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Industry 4.0

Keng Siau
Guest Editor

Cutter Business Technology Journal

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Opening Statement

by Keng Siau

Industry 4.0, also known as the Fourth Industrial Revolution (4IR), refers to the current technology period enabled by advanced technologies, such as artificial intelligence (AI), machine learning (ML), big data, the Internet of Things (IoT), cyber-physical systems (CPSs), robotics, and automation. Although some researchers use Industry 4.0 in a more restricted sense, defining Industry 4.0 as a subset of 4IR, in this issue, we take the broader view and use Industry 4.0 and 4IR synonymously.

Embracing Industry 4.0 has become an important source of competitive advantage as enterprises incorporate advanced technologies like AI, ML, IoT, CPSs, robotics, and automation into strategic plans, manufacturing and factory operations, and business procedures. New business models are sprouting up through digitization and automation of products and services. Industry 4.0 will have a disruptive and transformative impact on the economy, business, jobs, and society.

Many predict that Industry 4.0 will be different from the first three industrial revolutions because of its disruptive and transformative impact on the nature of work and the future of society.[1] The way we work, the way we are trained, the way we are educated, the way we play, and the way we live will all be altered and transformed.

The first industrial revolution spanned from the end of the 18th century to the beginning of the 19th century. The invention of the steam engine and the emergence of mechanization established the role of industry as the foundation of the economic structure, accelerating the development of the economy and society.

Nearly a century later, from the 1870s onward, the emergence and expansion of electricity, gas, and oil represented the beginning of the second industrial revolution. The steel industry began to develop. Chemical synthesis provided us with synthetic fabric, dyes, and fertilizer. The telegraph and telephone were invented, revolutionizing the way we communicate. The second industrial revolution also enabled the emergence of "large factories" and the economy of scale made possible by mass production.

In the second half of the 20th century, the third industrial revolution appeared with the emergence of a new type of energy (i.e., nuclear energy), the rise of electronics (i.e., transistors and microprocessors), and the development of information technology. This revolution gave rise to the era of high-level automation in production thanks to two major inventions: automatons (programmable logic controllers [PLCs]) and robots.

Many predict that Industry 4.0 will be different from the first three industrial revolutions because of its disruptive and transformative impact on the nature of work and the future of society.

Today, a fourth industrial revolution is unfolding before our eyes. Industry 4.0 builds upon the third industrial revolution and the digital revolution that has been taking place since the middle of the last century. Industry 4.0 will blur the lines between physical, digital, and biological spheres, enabling us to build a new virtual world from which we can steer the physical world. Technology, such as cloud computing, big data, and the IoT, enables us to connect all production means and allows them to interact in real time. Low-cost gene sequencing and techniques such as CRISPR (clustered regularly interspaced short palindromic repeats) massively expand our ability to edit the building blocks of life. AI is augmenting processes and skill in every industry, from self-driving cars and drones to virtual assistants like Siri and Google Home. Neurotechnology is making unprecedented strides in helping us understand cognition and enabling us to better utilize and influence the brain. AI and automation are disrupting century-old transport and manufacturing paradigms. The extent and depth of these changes will transform manufacturing, production, management, and governance systems on a global scale. These changes are transforming how we communicate, learn, entertain ourselves, and relate to one another and help us better understand ourselves as human beings.

> *Our responsibilities to one another, our opportunities for self-realization and self-actualization, and our ability to positively impact our communities and the world are intricately tied to and shaped by how we engage with and manage the technologies of Industry 4.0.*

On one hand, Industry 4.0 promises great benefits and advantages. New technologies are being developed and implemented at an accelerated pace. Indeed, the speed of current breakthroughs has no historical precedent.[2] Industry 4.0 can provide us with much more rewarding and fulfilling lives. On the other hand, our responsibilities to one another, our opportunities for self-realization and self-actualization, and our ability to positively impact our communities and the world are intricately tied to and shaped by how we engage with and manage the technologies of Industry 4.0. This revolution can yield greater inequality, especially in its potential to disrupt labor markets.[3] As AI and robotics become more intelligent and can substitute for labor across the entire economy, the displacement of workers may exacerbate the gap between returns to capital and returns to labor.[4]

Upcoming Topics

Is Software Eating the World?
Greg Smith

AI: Third Time Is Not the Charm
Lou Mazzucchelli

Digital Architecture
Gar Mac Críosta

Of course, all previous industrial revolutions have had both positive and negative impacts on different stakeholders. By recognizing the risks, whether of cybersecurity threats, educational misfit, misinformation on a massive scale through digital media, potential unemployment and displacement, or increasing social and income inequality, we can take steps to manage technological progress and align technological advancements with humanity's needs and values to ensure that Industry 4.0 places humanity first and foremost.

Industry 4.0 is much more than technology. It is an opportunity to unite global communities, reduce inequalities, build advanced economies, provide sustainable environments, and modernize governance and management models. Industry 4.0 is a *call for action*. Industry 4.0 can provide the impetus to develop, reengineer, and enhance our governing technologies in ways that foster a more empowering, collaborative, and sustainable foundation for social and economic development, built around ethical and moral values. We have a great opportunity to proactively shape Industry 4.0 to be both inclusive and human-centered. But we must integrate our response more fully by involving stakeholders from both the public and private sectors and embracing ideas from academia and industry.

In This Issue

This issue of *Cutter Business Technology Journal* examines the latest advancements in technologies related to Industry 4.0 and the impact of these technologies on work, business, and organizations. We feature six articles in this issue that cover a range of topics.

In the first article, Keng Siau, Yingrui Xi, and Cui Zou explore the challenges and opportunities that Industry 4.0 presents in four groups of countries: developed, newly industrialized, developing, and least-developed. Industry 4.0 will impact countries in these development stages differently. The article discusses the factors that will impact the development of Industry 4.0 and provides suggestions for countries to avoid the risks inherent in Industry 4.0 and capitalize on opportunities to develop their economies. The article is beneficial to business executives as they contemplate investment decisions related to Industry 4.0.

Next, Joel Nichols discusses the barriers and challenges facing regulated industries as they attempt to implement Industry 4.0 technologies and change their culture. The article examines the questions that regulated industries must address as they embrace digital transformation and the advances that specific Industry 4.0 technologies can yield. The author argues that although digital transformation may require more time in regulated than in nonregulated industries, "the impact of regulated industry transformation on producers and consumers alike ultimately will be greater than that of the nonregulated sector."

