbacks, all leading to the practice of "closed loop" manufacturing. Such an approach suited the Plan–Do–Check–Act (PDCA) methodology, which had come to dominate industrial thinking in this phase of industrial development. While PDCA became the backbone of competition, beginning 1950, after the solid foundational work done by Dr Deming, Dr Juran, Dr Ishikawa, Dr Crosby, Dr Shewhart, and others, it was the advent of Industry 3.0 in 1970s which gave a great push to "world class" manufacturing (see, for example, Artemis et al., 1990).

World class manufacturing

World class manufacturing was a terminology coined after the declaration of the Malcolm Baldrige model in 1987 (nist.gov/Baldrige). The idea was to create world class companies through the mechanism of business excellence, whose basic premise was to practice 11 core values. These core values were identified as: Visionary leadership, Customer-centered excellence, Valuing people, Organizational learning and agility, Focus on success, Managing for innovation, Management by fact, Societal contributions, Ethics and transparency,



(Source: Author)

Figure 1: Way Forward From Industry 3.0

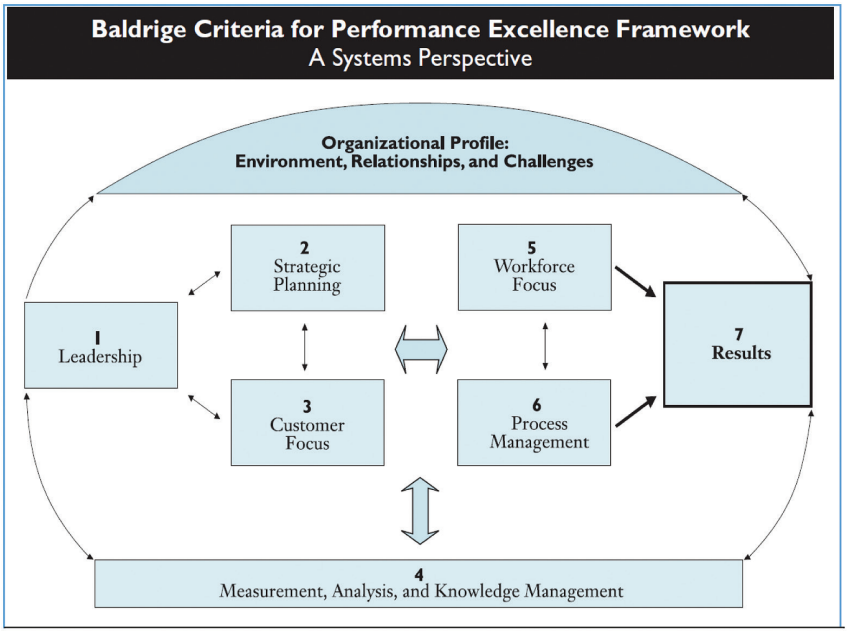


Figure 2: Framework for the Malcolm Baldrige Model for performance excellence

Systems perspective, Delivering value and results. Adopting these core values, companies were able to develop an "integrated organization" over time, which led to all round, holistic, responsive, and proactive excellence. Knowledge Management and Information and Analysis formed the foundation of the excellence model, as shown in Figure 2 below:

The measurement and analysis part was strengthened considerably with the advent of IT into the processes which governed the day-to-day management of companies. "Mass IT usage," signifying the extensive use of IT in all areas of work in an organization, led to speedy information transfer, quick analysis, more frequent, customized reports generation which then were used for decision making. The practice of the core values intensified due to the "Mass IT Usage," which, in turn, led to the creation of "Integrated Organizations." Such integrated organizations were responsive, efficient, proactive and functioned on the basis of well-defined methodologies as prescribed by ISO and other relevant systems standards. The pinnacle of the excellence movement was achieved through Industry 3.0 by around 2000 (see, for example, Muthuraman and Jayaraman, 2014)

Sometime in 1994, the triple bottom line (TBL) concept was enunciated, and, subsequently, criteria for evaluating how organizations addressed the TBL were included in the Baldrige Model. This inclusion increased the scope of work for creating "world class" organizations. Whereas, earlier, the intention to create world class organizations was limited to their economic activities, the TBL concept called for the creation of a socially responsible and environmentally friendly organization, in addition to their being successful in the economic marketplace. Addressing all three would lead to sustainability, both in economic and societal spheres. Thus, the TBL made possible truly holistic excellence in organizations, with the goal of sustainability being supreme. While organizations used Operations Strategies to achieve sustainable business competitiveness in the marketplace, the TBL put additional requirements on Operations Strategies to become holistic (R. Jayaraman, paper presented at a conference in Vishakhapatnam, 2019)

TBL, World class manufacturing, and Industry 4.0

While Industry 3.0 was adequate for creating economically successful organizations, the TBL demands put an additional strain on organizational profits and profitability. Costs incurred on CSR and environmental friendliness could not be recovered, partially or fully, from customers, who were already looking for better value propositions. Increasing prices was out of the question, and companies had to find new value propositions through other means. That's when Industry 4.0 was resorted to.

