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Quality insight: application of DEJI systems model for quality assurance in Industry 4.0

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Abstract: Industry 4.0 is now sweeping through business and industry. It is expected that other enterprises, including government, academia, and the military will be adopting and leveraging Industry 4.0 in the coming years. It is, thus, essential that product quality assurance under Industry 4.0 be fully understood. This paper adds to the growing knowledge base of Industry 4.0 tools and techniques. The specific methodology of the paper focuses on using the systems approach of DEJI systems model in coordination with other project implementation techniques to expatiate the efficacy of Industry 4.0 as well as quality 4.0 in diverse enterprises.

Keywords: DEJI; systems model; quality assurance; Industry 4.0, process improvement; quality standards; quality 4.0; triple C model; quality communication; quality cooperation; quality coordination; systems integration.

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1 Introduction

Industry 4.0 is simply the fourth industrial revolution. The common catch phrase for it is Industry 4.0. Sometimes, it is referred to as 4IR. The fundamental characteristics of Industry 4.0 is that it leverages rapid changes in technologies, design of industries, utilisation of digital tools, technical innovation, societal preferences, and creative workforce development. Essentially, Industry 4.0 centres on the three ingredients of an organisation:

- people
- technology
- process

How these three elements interface, interact, and interconnect in a global environment is what determines the efficacy of Industry 4.0. Since many of the pieces of these elements are already available in the nooks and corners of many organisations, albeit in often disjointed fashion, an overarching systems-based linkage is required. It is through systems thinking and implementation that the society can fully realise the benefits of Industry 4.0, which is a feature of a 21st-century operation. Although the moniker of Industry 4.0 is new, the underlying ideas are not new. The tools and techniques are just becoming more digitally based and integrated, from a systems framework.

The Fourth Industrial Revolution was introduced officially in 2015 by a team of scientists charged with developing a high-tech strategy for the German government (Schwab, 2017). It has since spread widely and fast through various international fora (Bai et al., 2020; Philbeck and Davis, 2018), including the world economic forum (WEF). Quality 4.0 is a direct natural outgrowth of Industry 4.0. Using a systems framework can help bridge the talent gap in digital operations, particularly where data barriers exist.

1.1 What is quality assurance?

The various definitions of quality are well understood and practiced in industry. Terms such as quality management, quality planning, and quality control are well grounded in how product quality is addressed in industry. By extension, quality assurance (QA) refers to the maintenance of a desired level of quality in a product, service, or organisational result. This requires paying attention to every stage of the production process, ranging from raw material integrity to the attributes of the delivered output. In this regard, a comprehensive systems approach can help identify all the elements within all the stages of the product process. In essence, QA focuses on ways, techniques, and tools for preventing mistakes and defects in outputs. QA is an essential part of the broad pursuit of quality management, designed to increase the confidence that quality requirements will be fulfilled for each product. It should be noted that error detection under QA precedes error detection at the quality control stage. QA focuses on quality parameters earlier in the process. For this reason, a systems tool that addresses the incipient design of the product environment is useful for preventing down-the-line errors later on in the product process. One such systems tool is the DEJI Systems Model®, which is a trademarked structure for doing design, evaluation, justification, and integration (Badiru, 2012, 2019).

2 Evolution of phases of industry

Because Industry 4.0 represents the fourth industrial revolution, it is important to touch on the preceding industrial revolutions as summarised in Table 1. As can be seen in the Table, industry has evolved and advanced consistently over the centuries (Badiru, 2014).

This matches the characteristic commitment of the discipline of industrial engineering, which is defined as follows:

Table 1 From the first industrial revolution to the fourth industrial revolution

Evolution of Industry 4.0	*Industrial revolutions*			
	First industry revolution	*Second industry revolution*	*Third industry revolution*	*Fourth industry revolution (Industry 4.0)*
Description and characteristics	The first industrial revolution emerged in Britain in the late 18th century. It facilitated mass production by using water flow and steam power instead of solely human and animal power. Finished goods were built with machines rather than manually.	The second industrial revolution evolved in the 19th century. It introduced assembly lines and the use of oil, natural gas, and electricity. The new sources of power sources, combined with new communications tools (e.g., telephone and telegraph) facilitated the expansion of mass production. Rudimentary automation in manufacturing processes started in this era.	The third industrial revolution started in the middle of the 20th century. It introduced the first generation of computers, advanced telecommunications, and data analysis to manufacturing processes. With computerisation, the digitisation of manufacturing processes started with the embedment of programmable logic controllers (PLCs) into machinery. Thus, helping to automate machine functions. Data collection and sharing became possible and widespread.	The fourth industrial revolution, christened Industry 4.0, is characterised by increasing automation and the use of smart machines and factories. Data collection and analytics guide more efficient, effective, flexible, and productive production of products. Value chain became an item of interest. Manufacturers can more readily meet customised market demands rapidly. Mass customisation emerged. Data manipulations facilitated the advancement of artificial intelligence (AI), robotics, smart factories, and internet of things (IoT). Rapid and adaptive decision making became commonplace.