Doug Hadden's article focuses on the opportunities and threats for governments in developing countries and emerging economies. Governments in developed countries exhibit a sophisticated policy design, enabling them to better exploit Industry 4.0, while developing countries and emerging economies, which have lower government effectiveness and less-sophisticated manufacturing, face more obstacles to benefit from Industry 4.0. Hadden discusses the government and country context that must be considered when developing policy interventions to optimize the potential of 4IR while mitigating vulnerability. In this context, the author suggests that policymakers use a VUCA (volatility, uncertainty, complexity, and ambiguity) analysis to determine potential and vulnerability. He then recommends public policy interventions to maximize potential and reduce vulnerability.

Our fourth article, by Barry O'Reilly, explores whether a skills crisis arising out of Industry 4.0 truly exists. Although organizations perceive a skills crisis as Industry 4.0 makes software a central part of every business, O'Reilly notes that the IT industry has complained of a skills crisis for years. He examines what the skills shortage really is, discusses past approaches to the crisis, and evaluates whether those approaches have worked. He then proposes a new view of the skills crisis and suggests alternative approaches to solving it. O'Reilly sees critical thinking and a reassessment of our view of skills as key components of resolving the perceived skills crisis.

In our fifth article, Feng Xu and Xin (Robert) Luo argue that because Industry 4.0 leads to potential new cybersecurity risks to manufacturing and supply networks, cybersecurity management must protect industry assets. The authors examine the issues specific to Industry 4.0, the three conventional essential security requirements, present and discuss the challenges of the security management cycle in Industry 4.0, and offer recommendations for cybersecurity management in Industry 4.0.

In our concluding article, Weiyu Wang and Keng Siau address the ethical and moral predicaments that Industry 4.0 creates. They discuss Industry 4.0 ethical and moral issues from the perspective of different business-oriented forces — stakeholders and business executives, employees, customers/clients, society — and different technical-oriented forces — designers and developers, users, intelligent agents. Their framework in Industry 4.0 considers ethical issues related to data and ethical issues related to systems, technology products, and services. Their discussion will enable business executives and technical designers/developers to have a better understanding and appreciation of the ethical and moral challenges in Industry 4.0.

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Industry 4.0: Challenges and Opportunities in Different Countries

by Keng Siau, Yingrui Xi, and Cui Zou

Along with the rapid development of artificial intelligence (AI), cyber-physical systems (CPSs), big data analytics, and cloud computing, Industry 4.0 — a subset of the fourth Industrial Revolution — has started to emerge and take root in many countries. Many expect that Industry 4.0 will be transformative and revolutionary for multiple industries and countries. Its impact will be much more significant than those of Industry 1.0, 2.0, and 3.0. Most studies and papers on Industry 4.0 have examined its impact on various industries, jobs, and organizations. In this article, we investigate the impact of Industry 4.0 on countries and groups of countries (e.g., developed countries, developing countries). Business executives will find this article informative as they contemplate whether to invest in and outsource to other countries. In addition, policymakers will learn about the challenges and opportunities of Industry 4.0 and how governments in various groups of countries should strategize to sidestep the dangers and realize the potential opportunities to transform and enhance their economies.

> *Countries are embracing Industry 4.0 to advance their manufacturing industries and to position themselves to compete in the future.*

Industry 4.0 is attracting more and more public attention. It centers on the ideas of intelligent manufacturing and the smart factory. The core of Industry 4.0 — combining the Internet with manufacturing — mainly consists of three parts: (1) CPSs, (2) the Internet of Things (IoT), and (3) cloud computing. In general, Industry 4.0 can be interpreted as the integration of automation and "informationization."

The German company Siemens is constructing a "digital enterprise" to push the manufacturing industry toward the 4.0 stage.[1] The idea is to introduce digitalization into every phase of Siemens's manufacturing, managing, delivering, and merchandising procedures. The company has adopted three main technologies in its plants and enterprise operations: (1) an intelligent data management library to aid with analysis and evaluation; (2) an open cloud platform; and (3) AI, instead of humans, for both production and management in the production process. Siemens aims to improve the accuracy of its decision making at all levels and enhance its quality of merchandise and service as well as production efficiency.

Countries are also embracing Industry 4.0 to advance their manufacturing industries and to position themselves to compete in the future. Some of the technological innovations related to Industry 4.0 include AI, big data, machine learning, CPSs, robotics, IoT, and cloud computing.

We have selected 24 countries and divided them into four groups: (1) developed countries, (2) newly industrialized countries, (3) developing countries, and (4) least-developed countries. The global map in Figure 1 depicts these 24 countries — and six additional developed countries — and lists the Industry 4.0 initiatives of selected countries to demonstrate different levels of awareness of Industry 4.0.

We have identified four factors key to comparing each country's performance and potential in Industry 4.0: (1) structure of production, (2) drivers of production, (3) the Human Development Index (HDI), and (4) the Global Innovation Index (GII). Finally, we analyze the unique opportunities and challenges of specific groups of countries and suggest solutions to move forward.

Industry 4.0 Around the World

Although discussions on Industry 4.0 have been ongoing for a while, only a few countries have formed clear initiatives to guide their manufacturing industries toward the fourth revolutionary wave. Most are developed countries, and a few are newly industrialized countries. (See Figure 1 for some examples of these initiatives.)