Since technology had become ubiquitous, and IT had gained wide usage, and experience gained, the next development was the learning of abilities to utilize the IT-generated data, information, and automation, to

improve company operations, in a systematic way, on a huge scale never imagined before. One of the first few companies to benefit from Industry 4.0 were the eCommerce organizations like Amazon, Flipkart, FedEx, UPS, and others, who used the internet and the worldwide webs to create a virtual marketplace. With heightened connectivity, with a 24*7 internet, the global village became a reality. Many companies could do 24*7 work using telecom-supported connectivity, software-driven networks, and newly developed software programs to process voluminous POS (Point of Sale) data, to aid decision making and profit making. As shown in Figure 1, there were two possible directions to move forward from Industry 3.0. One, use more IT through Artificial intelligence (AI), machine learning, automation, interconnected machine networks to greatly improve manufacturing efficiencies.

The improvement is achieved in many ways. AI controls can be pre-programmed, using algorithms developed through experiences and theoretical frameworks, thus becoming "intelligent controllers," many times replacing human interventions, and, which will "never make a mistake, never flag in performance rate, and make on-line, real-time corrections as needed, determined through feedback, to keep the output profiles constant." Such manufacturing systems make for low cost, high volume combinatories, very useful in competitive markets. AI enables connecting several machines to each other, thereby creating "intelligent networks," which can become self-driven factories. Human interventions can shift to other areas, such as, AI design, maintenance, developments, and continuous improvements. Designing "networked factories" will become a hallmark of Industry 4.0.

The other way is to go in for "data-driven operations," which essentially means that, capture data from various machines, from the marketplace, from vendors etc., and use data analytic tools to derive inferences and conclusions, and use them in the processes to obtain improvements and responsiveness. This method does not necessarily make use of networked machines, AI-driven equipment, which, at least to begin with, can involve long efforts and high costs. However, closed loop efficiencies can be achieved through data analytics, establishing appropriate connectivity, and then reprogramming the IT driving the machines. In single machine instances, or self-controlled devices, closed looping can be done without resort to AI. A sensor-controller mechanism should do the job, as is already being done by many climate control devices, such as, air conditioners.

In both of these alternatives, the Figure 1 shows that the next step would be "integrated manufacturing," which uses features from both the alternatives, AI-driven machines, and POS (Point of Sales) and other data-driven decisions, and algorithms to improve and integrate. Only such a combination will lead ultimately to a responsive and proactive TBL sustainable business. A description of what the "integrated manufacturing" could mean in future organizations is given in Jayaraman et al. (2018).

Big Data analytics and Industry 4.0

While data analytics was used in Industry 3.0, Big Data Analytics has changed the scenario. Higher data processing speeds, advancements in hardware like clouds, high storage devices, high-speed data transmission media like 4G, have enabled data crunchers to collect and analyze data like never before. Figure 3 shows the current scenario of the adoption of Big Data Analytics in industry.

Figure 3 clearly shows that, in the long term, high data analytics usage is the way forward, any other path will lead to "death." The "survive" quadrant is valid only in the short term. This is mainly because Big Data Analytics takes a different view of business, as opposed to the current,

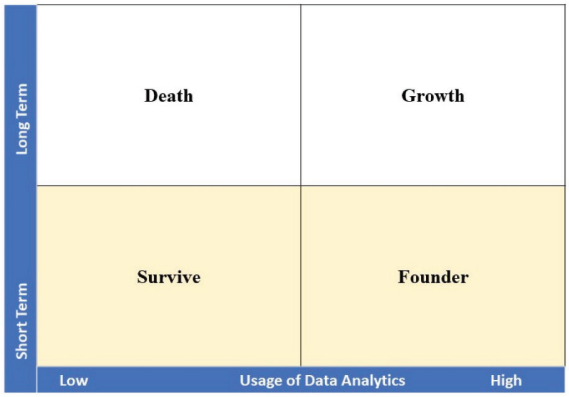


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Figure 3: The Big Data Analytics Imperative in Industry 4.0

