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Journal of Intelligent Manufacturing

ISSN 0956-5515
Volume 31
Number 7

J Intell Manuf (2020) 31:1607-1610
DOI 10.1007/s10845-020-01643-5

Springer

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https://doi.org/10.1007/s10845-020-01643-5

EDITORIAL

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Andrew Kusiak[1]

Introduction

The progress in science and engineering over centuries has been uneven with spikes in discoveries and innovations. The developments in early centuries, marked with the names such as Archimedes (400 BC), Aristotle (300 BC), Galileo Galilei (fourteenth century), and Isaac Newton (fifteenth century), have built the foundation of mathematics and science that sparked progress in technology in later years. The first industrial revolution (ca 1760–1840), begun with the transformation from manual to mechanized production. This in turn has ignited progress in agriculture with the invention of a steel plow by John Deere in 1837, the way of life attributed to the telegraph invented by Samuel Moore in 1844, and economic and social changes reflected in the income distribution and organized labor.

The second industrial revolution begun around 1870 with the expansion in technology and bringing new infrastructure (e.g., railroads, electric energy) and products (e.g., a telephone, an electric bulb). The twentieth century and especially the twenty-first century have brought spikes in events not seen in the previous centuries. This can be best illustrated with the growing green gas (CO_2) emissions and pollutions in general. The environmental phenomena have caught attention of the scientists and the public and are good examples illustrating extreme events, ranging from the extreme temperatures at different spots around the globe, frequent floods, fires, unusual rainfall patters, and pandemics such as Covid-19. The limits in technology, e.g., the quest for speed of processing in the semiconductor and computer industry have sparked search for new capabilities, including quantum computing expected to provide an order of magnitude gains in processing power. A cursory review of the literature across science and engineering domains points the use of the term 'extreme' in multiple contexts.

The major science and engineering domains impacted by the extreme events are listed next.

Biology—Examples of extreme events include: Behavior of partially unfolded proteins under extreme temperature and pressure conditions (Heremans 2004); Transformation of the genome size in conifers (trees used as the source of softwood, resins, and turpentine) growing in an extreme environment (Sedel'nikova 2016); Extreme biology of meteorites (Lee et al. 2017).

Computer engineering—Neural networks have progressed in the scale and capability and thus allow to model complex phenomena reflected in their names such as extreme, deep, and broad neural networks.

Economy—Disparity of income and standard of living between the poor and the wealthy. If no action is taken, this gap is to grow in years to come. The Covid-19 pandemics might have grown this gap (Wuest et al. 2020).

Environment—Tsunami, earthquakes, Australia fires of 2019/2020 (Phillips and Nogrady 2020), floods, changing weather patterns, all represent extreme events. Enhancing resiliency of communities against extreme events is considered in Bruneau (2006).

Manufacturing—Open manufacturing inspired by the open systems versus integrated is discussed in "Extrema in manufacturing industry" section and Kusiak (2020a). Extreme automation stretching beyond a factory floor is discussed in Adolphs (2015).

Medicine—Examples include new viruses such as Covid-19 that has caused world-wide disruptions; Growing frequency and spread of any known disease is also an extreme event.

Rare materials—The rare earth elements of the periodic table imply their limited availability. Even more significant are the critical materials sought by the industry when their supply cannot be met for geopolitical or sustainability reasons. Materials that are being depleted will join the list of critical materials. To mitigate limited quantities of materials such as neodymium needed to build wind turbine generators,

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or lithium used in electric batteries alternatives to mining (e.g., recovery and recycling) or design of new materials (e.g., organic) may be considered.

Physics—Catastrophic events affecting physical hardware (e.g., the space shuttle Columbia disaster).

Semiconductors—To continue progress expressed by Moore's law, industry is looking for new technology paradigms such as extreme ultraviolet lithography, bionic chips, and quantum computing.

Process and software—The growing speed and scope of phenomena and events, e.g., massive cyberattacks crippling economies, failure of the software during the 2020 primary elections in the State of Iowa, USA has caused unprecedented delays in providing election results.