2.1 *Industrial engineering*

The profession concerned with the design, installation, and improvement of integrated systems of people, materials, information, equipment, and energy by drawing upon specialised knowledge and skills in the mathematical, physical, and social sciences, together with the principles and methods of engineering analysis and design to specify, predict, and evaluate the results to be obtained from such systems.

3 Digital basis for Industry 4.0

What distinguishes Industry 4.0 from the preceding industrial revolutions is the digital environment in which modern industries operate. Of particular benefit is the emergence of AI as the driver for improving the design and integration of modern production systems. With digital platforms, the development of smart industries is possible. With data comes more opportunities to improve operations. Industrial revolution is predicated on the availability of new radical disruptive technologies that change the course of industry. For example, the introduction of steam engine revolutionised transportation in the 1800s. At the turn of the century, innovations in assemble lines facilitated mass-production setups that increased a manufacturer's ability to satisfy the growing demands for various consumer products. The emergence of computers rapidly changed the work environment for better. Each industrial revolution is ushered in by successive technological developments. Efficiency, effectiveness, and productivity improved rapidly as the society shifts from one industrial revolution to the next. In the present era of Industry 4.0, the primary drivers are cantered on digital platforms. Some of such examples are IoT, cyber-physical systems, autonomous systems, robotics, data analytics, cloud computing, virtual reality, smart supply chains, and metaverse systems. Digital transformation propels organisations onto the platform of Industry 4.0. With the diverse, but cooperating digital tools, it becomes even more crucial to have a systems-based approach to integrating the elements operating under Industry 4.0. This is where DEJI Systems Model comes into play.

4 Application of DEJI systems model

In all of the foregoing discussions, product is of the essence. Product, in this sense, can be composed of physical products, service outputs, or organisational results. Therein lies the need for a systems approach. The trademarked DEJI systems model® presents the structured steps to achieving the intended output through an explicit integration process (Badiru, 2012, 2019). The structured steps are:

4.1 Design

The design of the product, process, or organisational infrastructure. Design does not have to be limited to the conventional physical design of a product. Design can cover a variety of organisational desires and objectives, which may include both hard and soft areas of pursuit.

4.2 Evaluation

The rigorous evaluation of the design with respect to the prevailing attributes of interest.

4.3 Justification

The explicit assessment to justify the design for operational implementation. Not all well-designed and successfully evaluated products are suitable and justified for real-world implementation.

4.4 Integration

The rigorous commitment to align the product to the prevailing operating environment, considering the inherent limitation, preferences, and nuances of the people, tools, and processes that exist in the system.

Figure 1 Sample kernels of DEJI systems model® for Industry 4.0

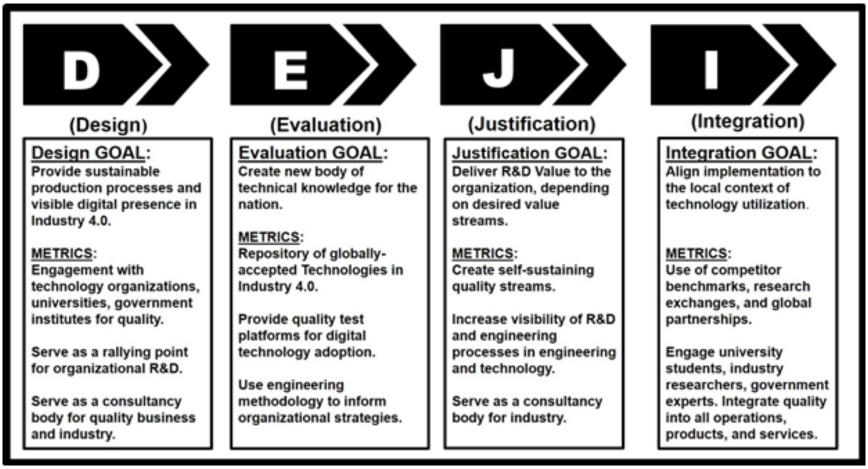
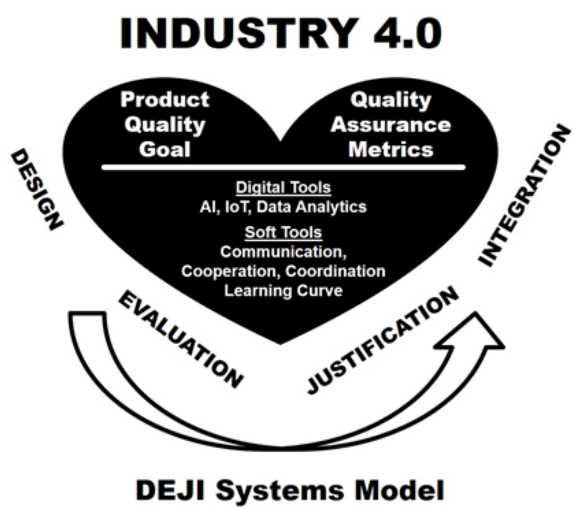