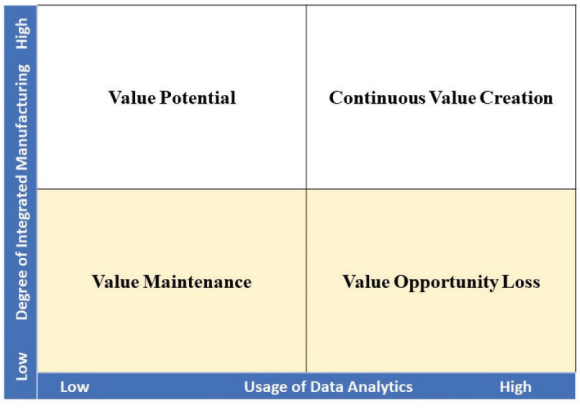

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Figure 4: Value Creation and Data Analytics

Industry 3.0 view. The word "integration" acquires a new meaning in Industry 4.0. The combination of several data capture points, speedy transmission of all such data, collation and analysis using powerful algorithms developed specifically for the purpose, AI-driven closed loop responsive machines, all make for a "mass customization" reality, which has been missing in Industry 3.0. In fact, many companies have tried and failed in their mass customization efforts using Industry 3.0 basis. Inadequate data collection, inadequacy of algorithms to analyze, lack of speedy transmission and, ultimately, a complete lack of a responsive networked machine structure to make use of the decisions from data analytic tools speedily and integrally, have made Industry 3.0 unsuitable for mass customization. However, the future will surely be driven by mass customization, and companies must respond to this demand.

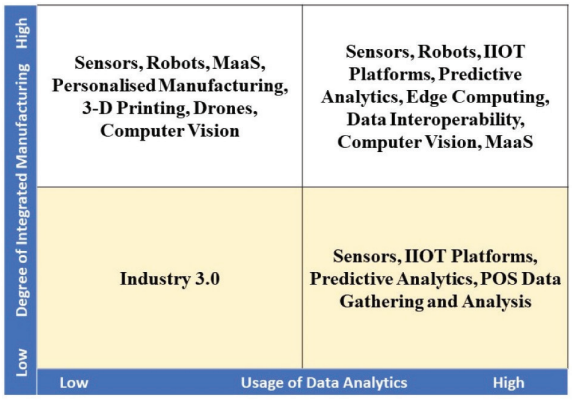

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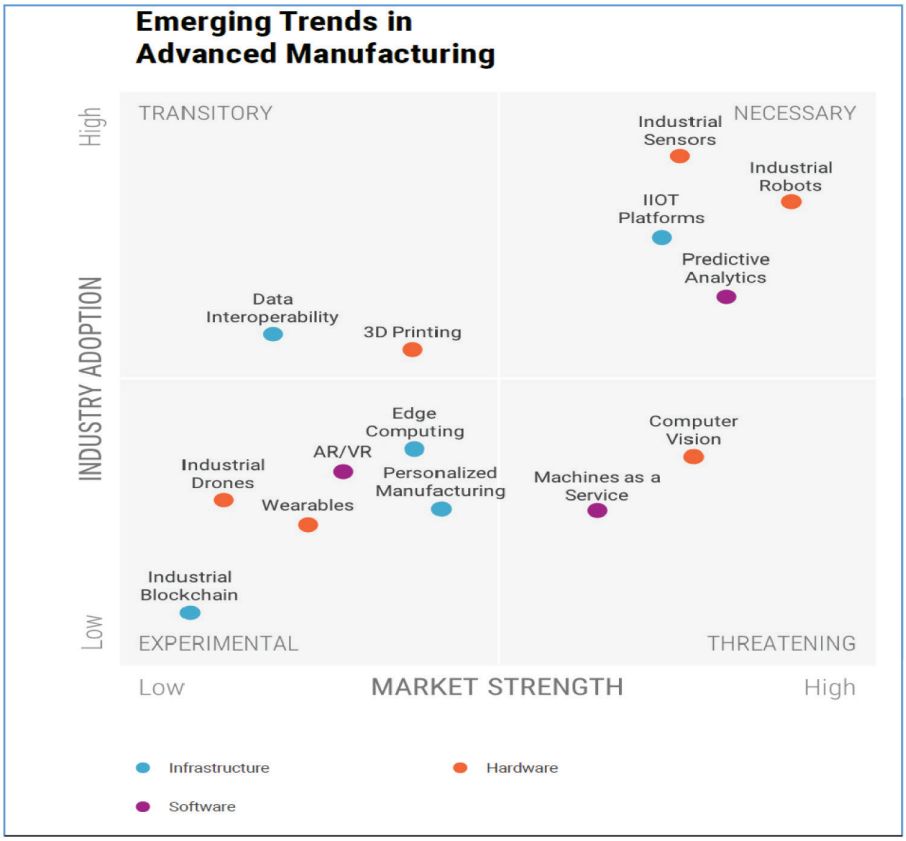
Figure 5: Data Analytics and Integrated Manufacturing