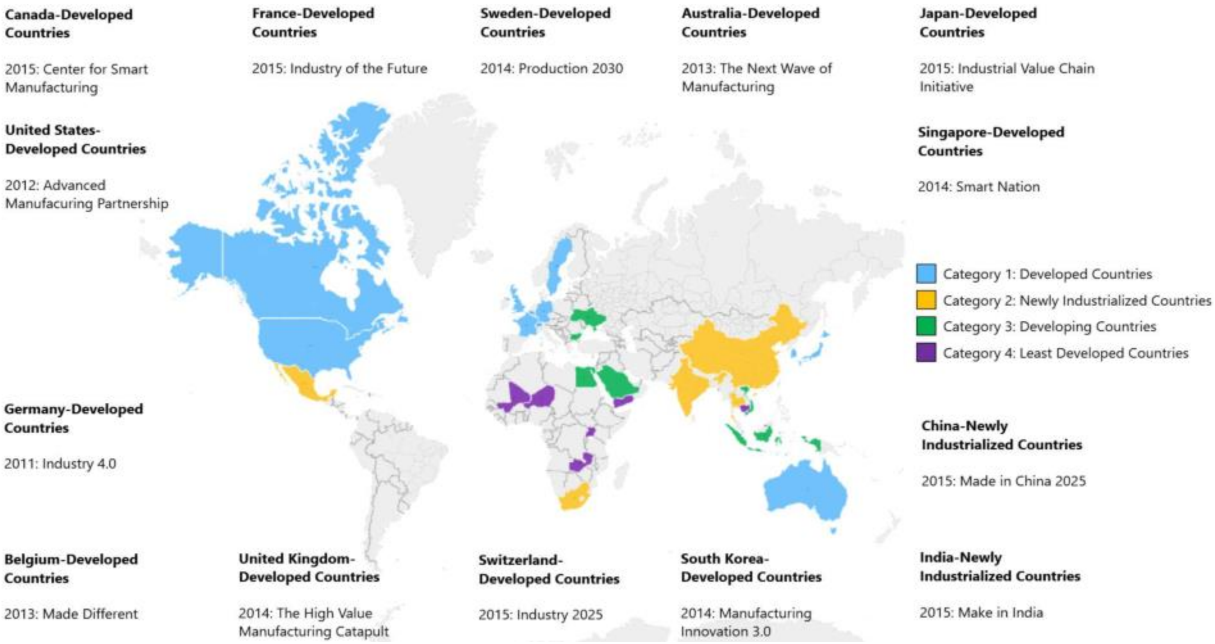

Figure 1 — Industry 4.0 initiatives around the world.

Developed Countries

Germany is the country that first put forward the idea of Industry 4.0, focusing on "engineering excellence." Germany aims to expand its strengths in engineering and machine building to informationization. The US, on the other hand, is the world leader in IT. Thus, the US aims to expand its strengths in IT to robotization, which it calls the "Industrial Internet." The Industrial Internet is the integration and linking of big data, analytical tools, and wireless networks with physical and industrial equipment or otherwise applying meta-level networking functions to distributed systems.[2] Sometimes, in the US, the term "advanced manufacturing partnership" is also used. In the US, "radical innovation," which aims to bring digital innovation into the physical world by encouraging startup companies to become more involved with and take advantage of the IoT, is taking root.

Switzerland has proposed "Industry 2025," with the ultimate goal of safeguarding and expanding the competitiveness of Swiss companies and the Swiss workplace.[3] Switzerland has been ranked No. 1 on the GII for a number of years,[4] and it also has a high HDI score.[5] Switzerland is one of the leaders in Industrial 4.0 and has great potential for continuous growth in this area.

Singapore aims to lead the way in Industry 4.0 among Asian countries. Indeed, the country has seen the launch of its first Asian Innovation Centre for Operations, as well as the Industry 4.0 Accelerator Program. Further, Singapore has taken steps to realize Industry 4.0 from the perspective of both the government and the private sectors. In fact, a government unit known as the Agency for Science, Technology, and Research (A*STAR) launched two model factories in 2017 to encourage and support small and medium-sized enterprises to learn and adopt advanced new technology. Industry 4.0 is part of Singapore's plan to become a Smart Nation.

Two other developed countries in Asia mentioned in Figure 1, Japan and South Korea, have focused on "ability to scale." They are devoted to expanding the scale of production and applying advanced technology in their manufacturing industries.[6] Japan and South Korea concentrate their efforts on constructing a large number of smart factories as well as on improving the quality and technology content of their products to enhance domestic demand and foreign exports.

Newly Industrialized Countries

In 2015, the Chinese government proposed its 10-year action plan to become an advanced manufacturing power — "Made in China 2025" — which details the integrated development of the manufacturing industry sector by combining industry technology and IT in each step of manufacturing.[7] China aims to transform itself from its current global position as a manufacturing giant into an advanced manufacturing power. In conjunction with "Made in China 2025," the Chinese government has presented its goal of transforming

China into one of the leading manufacturing powers by the year 2049.

Other newly industrialized countries such as Thailand, Mexico, the Philippines, and India, have favorable current production bases but future development is potentially challenging. Among them, India is the one country that has its own initiative for Industry 4.0, known as "Make in India."[8] South Africa, though regarded as a newly industrialized country, needs to demonstrate its readiness for Industry 4.0.

Developing Countries

Most developing countries have not shown a concerted effort to embrace Industry 4.0. Although only a few of these countries have an overall initiative, almost all of them are laboring to catch up with the emerging manufacturing trend and are introducing AI, cloud computing, big data analysis, and many other emerging high-end technologies.

The developing countries we analyzed are Indonesia, Bulgaria, Ukraine, Saudi Arabia, Egypt, and Vietnam. We found that they have potential in Industry 4.0, although their current base of production needs further development.

Least-Developed Countries

Least-developed countries, such as the six we analyzed (Cambodia, Zambia, Uganda, Mali, Niger, and Yemen), currently have a limited manufacturing base and their potential in Industry 4.0 is not encouraging. Most of these countries show little action on, or poor performance in, automation and informationization. Adopting core technologies of Industry 4.0, such as CPSs, IoT, or cloud computing, will be challenging. Furthermore, their present educational situation is anything but promising in both mean years of national education and educational attainment.

A Four-Factor Comparative Analysis

We propose a four-factor comparative analysis to quantify the potential of Industry 4.0 in different countries. In our study, we selected 24 countries to form four groups based on development status. For each group, there are six representative countries. They are selected based on data availability and geographical location, as well as on the level of development in the manufacturing sector and level of informationization.

Table 1[9] depicts the first two factors: structure of production and drivers of production. For both Table 1 and Figure 2, the highest possible score was 10. We collected data from the World Economic Forum's "Readiness for the Future of Production Report 2018."[10] Structure of production consists of two dimensions: complexity and scale. "Complexity" is used to analyze how a country's different types of knowledge and technology are combined with each other in the manufacturing sector and their contributions to the uniqueness and functionality of products. "Scale" assesses "both the total volume of manufacturing output within a country (Manufacturing Value Added) as well as the significance of manufacturing to the economy (Manufacturing Value Added, % of GDP)."[11]

Drivers of production include six measurements: (1) technology and innovation, (2) human capital, (3) global trade and investment, (4) institutional framework, (5) sustainable production, and (6) demand environment. For Mali, Niger, and Yemen, there is no data available in the World Economic Forum report.