Figure 2 Industry 4.0 elements within DEJI systems model



A missed aligned is often the reason many organisational efforts falter and fail. The essence of using the DEJI systems model is that it encourages and forces an organisation to follow a structured path to the eventual desired outcome. The kernel of the model is captured in its operational framework presented in Figure 1. With this systematic approach, all the existing industrial process improvement tools and techniques can be brought to bear on the outputs of Industry 4.0 as illustrated in Figure 2, in which each organisation can determine and embed the prevailing and pertinent factors, attributes, and indicators. In other words, DEJI systems model can be customised to each organisation's specific needs.

Digital technologies are positively impacting operations. This will become even more pronounced in the future, in a post-pandemic era. Due to Covid-19 lockdowns, companies have been forced to discover the power of digital operations. There is now remote work revolution, which can enhance the ideals of Industry 4.0. Work designs of the future must take into account how digital and conventional processes interface (Badiru and Bommer, 2017). Some of the elements to pay attention to in the digital platform of Industry 4.0 are:

- cybersecurity
- efficacy of autonomous robots
- augmented reality
- big data and data analytics
- direct digital manufacturing (aka additive manufacturing, 3D printing)
- cloud operations
- software designed for integration

5 Soft and hard elements of Industry 4.0

A case study presented at IEOM 2021 – Mexico (IEOM 2021) reveals that over 65% of international companies surveyed report that soft skills are the number one impediment for implementing and sustaining quality 4.0 under the broad pursuit of Industry 4.0. Many of the soft and hard elements to make Industry 4.0 successful and sustainable are available in the existing literature (Agustiady and Badiru, 2013; Badiru and Bommer, 2017; Badiru, 2008). Even in a digital world, human communication is still very essential. Using the triple C model, Badiru (2008) lays out the process of effecting communication to facilitate cooperation, which is essential for the coordination of human efforts. Without coordination, even the best-laid plans will not enmesh and the intended outputs may not be accomplished. Triple C highlights who, what, why, when, where, and how of any Industry 4.0 pursuit. Even in digitally controlled automated systems, the humans in the loop need to be recognised vis-à-vis what the machine is expected to do when and how.

Questioning is the best approach to getting information for effective project management. Everything should be questioned. By upfront questions, we can pre-empt and avert project problems later on. Typical questions to ask under triple C approach relate to who, what, when, where, why, and how in the pursuit of communication, cooperation, and coordination to get project objectives accomplished. For the purpose of this present column, readers are referred to Badiru et al (2019) for the nuts and bolts of implementing communication, achieving cooperation, and executing coordination across the human interfaces of a quality project. These same guidelines can be carried out for the new wave of Industry 4.0.

What really gets a project done is a sustainable commitment, which is, inherently, a human attribute in spite of whatever technological advancements exist in the project environment. Thus, soft skills are essential under Industry 4.0. Cooperation, the mid-point of the Triple C model, must be supported with commitment. To cooperate is to support the ideas of a project. To commit is to willingly and actively participate in project efforts repeatedly and consistently through all project obstacles. The provision of resources (budget, infrastructure, and empowerment) is one way that management can express commitment to a project.