Society—Growing openness expressed at social sites (e.g., Facebook) versus the raise of nationalism in different countries. The meritocracy and mediocrity attitudes are the emerging extrema in some societies. Neither of the two is beneficial as meritocracy leads to mediocrity.

In 2017 the World Economy Forum published four possible scenarios that mark the progress in technology (see Fig. 1).

Scientists and engineers tend to focus on scenario (a) in Fig. 1. Developments following upward shaped trends are cherished and remain the focus of research and practice. The Covid-19 pandemic has demonstrated that scenario (d) with the new viral disease as an adverse event needs attention. Evidence of scenario (c) has been emerged in some countries. A day could come when scenario (b) may occur. There is a possibility that all three adverse scenarios could happen simultaneously.

Extrema in manufacturing industry

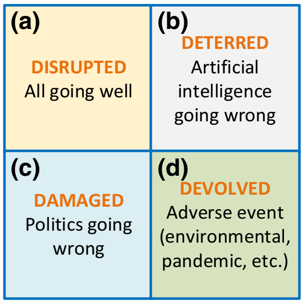
The concept of polarization and emergence of extrema is illustrated with the developments in manufacturing industry (Kusiak 2020b). For decades, manufacturing industry has been centralized with each corporation producing many components making the final product such as a car. To reduce the cost and increase efficiency, the industry begun to decentralize. Production of some components and products has moved to regions with low labor costs. Subcontracting, outsourcing, and forming new businesses to manufacture components and assemblies have become common strategies. Information technology and networked systems have contributed to the massive restructuring and partitioning of the industry. Supply chains have become major actors in the corporate world. The last decade has contributed new initiatives driven by artificial intelligence. One of the necessary conditions for deployment of artificial intelligence in industry is digitization.

This digital transformation of industry was initiated with computer control applied to manufacturing equipment (e.g., numerically control machines, introduction of industrial robots), and computerization of corporate processes (e.g., enterprise resource planning systems, customer relationship management systems), management of supply chains, and the introduction of computer-aided design solutions for production of components and products.

The digital content of enterprises has been enhanced by sensors monitoring status of manufacturing equipment and systems.

Tools such as MTConnect (mtconnect.org), Net-Inspect (net-inspect.com), and ShopFloorIQ (shopflooriq.com) support digitization of manufacturing industry and connectivity to the cloud platforms offered by Amazon, IBM, Microsoft, and other providers.

The confluence of factors, including digitization, globalization, service orientation (Kusiak 2019a), and democratization (Kusiak 2019b), will have a profound impact on the manufacturing of the future. One model of manufacturing that is emerging is that inspired by the open system architecture and referred to as open manufacturing (Kusiak 2020a). It will constitute one of the two extrema in manufacturing, the openness extreme. The openness extreme and the integration extreme make the boundary of the science and manufacturing space (see Fig. 2).



(a) DISRUPTED All going well	(b) DETERRED Artificial intelligence going wrong
(c) DAMAGED Politics going wrong	(d) DEVOLVED Adverse event (environmental, pandemic, etc.)

Fig. 1 The World Economy Forum outlook for technology development

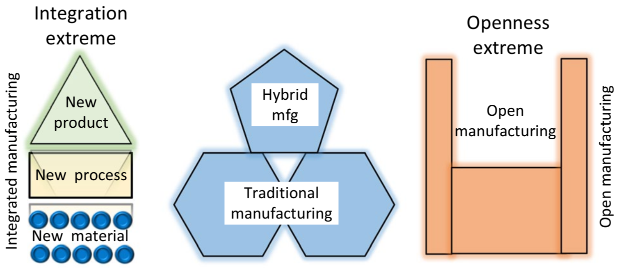


Fig. 2 Two extreme enterprise architectures

The openness extreme

An open manufacturing enterprise (Kusiak 2020a) is a collection of physical assets and services configured for the purpose of producing products. In many instances, the physical manufacturing assets will operate in manufacturing-as-a-service mode (Kusiak 2019a). Open manufacturing enterprises will compete on metrics that are different from the classical enterprises. The ability to configure, reconfigure, and optimally operate distributed services and their physical assets will be reflected in these metrics. Open enterprises are likely to become proponents of open innovation. The speed of innovation may become a new measure of competitiveness.