Figure 2 is a scatter diagram of these two groups of data that clearly depicts the differences between countries in different development stages. From Table 1 and Figure 2, we see that the four country groups are at least somewhat distinct. Developed countries have higher structure and drivers of production than do newly industrialized countries. The same is true between newly industrialized countries and developing countries, as well as between developing countries and least-developed countries.

For most developed countries, the scores for the structure of production and drivers of production are close, as they are for developing countries and least-developed countries. For newly industrialized countries, the scores are farther apart. One possible explanation is that for newly industrialized countries, the structure of production has been enhanced much faster than the drivers of production. Scale, one of the two components in measuring the structure of production, is important in these newly industrialized countries because of the importance of manufacturing to these countries' economies (i.e., percentage of GDP). This is the case for China, whose structure of production is significantly higher than its drivers of production. China is ranked number one in the world on its scale of production.[12] On the other hand, for some countries, the drivers of production score is higher than the structure of production score. One such example is Canada, which is an exceptional case for developed

		Country	Structure of Production	Drivers of Production
Developed Countries	1	Germany	8.68	7.56
	2	United States	7.78	8.16
	3	Switzerland	8.39	7.92
	4	Singapore	7.28	7.96
	5	United Kingdom	7.05	7.84
	6	Canada	5.81	7.54
Newly Industrialized Countries	7	China	8.25	6.14
	8	Thailand	7.13	5.45
	9	Mexico	6.74	5.04
	10	Philippines	6.12	4.51
	11	India	5.99	5.24
	12	South Africa	5.03	5.02
Developing Countries	13	Indonesia	5.41	4.89
	14	Bulgaria	5.23	5.02
	15	Ukraine	5.17	4.47
	16	Saudi Arabia	5.16	5.44
	17	Egypt	4.99	4.46
	18	Vietnam	4.96	4.93
Least Developed Countries	19	Cambodia	3.56	3.63
	20	Zambia	2.39	3.54
	21	Uganda	2.25	3.31
	22	Mali	NA	NA
	23	Niger	NA	NA
	24	Yemen	NA	NA

Table 1 — Structure and drivers of production of different countries. (Source: World Economic Forum.)

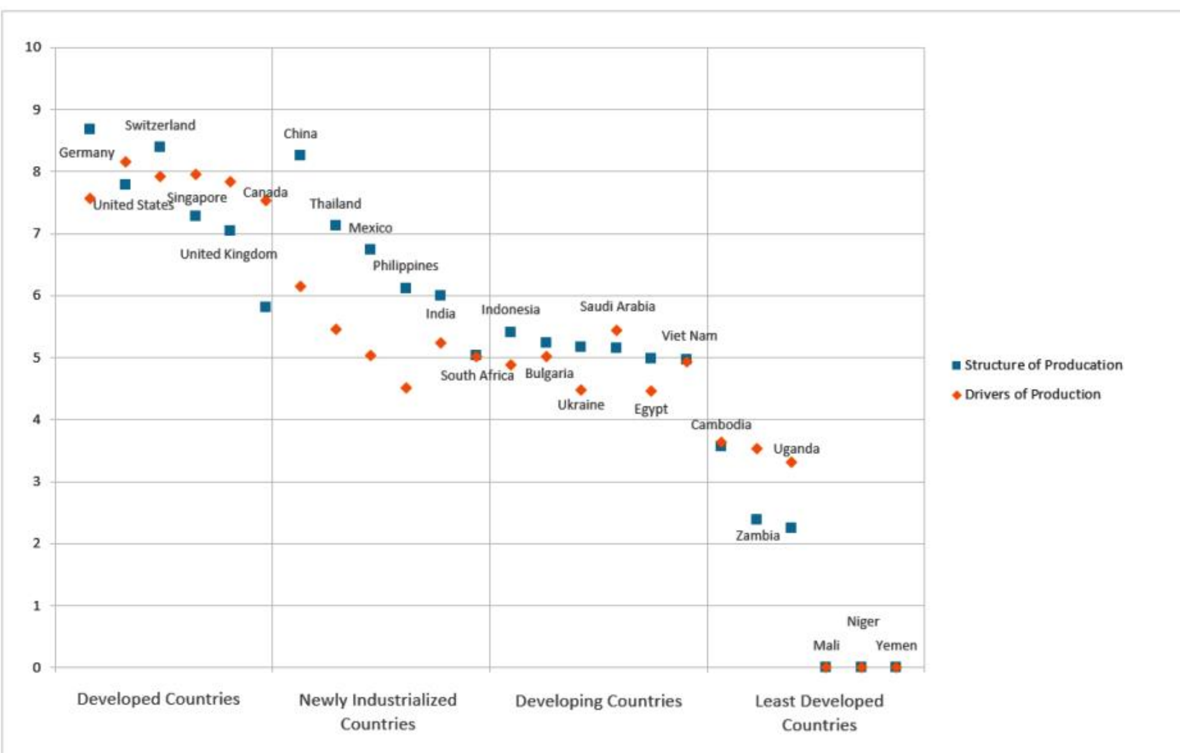

Figure 2 — Structure and drivers of production of different countries.

countries, showing a significant difference between the drivers of production and the structure of production.

Table 2[13] shows the other two factors in our study: HDI value and GII score. These two factors measure vital influences in successfully implementing and achieving the potential of Industry 4.0. The HDI, which has a full value of 1, is a comprehensive measurement that demonstrates the status of human development through four primary components.[14] The four components are: (1) life expectancy at birth, (2) expected years of schooling, (3) mean years of schooling, and (4) gross national income per capita. The GII, with a maximum value of 100, is the simple average of two subindices: the innovation input subindex and the innovation output subindex.[15] The innovation input subindex consists of five measures: (1) institutions, (2) human capital and research, (3) infrastructure, (4) market sophistication, and (5) business sophistication. The innovation output subindex has two dimensions: one is knowledge and technology outputs and the other is creative outputs.