6 Quality tools for Industry 4.0

Standard quality-improvement tools are applicable to the environment of Industry 4.0. The most popularly used quality tools are Six Sand lean principles. Details both are provided by Agustiady and Badiru (2013) as well as Badiru and Agustiady (2021). Six sigma is one of the several quantitative tools useful for QA in Industry 4.0. Six Sigma is a process-improvement technique that seeks to eliminate or reduce variations. The basic methodology of Six Sigma includes a five-step approach, as summarised:

6.1 Define

Define the project environment. Initiate the project with specific reference to scope and goals. Incorporate the critical requirements of customers. In a digitally oriented process, the step of properly defining the project and/or product becomes even more critical.

6.2 Measure

Understand the data and processes involved in the project, with a view to specifications needed for meeting customer requirements. What cannot be measured cannot be controlled. So, measurement is the precursor to other quality enhancement efforts.

6.3 Analyse

Identify potential cause of problems, analyse current processes, identify relationships between inputs, processes, and outputs, and carry out data analysis. Engineering analysis is one of the fundamental components of engineering problem-solving methodology. Focus, efforts, and attention must be directed at collecting and analysing data under Industry 4.0.

6.4 Improve

Generate solutions based on root causes and data driven analysis while implementing effective measures. The point of doing product assessment is to improve product quality and characteristics. This becomes even more crucial under Industry 4.0 because of the fast-moving and changing digital technological developments.

6.5 Control

Righting the ship, so to speak, is the item of interest in the control phase of product management. Automation-driven digital implementations can run the risk of loss of control, should human in the loop not be properly embedded. Industry 4.0 will stretch the capabilities of manufacturers. Once again, a systems approach can help identify all the nuances and requirements in the organisations in the era of Industry 4.0. Beyond six sigma, lean principles also have a large role to play in Industry 4.0 (Dallasega, 2021). Lean principles present guidelines and processes for streamlining operations and eliminating waste. Even though digital operations facilitate repeatable processes, the outset design of the production system must incorporate the Japanese philosophy of 5S, which is encapsulated below:

6.5.1 Seiri (organise: sort)

This focuses on eliminating whatever is not needed by separating chaff from wheat, so to speak. Tools and parts not immediately needed are sorted into a secondary, but important category. They only come up when needed. Thereby, creating room for what is immediately needed.

6.5.2 Seiton (orderliness: set in order)

This focuses on organising whatever remains neatly and arranging parts via explicit identification. Orderliness is the bastion of well-organised production systems. Organise tools for ease of access and use.

6.5.3 Seiso (cleanliness: shine)

This requires that the workspace be cleaned to a shining profile to facilitate visibility and accessibility.

6.5.4 Seiketsu (standardise regiment)

This recommends following a regimented template of getting things done. Sustained maintenance of production processes is expected to produce consistent outputs, whether in products, services, and results.

6.5.5 Shitsuke (discipline: sustain)

This last stage of the 5S process requires that whatever gains have been achieved must be sustained with explicit discipline. This, essentially, implies making the commitment to improvement a way of normal life.

In some cases, the 5S approach is expanded to 6S, in which case safety is added as an explicit component. When six sigma and lean principles are combined, we achieve a powerful lean-six-sigma practice that can enhance the overall advancement of Industry 4.0. With new technologies of AI creeping into production systems, a combination of the DEJI systems model and Lean-Six-Sigma techniques will make the promises of Industry 4.0 realisable. The ecosystem of quality 4.0 tools may be crucial for supporting digital transformation in business and industry. One of the tools under the umbrella of quality 4.0 is AI, computational simulation, and related data science, such as big data, machine learning, and deep learning. Readers are encouraged to consider these topics for future research, within the spectrum of DEJI systems model.

7 Conclusions

Variation is present in all processes, but the goal is to reduce variation as much as possible. For Six Sigma to be successful in an Industry 4.0 operation, the processes must be in control statistically and must be designed to reduce variation right from the beginning. Two types of variation are generally noticed in manufacturing operations, namely special-cause variation and common-cause variation. Special-cause variation refers to untypical events, such as production disruption. By comparison, common-cause variation is inherently embedded in all processes and can be difficult to spot and identify, particularly in a fast-changing digital environment. A root-cause analysis should be done on special-cause variation so that it can be pre-empted in future production runs. Management action is often needed to rectify common-cause variation. In all of these, a systems framework using the DEJI systems model, can improve the efficacy of QA for Industry 4.0. Through this quality insight column, it is anticipated that appropriate research studies will ensue to continue to promote a systems approach to QA in Industry 4.0. In this context, this paper recommends leveraging the triple helix of government, university, and industry collaborations. If all stakeholders cooperate and coordinate, per the triple C model, better outcomes can be achieved in Industry 4.0.

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