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Impact of Industry 4.0 on Quality Management in Capital Energy Projects

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Abstract:

The Fourth Industrial Revolution (or Industry 4.0) is the present development of the digitized industry owing to information exchange and computerization. Digital transformation of businesses has become widespread among corporates over the past decade; however, the movement of adopting new technology platforms had not seen a major boost until the force majeure caused by the COVID-19 pandemic since early 2020.

With oil prices at record low and declining energy demand owing to the pandemic, the energy industry is currently facing its greatest challenge. Owing to these events, the need to navigate disruptions effectively and bring innovative thinking to the forefront have further accelerated, and quality management is not an exception in this transformation. Industry 4.0 empowers digital transformation of quality systems in many organizations and pushes toward eliminating traditional paper-based quality management system.

However, quality movement in capital energy projects has not picked up the pace, unlike other business sectors. While most literature summarizes Industry 4.0 in 12 technological areas, in this article the author aim to open a window for predicting how digitization can impact quality management in capital energy projects with the focus on six technologies:(a) artificial intelligence, machine learning, and big data; (b) block chain; (c) augmented reality or mixed reality;(d) remote visual inspection;(e) three-dimensional (3D)laser scanning and digital profiling; and (f) 3D printing.

Keywords: Industry 4.0,Quality 4.0,capital projects, energy industry, quality, quality management system

I. INTRODUCTION

The Fourth Industrial Revolution (or Industry 4.0) is the present development of the digitized industry owing to information exchange and computerization. Digital transformation of businesses has become widespread among corporates over the past decade. Industry 4.0 already empowers digital transformation of quality systems in many organizations and pushes toward eliminating traditional paper-based quality management system.

While most literature summarizes Industry 4.0 in 12 technological areas [Figure 1], in this study the author will discuss the potential impact of Industry 4.0 on quality management in capital energy projects with the focus on six technologies: artificial intelligence, machine learning, and big data; block chain; augmented reality or mixed reality; remote visual inspection; three-dimensional (3D) laser scanning and digital profiling; and 3D printing.

While these technologies are not unique to quality, this study attempts to provide energy industry with tools and insights required to start the quality transformation journey, or what is now known as Quality 4.0.

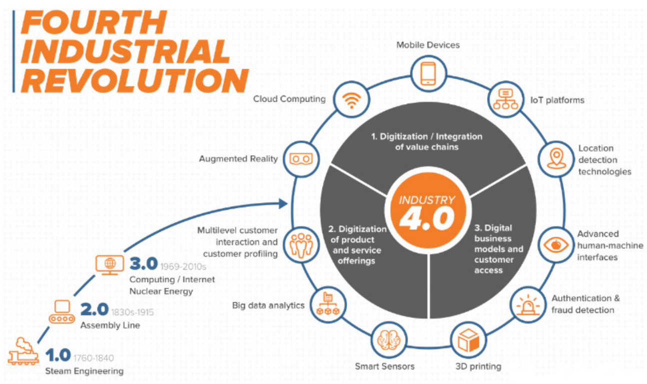

Figure 1: Industrial revolutions and 12 categories of Industry 4.0

A. *Big Data, Artificial Intelligence, and Machine Learning*

Big data is a term applied to data sets whose size or type is beyond the ability of traditional relational databases, and their purpose is to capture, manage, and process data with low latency using conventional computers. However, with enhanced communications via the ever-growing internet speed and inexpensive computational power (through cloud computing), combined with advances in real-time analysis, the impossible becomes possible.

Artificial intelligence (AI) refers to the quality or capability of a computer or a machine to mimic a level of intelligence of humans.

Machine learning (ML) is an application of AI that provides systems with the ability to learn and improve automatically from its experiences without being explicitly programmed. There is a strong connection between these three fields of technology, and organizations focusing on one of these usually somehow become involved in the other two. A recent survey [1] reported that 88% of respondents from the most data-driven companies said that “AI and ML are an important component of their data platform and analytics initiatives.” While the energy industry (traditionally oil and gas)has not adopted these technologies yet, early adopter industries, inspired by Industry 4.0, have reported growth of 10%–30% in the first few years [2].

In capital energy projects where hundreds of suppliers on global scale are involved, keeping pace with what is happening in the supply chain on a daily basis is a very difficult task. Quality-related problems that can be prevented are difficult to predict using conventional analytic methods. Energy projects can benefit from AI and ML to provide prediction, and therefore, preventive measures to ensure that costly quality-related issues and non-conformities can be avoided.