Figure 3 demonstrates the development potential of Industry 4.0 for our 24 selected countries. From Figure 3, we see that developed countries are clustered together and score high on both the HDI and GII. On the other end of the spectrum, the least-developed countries score low on the GII and low to medium on the HDI. The newly industrialized and the developing countries cluster together on both indices. It appears that HDI and GII are good factors to separate the developed countries from the newly industrialized countries and the developing countries. Similarly, the GII can be used to differentiate the least-developed countries from the rest.

The most notable outlier is China. Its GII is as high as that of some of the developed countries. Its HDI, however, is significantly lower than those of the developed countries.

Generalizing from Tables 1 and 2 and Figures 2 and 3, we see that developed countries, such as Germany, the US, Switzerland, Singapore, the UK, and Canada, have the best potential to capitalize on the development of Industry 4.0 and are in the best positions to further excel in Industry 4.0. The newly industrialized countries will have to continue to improve on their drivers of production, GII, and HDI. Industry 4.0 may provide them the opportunity to move from newly industrialized countries to developed countries. China, with its

		Country	Human Development Index Value	Global Innovation Index Score(2018)
Developed Countries	1	Germany	0.936	58.03
	2	United States	0.924	59.81
	3	Switzerland	0.944	68.40
	4	Singapore	0.932	59.83
	5	United Kingdom	0.922	60.13
	6	Canada	0.926	52.98
Newly Industrialized Countries	7	China	0.752	53.06
	8	Thailand	0.755	38.00
	9	Mexico	0.774	35.34
	10	Philippines	0.699	31.56
	11	India	0.640	35.18
	12	South Africa	0.699	35.13
Developing Countries	13	Indonesia	0.694	29.80
	14	Bulgaria	0.813	42.65
	15	Ukraine	0.751	38.52
	16	Saudi Arabia	0.853	34.27
	17	Egypt	0.696	27.16
	18	Vietnam	0.694	37.94
Least Developed Countries	19	Cambodia	0.582	26.69
	20	Zambia	0.588	20.66
	21	Uganda	0.516	25.32
	22	Mali	0.427	23.32
	23	Niger	0.354	20.57
	24	Yemen	0.452	15.04

Table 2 — Human Development Index values and Global Innovation Index scores.
(Sources: United Nations Development Program; and Cornell, INSEAD, and WIPO.)

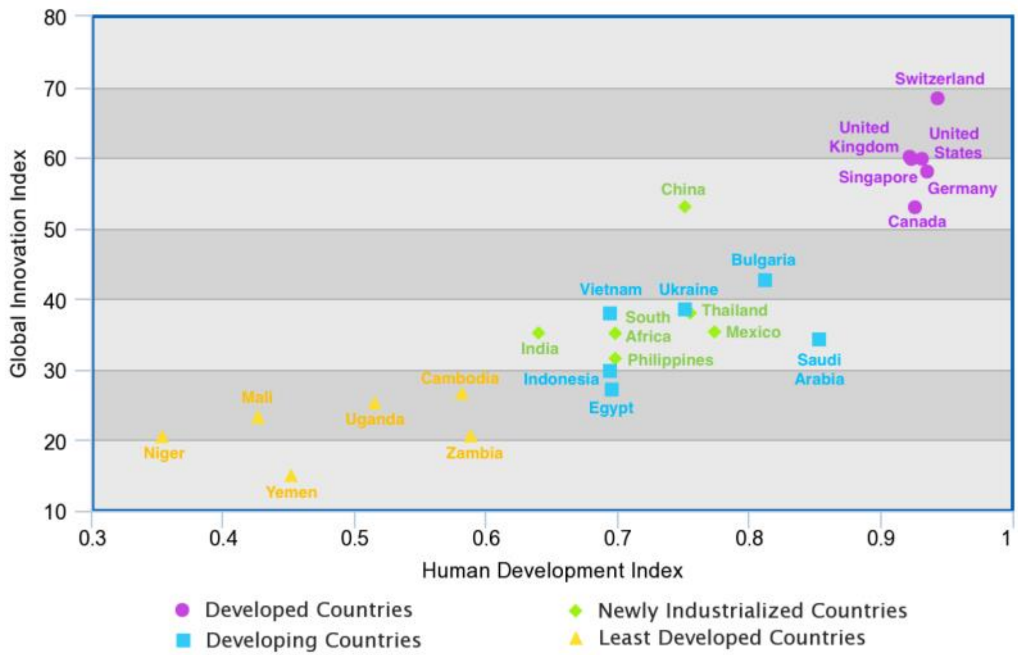

Figure 3 — Development potential based on the Human Development Index and the Global Innovation Index.

relatively high GII, has the most potential to become a developed country, but it has to enhance its drivers of production and HDI. The developing countries, similarly, have the potential to embrace Industry 4.0 to enhance their economies. The least-developed countries are, unfortunately, in danger of being left behind by Industry 4.0.

Opportunities and Challenges for Future Development

Opportunities

Industry 4.0 provides opportunities for a country to develop economically and provide its citizens with a better income and lifestyle. Nevertheless, some countries are more equal than others when it comes to equality of opportunity with Industry 4.0.

Developed Countries

Without doubt, Industry 4.0 offers great opportunities in economic gains, more reliable and smart production, sustainable manufacturing systems, technology innovation, and many other areas to most developed countries. Based on the four factors used in our study, these countries are most prepared to benefit from Industry 4.0. They have accumulated tremendous competitive advantages in the knowledge economy, innovation, and smart manufacturing. These could translate to new markets and job opportunities in the near future.

Newly Industrialized Countries

According to our four-factor comparative analysis, newly industrialized countries are catching up with developed countries on the structure of production (see Figure 2), which means they are doing well on complexity and scale of manufacturing. Therefore, these countries will be able to further enhance their economies by adopting advanced manufacturing systems and embracing cutting-edge technologies. For example, robotics, AI, and IoT are transforming the industry sectors of many developed countries. Similarly, these technologies can be used in India, a newly industrialized country, to enable it to leapfrog some stages of development.[16] China's efforts to upgrade its manufacturing-intensive economy to an innovation-oriented economy also demonstrate leapfrogging opportunities. Unlike developed countries, newly industrialized countries usually do not have extensive infrastructure legacy issues and are thus more able to embrace changes.[17]

Developing Countries

The most valuable benefits developing countries may gain from embracing Industry 4.0 could be financial enhancement and life-quality improvement for their citizens. Being able to access the digital world and own high-tech products will enable people living in developing countries to procure products worldwide and to sell their products globally. Digital connection also means high-quality services, such as making payments by scanning barcodes, calling a cab via a mobile app, or seeing a doctor virtually from a rural village. New technologies enable more-efficient and smarter dispensing of resources and funding.