The integration extreme

An integrated enterprise will capitalize on the emergence of new technology. One of the paths to an open enterprise is scaling-up laboratory developed concepts to a viable industry. Such a transformation may involve development of new products, processes, and materials. An example of the integration extreme are perovskites solar cells (Extance 2019). The promise of increased energy efficiency of the photovoltaic solar cells has attracted several corporations to engage in high risk projects to bring the perovskites solar panels to the market. Different forms of materials (e.g., powders), manufacturing processes (e.g., additive manufacturing), and designs of solar panels (e.g., layered structures) are pursued.

The two manufacturing extrema will initially make a small percentage of all product development and manufacturing activities (Fig. 2). In the foreseeable future, most product development and manufacturing activities will follow the traditional and hybrid (integration and openness extrema) business path. However, it is likely that the middle area in Fig. 2 will shrink in time as the two extrema expand.

What is needed?

The number and severity of extreme events grows from biology and environment to physics and engineering. A new science, extreme science, is needed to study extreme events, for example, manufacturing that may be impacted by previously unseen events calls for accurate predictions climate changes to avoid controversies addressed in Hausfather and Peters (2020), and development of treatments for yet unknown diseases. The extreme science would enable understanding and solving problems across many domains, including economy, society, and industry. The characteristics and behavior of the extreme phenomena appear to be different than the classical ones. The science and tools used to study the latter may not suffice to explore the former, and therefore a new science to study extreme events is needed. For example, if the tools such as the one developed by BlueDot (bluedot.global) were widely distributed and used by the health and public safety organizations, the spread of Covid-19 could have been contained. The BlueDot software detects outbreaks and assesses risks for 150 different pathogens, toxins, and syndromes by scanning over 100,000 information sources per day in 65 languages, and considering data on billions of flights, climate conditions, animal and insect populations, and health system capacity. Though the BlueDot software was likely developed by using the existing artificial intelligence concepts, having a formal science describing the phenomena modeled by the BlueDot would be most valuable. Extreme science could become a formal arm of the systems of systems approach such as the Hsue-Shen Tsien theory summarized in Oberst (2019). As a new science, extreme science, is likely to draw and build upon and support the existing concepts, models, and theories, e.g., the systems of systems theory of Hsue-Shen Tsien, marked with the departure from reductionism and holism. The 'draw and build upon' existing science approach has independently offered a proven path in developments of, e.g., operations research and data science. The limits of classical optimization in handling high-dimensionality nonlinear problems have sparked interests in machine learning. Extreme science is likely to embrace heterogeneity of data and information (e.g., times series, text, longitudinal images), different scales, and go as far as incorporating alternative inputs and different forms of output (e.g., dynamic graphs, virtual reality).

The extreme value theory pioneered by Leonard Tippett (called also extreme value analysis) could be a candidate science to build upon. Extreme value theory belongs to statistics and it deals with extreme deviations from the median of a probability distribution. It has been applied in engineering, finance, and earth sciences. It allows to predict the probability of extreme floods such as the 100-year flood. The extreme value theory has been developed in a 'small data' environment. The big data stores of today open doors to a novel science to address extreme phenomena based on multiple heterogeneous variables.

The emerging science could contain elements of the existing model and algorithms Once integrated, these seemingly unrelated elements of different domains, could make extreme science powerful. The design of composite materials may serve as an example, where the properties of the layered material exceed the properties of the component materials. It is not unusual for technology to be developed ahead of science behind it. For example, the development of computers has led the expansion of computer science. Therefore, it might be beneficial to establish extreme science to develop understanding of the emerging extreme phenomena, explore synergy among them, and produce ways to better deal with them.

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