In a recent project, where the author was involved, a set of advanced data analytic tools were used to analyze past and recent performance of project suppliers, obtained from inspection and performance reports stored in a company’s database of previous projects and from its third-party inspection agencies. The analytics draw a risk profile for each vendor showing where could be the risk exposure. The analysis results helped in establishing a risk-based quality program where quality assurance and control resources are focused on hot spot areas. Hence most of the date was un- or semi-structured, manual sorting and classification of was used to avoid false interpretation.

In a recent study conducted by Boston Consulting Group (BCG), in partnership with ASQ and Deutsche Gesellschaft für Qualität (DGQ), to better understand technology's role in quality management transformation, more than 60% of the participants said that predictive analytics will significantly affect quality performance and the bottom line within five years, compared with only 16% who cite a significant impact today [3]. This shows how AI and other cutting-edge data analytic technologies will play a vital role in providing streamline data analytics and predicting quality performance in supply chains in the future. Various information sources, such as engineering reports, inspection reports, e-mails, progress reports, and minutes of meetings, will be scanned by data analytic algorithms powered by AI to identify emerging risks in a timely manner. Quality professionals will quickly find more prescriptive information that will enable them to make right and timely decisions.

Several other applications that are enabled by advanced data analytics, ML, and AI are currently under development, such as root cause analysis, material inspection and testing, asset management, preventive/predictive maintenance, and risk-based inspection. The potential of these applications is non-exhaustive with new applications are developed daily. These technologies will not only help improve quality, but will also help reduce the cost of poor quality and improve certainty of project time schedules.

B. Block chain

Block chain was originally developed to crypt transactions between two parties using computer systems to ensure security. The technology has been mainly adopted by financial institutions since 2008 and is growing rapidly, with the spread of crypto currencies such as Bit coin [4]. However, many other industries have started considering the block chain technology with some promising applications such as smart contracts. In quality, there are already some applications, in their early experimental phases, that use the block chain technology in the signing off and timely stamping acceptance of products between suppliers and purchasers. Similar to financial transactions, acceptance and release of products could be considered as block chain. Each step involving signing off and inspection of fabrication, or installation in the supply chain, are similar to a transaction in E-Ledger.

Some energy projects and EPC contractors whose supply chains include high-value “make-to-order” products have started developing digitized or Smart Inspection and Test Plan (S-ITP),which is based on the blockchain technology. Similar to traditional Inspection and Test Plans (ITPs), an S-ITP consists of blocks representing the stages of inspection and testing with associated procedures, acceptance criteria, certification requirements, etc. After each stage is completed and accepted by both the supplier and the purchaser, it is time stamped and registered in E-Ledger, which cannot be further modified. Sub sequently, the next stage of testing can continue; this ensures full transparency and traceability of materials and components. In the future, ITPs will be automated and secured using block chain technologies to enable reliable transactions and reduce the need for third party verification.

The other revolutionary aspect of the block chain technology is that distributed ledger technologies allow transparency, verification, and “immutability” without limiting a user’s options to a single central third party [5]. The immutable ledger ensures product quality by checking whether the suitable materials are blended with the appropriate manufacturing process. This is the development of the “outcome economy,” which is set to change plans of action for future business opportunities [6].

According to the Organization for Economic Co-operation and Development (OECD), counterfeiting market is estimated to account for up to 3.3% of world trade [7]. Thus, the use of distributed ledger based on the block chain ecosystem helps eliminate the risk of counterfeit and rogue materials slipping into the supply chain, assure traceability and ensure that only certified and authenticated materials are used.

Block chain has the potential to change the traditional testing, inspection, and certification (TIC) business. Energy and construction industries are now discovering the benefits of using this technology in an increasing number of applications. In the near future, we will witness a complete project completion management system that is based on the block chain ecosystem.

Advantages

- Secure and trustworthy platform
- Acceleration of transactions
- Cheap to adopt (i.e., large investment not required)
- Open technology (i.e., licensing not required)
- Already proved in several industries
- Less number of audits and inspections
- Opens the door for small businesses

Disadvantages

- Smart contracts or block chains possibly not yet recognized as legally binding by regulatory requirements in certain countries
- Lack of governance frameworks
- No existing standards to facilitate technical and data interoperability across various block chain technologies or implementations

C. Augmented Reality (AR) or Mixed Reality(MR)

The current literature does not strictly discriminate the two terms, augmented reality (AR) and mixed reality (MR) and uses them interchangeably. Unlike virtual reality (VR), which attempts to replace the user's physical world with a completely synthetic environment, AR attempts to preserve the user's awareness of the real environment by compositing the real world and virtual contents in a mixed 3D space [8].