Least-Developed Countries

Clean energy and a sustainable development mode are among the most exciting topics in Industry 4.0; both of which provide opportunities for the poorest countries around the world. For example, these countries' ample solar energy and wind power may supplant an unreliable centralized grid infrastructure, if one exists at all, benefiting local residents. Nevertheless, least-developed countries may need help to capitalize on these opportunities.

Challenges

While the opportunities arising from Industry 4.0 are appealing, we should not ignore the challenges that the countries will face as they try to ride the Industry 4.0 wave.

Developed Countries

Although developed countries performed much better on both length and quality of education than did the other country groups, they may not be fully prepared for high-tech manufacturing and knowledge-based businesses.[18] Although Switzerland was ranked number one among 126 countries on the GII,[19] it achieved a score of only 68.40 out of 100 (refer to Table 2), which indicates that most developed countries still have much room for improvement. It is predicted that over a third of the required skills in smart manufacturing will change by 2020, and skill mismatch is very common among workers in OECD countries.[20] Many workers today are expected to understand and be able to work with robotics, big data, AI, and blockchain.[21] However, these advanced technologies are relatively new and not many workers have mastered the skills needed to work with them. Lifelong learning and continuous retooling become imperative, which means learning new competencies to fit into a totally new job environment or even to stay in a current job is constantly needed.[22] However, in practice, companies are inclined to provide reskilling training to high-performing workers rather than those at risk of being left behind or with low skills.[23] In other words, employees needing reskilling and upskilling the most may not be the most preferred candidates to receive such training.

Newly Industrialized Countries

Job losses caused by population booms and automation are a challenge for newly industrialized countries. The United Nations' latest world population projections show that India, one of those newly industrialized countries, will replace China as the most populous country in the world in less than 10 years.[24] This population explosion will not fuel the near-term development of Industry 4.0, which is moving toward smart manufacturing. Smart manufacturing usually means fewer workers are required. Job displacement, unemployment, energy shortages, and hunger are issues to consider.

Developing Countries

Unlike the previous industrial revolutions, Industry 4.0 will not attract global investment simply by providing low-cost labor and low- to medium-skilled jobs. Many newly industrialized countries, such as China and Mexico, drove their economic growth by supplying an abundance of low-skill labor. However, this development model is not likely to be a silver bullet for current developing countries, especially low-cost manufacturing export countries. Automation, IoT, and AI, among many new technologies, make it possible to produce massive amounts of goods at a competitive cost and may trigger reshoring or nearshoring.[25] As shown in Table 1, some developing countries did not score as high on the drivers of production as they did on the structure of production. Global trade and investment is a key component of drivers of production and provides an indication of how well a nation may perform in the future.

Least-Developed Countries

In our study, we used the United Nations' HDI to quantify each nation's potential in innovation and human capital. Mean years of schooling is an important component in calculating the HDI. The World Economic Forum identifies human capital as one of the six key drivers of readiness for Industry 4.0 because it captures how fast a nation can respond to the transformation of production systems.[26] To unleash the potential of human capital, education and reskilling are critical.

However, many least-developed countries are struggling with these two aspects.

Based on data from the 2018 United Nations' Development Programme report on human development,[27] we plotted the mean years of schooling for each of the country groups in our study (see Figure 4). The least-developed countries, such as Niger and Yemen, lag far behind developing and newly industrialized countries (and, of course, far behind developed countries).

In addition to the length of education, the quality of education is also important.[28] As discussed earlier, the GII captures measures contributing to innovation input and output, with institutions being one of the measures contributing to innovation input. Table 2 illustrates that the least-developed countries fall far behind the newly industrialized and developed countries and behind developing countries on the GII.

According to the "2019 QS World University Rankings," a majority of the top 100 universities worldwide are in developed countries.[29] Only nine universities are in newly industrialized countries such as China and Malaysia. Two are in developing countries (Russia and Argentina). None is in the least-developed countries. While some people have proposed MOOCs (massive open online courses) to offset the limitations of traditional education, more than 4 billion people around the world have no access to the Internet.[30] Therefore, it is difficult for many least-developed countries to utilize digital higher education to educate their populations. Without sufficient educational resources (whether traditional or digital), people in the poorest countries have little chance to become skilled labor and to be prepared for smart manufacturing and Industry 4.0. They risk being left behind by Industry 4.0.

We should stress that education is key to countries in all groups, irrespective of their development status. Even the delivery modes of education and the curricula need to be reengineered to address the needs of Industry 4.0.

Conclusion and Recommendations

Human capital is crucial for any nation wanting to develop a competitive edge to embrace and excel in Industry 4.0. Developing and least-developed countries face greater challenges and need to make serious commitments to education. Developed countries need to focus on reskilling and upskilling their most at-risk employees. Newly industrialized countries should be aware of the issues caused by population booms. Least-developed countries will need help to avoid being left behind.

Industry 4.0 is here, and it will continue to grow in importance and accelerate in development. Countries need to formulate a plan to embrace, adapt, and capitalize on Industry 4.0, as avoiding or ignoring it is futile.

Figure 4 — Mean years of schooling for different groups of countries.

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Bring on Digital Transformation in Regulated Industries

by Joel Nichols

The hype surrounding Industry 4.0 technologies, and their assumed criticality for digital transformation, will surely follow the typical path determined by human psychology as it relates to technology: New technology generally piques unwavering interest. Greater investigation into said technology often leads to more promises of what it will deliver, with use cases seemingly endless. The reality of implementing the technology, however, may quickly turn downward into pessimism, especially when many promising use cases fail to come to fruition. Consequently, fear and distrust of the technology increase, and most people abandon it. Of course, some use cases become success stories, and the technology may indeed gain some traction — but only in a slow, methodical way. The real problem, however, was never with the technology itself; rather, it was likely with the human psyche's perceptions of it.