Integrated manufacturing, Big Data Analytics, and Industry 4.0

The ultimate goal of excellence in holistic manufacturing, is "integrated manufacturing." Such manufacturing is takt time-driven, responsive, self-adjusting, and able to meet mass customization needs. Right since inception of the Baldrige model, many companies have tried to create value using "integrated manufac-



(Source: https://www.cbinsights.com/) CB Insights (undated)

Figure 6: Emerging trends in Industry 4.0

turing," many achieved a good degree of success, but, as mentioned earlier, the TBL changed the goal post. Just like the Bharat I, Bharat II etc. series of specifications shift the goal post to drive auto companies to achieve higher and sustainability promoting standards, TBL has acted as a driver of continuous value creation, to achieve the objective of creating a livable planet. In India, many corporate houses have used the concept of TBL to drive down effluents, improve quality of air, serve communities, and contribute to social obligations. The government's introduction of the "Corporate Social Responsibility" tax (CSR tax) has enabled organizations to channelize their energies in a focused manner to achieve TBL and sustainability goals. Companies like Tata Steel already had a variety of CSR activities, like Tata Steel town (Jamshedpur), Tata Motors contributes actively to villages in and around Jamshedpur and Pune, NTPC and SAIL run several townships, TVS group, HCL, Infosys, and Wipro run foundations to conduct CSR activities. Apart from being economically profitable, these and other companies in India have also addressed the other two pillars of TBL also.

Industry 4.0 is poised to further contribute to this effort, and data analytics is a key pillar of Industry 4.0. Figure 4 shows that integrated manufacturing and data analytics go hand in hand, and, in case any one of them is deficient, value creation is hampered. Here, value creation is used in the sense of an organization delivering TBL compliant outputs.

Figure 5 also conveys the same theme, but with the addition of some of the details of data analytics.

Integrated manufacturing is the essence of Industry 4.0. TBL compliance can be achieved only through integrated manufacturing. Big Data Analytics (or Data Analytics) is a key piece in this scenario; it drives, and, in turn, is driven by the needs of integrated manufacturing. Already, considerable advancements have been made in both these areas. However, the gaps in AI, machine learning, IIOT, and development of new business models which can "carry the load of the TBL requirements" and still remain profitable, are evolving. The benefits due to the new developments in computer and related technologies will surely provide a channel for making Industry 4.0 happen. The current status is shown in Figure 6 below:

Conclusion

It is evident that Industry 4.0 will eventually be ushered in by all organizations, for several important reasons. One, the required technology elements are available and use of these will provide low-cost, large variety products in small batches to address mass-customized products. Second, the big data ability will enable organizations to collect and analyze information and data efficiently and usefully. Third, applications development will lead to apps, which can be directly downloaded without expensive R&D by individual organizations. Speed of new products introduction, larger variety, catering to individual customer likes and dislikes will become possible. Waste will reduce considerably due to the highly responsive equipment which will be controlled by high-speed computers linked through clouds. This will enable simultaneous manufacturing, zero-defect production, and tailored product and service regimes. All these developments which will be possible through integrated manufacturing foretell of a pleasanter way of life in the years ahead.

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Global Technology Governance Report 2021:

Harnessing Fourth Industrial Revolution Technologies in a COVID-19 World

An essential consideration for government, business and civil society is how technologies are harnessed and regulated to accelerate growth, encourage innovation and build resiliency in the wake of COVID-19. How governments and other stakeholders approach the governance of technologies will play an important role in how we reset society, the economy and the business environment.

This World Economic Forum (WEF) report examines some of the most important applications of Fourth Industrial Revolution technologies if we are to thrive in a post-pandemic world and the governance challenges that should be addressed for these technologies to reach their potential. The technology areas it focuses on are artificial intelligence, blockchain, internet of things, mobility and drones and unmanned air systems.

For more information, access:

http://www3.weforum.org/docs/WEF_Global_Technology_Governance_2020.pdf