Currently, AR spatially aware applications allow mapping and sharing of holographic content at real-world scale; meaning that you can position a virtual hologram over an actual object or location with high degree of accuracy. With the development of the AR technology, coupled with the use of AI and the power of cloud computing, accuracy will increase and enable real-time visualization of deviations in tolerances between actual product dimensions and the virtual or design model. MR technology is currently available in the form of handheld devices, such as tablets and mobile phones, or in more specialized technology with spatial mapping, such as MS Holo Lens® [9].

In a recent testing experiment where the author was involved, AR technology was used to overlay a 3D hologram or a digital twin of a 4.0 meters methane storage tank over the actual manufactured tank. In particular, the operator was able to visualize a deviation of 5.0 millimeters in an annular plate dimension, which has been confirmed through traditional measurements. However, AR technology took fracture of the time used by traditional measurement techniques to detect the deviation.

Future developments of AR technology, coupled with 3D laser scanning and AI-enabled applications, will result in a new generation of AR devices that can identify real time deviations, not only in dimensions, but also in physical properties and surface defects and coating breakdowns. This technology will enable operators and Quality Control personnel to detect and visualize deviations or defects during the development, installation and testing of products. AI can further identify various types of deviations and provide predictions on whether the properties are within or outside acceptable tolerances. Moreover, AR devices will be more ergonomic, wearable, and integrated with common equipment such as safety helmets.

D. Remote Video Inspection (RVI)

Remote video/visual inspection (RVI) has been in use for quite some time, either using basic tools (e.g., cellular telephones/smart phones) or specialized technologies (e.g., bore scopes, robots, or drones). RVI methods can be those techniques requiring the operator to carry the equipment or operate it from a distance, which allows an inspector positioned away from the visual inspection range to inspect the target area.

RVI is mainly utilized in the inspection of equipment with limited accessibility or when it is not safe for humans to carry out visual inspection the conventional way. With the COVID-19 pandemic, many companies were faced with very unusual situation where the normal in-person inspection of goods and products at vendor shops was no longer a safe option. Businesses have suffered immensely owing to social distancing, lockdowns, and curfews. Consequently, RVI emerged as the only practical option to maintain business continuity. However, most of the capital energy projects and their supply chain vendors were not ready for that, and they did not have proper infrastructure or technology to enable effective remote inspection. Companies who were skeptical about investing in RVI technologies have been desperately forced to do so.

Remote inspection with acceptable levels of video and sound clarity has to be established to enable successful inspection. Video tools that enable proper inspection, with quality similar to the naked eye, are not yet available everywhere. With 5G networks and IoT, technologies will further improve in the next decade, and remote inspection will be the standard, rather than the in-person. This will also help reduce travel cost and provide the opportunity for technical experts anywhere in the world to inspect products and resolve issues in more efficient ways.

RVI technology has been matured over the years in some industries such as ship building, where major classification societies, such as ABS and DNV-GL, are already embracing the so-called remote inspection techniques (RIT) for their class survey prosecution[10].The energy industry is lagging behind as most of the capital projects still rely on the more expensive in-person inspection.

Most of the industrial codes and standard sin energy industry are not explicitly accepting RVI. There is no current standards, guidelines or regulations embraced by regulatory bodies in many countries to standardize acceptable techniques and levels for remote inspection. Energy industries will take some time to come up with clear guidelines and minimum acceptable processes and technologies. This however, thanks to the impact caused by COVID-19, will be accelerated in the next few years.

Advantages

- Safer to access restricted, high-risk, and environmentally hazardous areas
- Cost effective (i.e., reduce travel costs)
- Time effective (i.e., instant feedback–real-time or near-real-time results)
- Environment friendly (i.e., reduce carbon footprint because of a low travel frequency)
- Real-time collaboration
- Can maintain inspection trail video recording of inspection results

Disadvantages

- Require pre-investment in remote video technology and data management
- May require a highly trained operator
- May have issues related to privacy and IP wrights
- May not be useful for complex inspections or testing

E. Digital and laser profiling

Lately, three-dimensional (3D) laser scanning (also known as LiDAR) and digital imaging technology have increased the importance of digital photogramme try technology and took it to a new height in industrial applications. Within the field of 3D object scanning, LiDAR combines controlled steering of laser beams with a laser rangefinder. By taking a distance measurement at every direction, the scanner rapidly captures the surface shape of objects, buildings, and landscapes. Construction of a full 3D model involves combining multiple surface models obtained from different viewing angles or the admixing of other known constraints.