This same human psyche may be the greatest barrier to implementing change. Yet, the ability to change at an ever-increasing pace is likely the most critical element of being a digital organization. Next comes another big barrier: regulation. Regulated industries face not only the human psyche battle of implementing change but also the necessity of doing so within the constraints and barriers imposed by regulation. If a digital transition were strictly a matter of applying new technologies to old problems, regulated industries wouldn't lag so far behind in the transformation arena when compared to other industries.

But digital transformation requires more than the application of new technology. It requires a fluent change culture, one that regulations and regulatory bodies tend to impede by protecting against dangerous and rushed implementations. Consequently, regulated industries have become known for being change adverse and slow to implement change. More than ever, we need innovation champions within regulated industries to step up and bring the regulators up to speed and on board when it comes to Industry 4.0.

Questions to Tackle

Regulated industries should not pull back in their quest toward digital transformation but should instead find a way to embrace it. To do so, let's first examine some questions regulated industries should consider:

- **Does being in a regulated industry mean an inherently slower transition to becoming a digital organization?** In almost any company within a regulated industry (e.g., healthcare, finance, transportation), there are some parts of the company to which regulations do not apply, be it recruiting, distribution, finance, or employee social groups. So, if some parts of the company are not under the regulatory oversight that could potentially slow down a digital transformation, why not apply a "two-speed digital transformation," with one part of the organization transforming intentionally faster than another part of the organization? Theoretically, an organization could choose to adopt digital tools and methods in the parts of the organization not governed by regulatory bodies while taking a slower approach in the parts that must abide by regulations.

  The challenge of a partially transformed organization is the effect on the culture of the company as a whole. Consider, for example, someone from research, accustomed to using tools in the cloud with new builds deployed daily using data from all sources in the ecosystem, who moves to a regulated manufacturing position. How will that employee impact and be affected by such a starkly different culture? Management of change, including digital change, requires a beginning-to-end vision. In a two-speed digital transformation, it should be clear that different digital adoption speeds transcend a vision toward a unified transformation, requiring patience from those at the "higher" speed and stimulating curiosity from those at the "lower" speed. But to achieve this type of unification, we need regulatory authorities that are in line with the new digital world.

- **Can we influence regulators to make the transition to digital?** It seems self-evident that a regulatory body not fully versed in Industry 4.0 tools and techniques will not be able to properly regulate a company leveraging such tools and techniques throughout its operations. Regulatory bodies exist because the country or government they represent wants to ensure that "experts" oversee the actions of companies within a given industry to protect the public from unethical or uneducated decisions with regard to products or services that impact public well-being. If regulatory bodies don't have expertise in newer technologies or processes, how can they possibly be expected to regulate these technologies within the companies they oversee? At the same time, do companies within the regulators' domain really have a grasp on the level of expertise the regulatory bodies possess? Active communication between regulated companies and regulators would allow each to fully understand what the other is undertaking in regard to a digital transformation.

If a regulatory body hasn't digitally transformed itself — or educated itself on digital transformation — is there a path to help educate or drive the regulatory body toward such a change?

Regulations often blaze a path to widespread use of new technologies. If the US government were to dictate the use of blockchain for HIPAA-related data by a certain date, for example, companies would be looking at blockchain for many other ecosystems of shared data. However, many regulatory bodies lack the vision to allocate funding to properly understand the impact of a digital transformation on the industry they govern. If a regulatory body hasn't digitally transformed itself — or educated itself on digital transformation — is there a path to help educate or drive the regulatory body toward such a change? The answer lies in the concept of *transparent collaboration and communication* between the regulators and the regulated. To avoid any perception of compromise, such as bribes to induce favoritism, the industry would need to create a neutral third party that would accept funding from companies within the industry and offer tools, training, and consulting to the regulators. Industry lobbyist organizations exist today and could perhaps take on this neutral third-party role, but a more direct and targeted intervention is needed to expedite transformations that are positive for both producers and consumers. The benefits of Industry 4.0 processes and technologies benefit everyone in the ecosystem, not just the companies that have implemented them. One potential path is for regulatory bodies to host incubators that make possible the creation of such a collaborative environment. Last year, US Food and Drug Administration (FDA) Commissioner Scott Gottlieb announced that the FDA was creating such an incubator environment for digital health tools.[1]

- **Is becoming digital within a regulated industry worth the effort?** Consumers within regulated industries receive protection in one form or another — including as safety (e.g., improved data enhances safety in air travel), transparency (e.g., clear view of all parties/charges in financial systems allow for greater transparency in mortgages), and equality (e.g., creating easier access for startups to offer Internet services provides more opportunities) — making the effects of Industry 4.0 in regulated industries potentially more impactful than in other industries. In nonregulated industries, the benefits passed on to the consumer are clear: lower cost, higher quality, closer business-customer relationships, and increased speed of innovation. While many of the applications and use cases will be industry- and even company-dependent, it is the interest in the Industry 4.0 digital tools that sparks much of the interest in the transformations around the world.

Toward Advancement

Let's take a look now at how some specific Industry 4.0 technologies can create advances within regulated industries:

- **Artificial intelligence and machine learning (AI/ML).** Analyzing data to find correlations not previously seen is clearly a way to speed new innovations, as well as reduce costs and improve safety. One common challenge within regulated industries involves the requirements on software testing, ensuring that the software works as intended and that new changes haven't introduced unwanted results. Despite testing, "programmer bias" will always exist. Regression testing based on criticality is certainly beneficial, and testing automation has allowed for greater use of more robust and complete sets. But why not let the computer itself look for unexpected and ignored bugs? Training a model on what the software is intended to do can allow AI to test beyond the design to predict and demonstrate "unintended features" in the software. For regulated industries, AI/ML-assisted testing would extend testing beyond what today's regulations require — and let all of us as consumers sleep a bit better as a result.

- **Cloud computing.** The horsepower of cloud computing has allowed companies of all sizes to do things they wouldn't ordinarily have the data centers to do and allows them to more easily take advantage of powerful tools that never existed before. Despite early concerns about the security of cloud-stored data, most users would readily opt for the cloud in a decision between storing data in a small server room in a remote distribution center or in a military-grade secure facility with redundant everything. Cloud computing offers the kind of security for consumers that many companies operating in the ever-increasing ecosystems of regulated industries can't normally obtain on their own. The result is increased protection and greater reliability (i.e., consistent results) of consumers' critical and private data.