A 3D scanner is any device that collects 3D coordinates of a given region of an object surface automatically and in a systematic pattern at a high rate (hundreds or thousands of points per second), achieving the results (i.e., 3D coordinates) in (or near-) real time. The result is a collection of XYZ co-ordinates in a 3D co-ordinate system called the point cloud. It may also include additional information, such as color and reflectivity values. Since its inception in the 1960s, the LiDAR technology has been evolving over the years, and now it has become the common method for calculating accurate geospatial measurements. Contrary to traditional metrology where operators' skill and experience and equipment accuracy are critical to quality of the measurements, LiDAR technology enables more accurate measurement in a fraction of the time taken by traditional metrology techniques. The potential of LiDAR technology is realized in scanning of complex equipment which may take long time, effort and cost to measure using conventional metrological techniques, and yet not all dimensions and profiles can be measured.

LiDAR allows the manufacturer and the purchaser to check the dimensions and compare it to the design model during various stages of fabrication, whether the actual equipment is rotated or the LiDAR equipment moves (or flies) around the equipment. The output of the laser scan will be an actual 3D representation of the dimensions and features of the part being measured in the so-called "point cloud." The 3D point cloud can be superimposed over or compared to the 3D computer-aided design (CAD) model so that deviations can be easily identified with very high degree of accuracy.

Current software can produce different types of analytical reports such as colored graphs or detailed dimensional report (see, for example,http://www.laserdesign.com/wp-content/uploads/2015/04/vintage-gas-pump-inspection_article.pdf) [11]. In capital energy projects where, modern plants are designed and built on modular basis, dimensional control plays an essential role in ensuring that all parts and pieces fit together without any deviation when they are finally assembled. Small deviations can be very costly.

With the development in laser scanning technology, drones, and IoT, laser scanning devices have become more versatile and portable and probably can be even worn. With an algorithm based on machine learning and data analytics software, laser scanning technology will become more powerful for identifying small deviations, not only in dimensions, but also in material properties and surface defects. 3D scans of various components can be stitched together to ultimately become the as-built digital twin of the asset.

Although 3D laser scanning is already in use in energy projects with mega module design,going forward, 3D laser scan will play a significant role on verifying dimensions and surface profile at component level, and at various stages of development. This shift in quality control will have a significant impact on reducing modification costs when defects or misalignments are only discovered at the later stage during project development.

F. 3D printing

3D printing technologies allow for the production of unique parts and products, which cannot be achieved or may take a long time to achieve and have high production cost, using conventional manufacturing technologies. In the past decade, metal and additive 3D printers have changed the perspective of manufacturing.

3D printers can now produce everything from engine parts to foodstuffs to living cells. The 3D printing technology has the potential to disrupt not only the traditional supply chain cycles, but also the way we design products, especially those of complex shapes. Further, this technology enables the improvement efficiency by reducing the lead time traditionally taken for developing products.

In addition, the 3D printing technology can also have a significant impact on quality assurance and control. Complex equipment used in energy projects, such as heat exchangers, or complex parts in turbines, gas compressors, and pumps can now be printed using 3D printing technology. This not only reduces the delivery time but also improves the quality of the equipment as online monitoring of 3D production ensures better integrity, and material properties and tolerances. The technology will help in further improving complex products by eliminating joints, welds, and hence, wear and tear. Additionally, Quality Control can be optimized to ensure the integrity of a product from one layer to the next. The need for sampling plans drawn from production runs can be eliminated because each unit will be equally quality assured.

Advantages

- Reduces costs especially for unique and complex products
- Improves QA and QC
- Improves innovation
- Reduces lead time

Disadvantages

- Concerns regarding product liability and intellectual property
- Data security and policies
- Not suitable for all types of metals

II. CONCLUSION

The challenges brought about by Industry 4.0 are not in technology, but in systems and integration. New technologies are connected to one another in that they all require and build on the digital capabilities and overall strategy. The energy industry needs to examine digital transformations in a strategic way with plans on long- and short-term investment in infrastructures that enable this transformation. Hence, energy companies that cannot reform their vertically oriented, siloed organizational structures are likely to become increasingly uncompetitive.

Quality function in capital energy projects does not differ from this digital transformation. If these technologies are not yet available today on your disk, they are probably in your backyard. Further, the role of quality professionals in the future will be closer to data scientists, rather than inspectors. Foundational quality and inspection will still be required, but will be blended and automated within the overall digitization strategy empowered by Industry 4.0. Any set of skills required for quality professionals in the past and the present will not be sufficient in the future. Companies need to invest in training and development of their quality teams to learn how to leverage technologies to solve quality problems and drive improvement. Quality leaders will need to be more innovative and creative. Success of quality leaders in the future will lie in being able to communicate, share, and use information to solve complex problems, adapt and innovate in response to new demands and changing circumstances, marshal and expand the power of technology to create new knowledge and expand human capacity and productivity [12]. Exceptional skills will be required to lead people in collaborative and innovative business processes. The most important skills for quality management leaders in five years will be communication, change management, and strategic and long-term planning.

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