- **Blockchain.** Blockchain as a technology is gaining momentum. You can already find blockchain technologies in use in finance, as countries see great savings through the use of a shared ledger.[2] Blockchain offers the world of multichannel ecosystems within regulated industries a way to operate that is both safe and fair to producers and consumers alike. As a patient, for example, you want your medical data shared with the group of healthcare providers caring for you, but you likely want to share only the data relevant to the condition being treated. At the same time, if one of those providers makes a change to your treatment plan, you would like that to be immediately communicated to the team treating you. While you want your insurance provider to have some information regarding your treatment as well, there is a good chance you aren't comfortable with your insurance company having access to all your information. Blockchain makes accountability for the sharing of patient information transparent and can limit sharing to your treatment team.

- **3D printing.** We have already seen 3D printing, and its wide variety of use cases, develop into a niche technology. Although it is always easier to purchase an item that is "stock" and "close enough" to meet specific needs, 3D printing offers the opportunity to meet the *exact* needs of a specific application. The capabilities of 3D printing can thus improve the raw materials and tools used in manufacturing within regulated industries. Moreover, as a delivery solution, 3D printing can eliminate tampering and counterfeiting. Indeed, once regulators approve something created via 3D printing, the manufacturing of your medicine, for instance, could occur while you wait at the pharmacy.

The more easily and accurately devices and machines can share data, the better they can make use of this data and the more understanding they have about the world in which they operate.

- **Industrial Internet of Things (IIoT).** Just as with humans, proper communication leads to expected results with machines. The more easily and accurately devices and machines can share data, the better they can make use of this data and the more understanding they have about the world in which they operate. In a simple regulated industry example, a large mixing vessel preparing to add a toxic chemical could stop the process if it becomes aware that a person is unexpectedly in the area. IIoT will allow that mixing vessel to ask its ecosystem whether any humans are present, providing greater flexibility than today's need to push information to the vessel.

- **Augmented reality/virtual reality (AR/VR).** Today's AR can allow remote experts to provide support for maintenance in regulated industries, while VR can provide a new dimension of training, where variants of unsafe and unfit environments can be created as experiences for trainees. But we can take these benefits even further. Providing just-in-time training — and augmenting it with visuals — improves success in new ways. Now imagine if we can also add in digital twin elements and allow the computer to evaluate actions to flag potential variances along the way. Training then becomes a significant step in quality, the likes of which we have never seen before.

- **Big data/smart data.** While we often see data as a way to improve insights and understanding along the way, data goes way beyond that. *Smart data* seems to have replaced *big data* in importance because we now realize that data beyond our understanding and control becomes noise. Smart data, which specifies the data context — to whom the data belongs and its risk profile for safety, quality, and privacy issues — creates a world of understanding to look to when things go wrong. Smart data makes knowing the impact of a security breach possible, for example, allowing appropriate notification without causing worry and panic. Smart data could also avoid holding up a series of flights due to a data out-of-limits event because sufficient other data would exist to allow the making of the right decision with a safe path for the airlines and passengers.

While there are many use cases for each of these technologies, their true impact occurs when they all work together in an organization that embraces them along with the rapid changes that are intertwined in their use. Digital transformation is said to be exponential because each of these technologies has the power to act as a multiplier.

Although the path to digital transformation may be slower in regulated industries than in nonregulated ones, the impact of regulated industry transformation on producers and consumers alike ultimately will be greater than that of the nonregulated sector. Thus, innovative Industry 4.0 champions within regulated industries need to step up for regulators, producers, and consumers — and make things happen. After all, disruptive innovation with the right change management has the power to improve quality of life globally. So now is the time to push the boundaries of change management and find new ways to collaborate with regulators.

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Adopting 4IR Policies in Developing Nations and Emerging Economies

by Doug Hadden

The Fourth Industrial Revolution (4IR) — aka Industry 4.0 — challenges developing nations and emerging economy[1] governments to "reassess their national competitive advantages and development strategies."[2] Developed countries clearly benefit from advanced technology manufacturing, intellectual property, and knowledge economies. Moreover, advanced economy governments exhibit sophisticated policy design; therefore, limited retooling is required in these countries to exploit Industry 4.0. In contrast, developing nations and emerging economies, with lower government effectiveness and less-sophisticated manufacturing, are more vulnerable to negative 4IR effects.

Faced with contrary projections on 4IR effects, policymakers in less-advanced economies grapple with all the "VUCA" elements of volatility, uncertainty, complexity, and ambiguity. Emerging "Policy 4.0" frameworks offer these policymakers conflicting advice. Frameworks littered with traditional industrial policy thinking urge government leaders to systematically plan for future years yet contradictorily govern in an agile fashion. To consider the country context without explaining how. To coordinate across government silos without explaining how, leaving a policy-making enigma.

This article explores why policymakers need 4IR Policy 4.0 approaches that integrate *country context*, *technology effects*, and *coordination techniques*. Business leaders must examine the 4IR developing nations and emerging economy effects. These effects could include persistent pestilence, conflict, extinction, and resource depletion. Billions of customers could become unable to afford products and services.

More Potential, Yet More Vulnerability

Observers disagree whether 4IR effects are more likely to disrupt developing or developed country economies. One analysis suggests that "advanced economies [are] more affected by automation than developing ones, reflecting higher wage rates and thus economic incentives to automate."[3] Another analysis found that "developed economies are likely to be relative winners at this stage, whereas developing economies face greater challenges as their abundance of low-skill labor ceases to be an advantage and becomes more of a headwind."[4] Indeed, the World Bank estimates that two-thirds of jobs in the developing world are vulnerable to loss because of technology automation and disruption.[5] Overall, developing nations and emerging economies have more *potential*, yet more *vulnerability*, to 4IR effects than do advanced economies. Moreover, these countries also suffer from poor government effectiveness in policy planning and implementation.

> *Effective policy optimizes potential while mitigating vulnerability.*

Government and Country Context

Developing nations and emerging economies tend to possess differing potential and vulnerability regarding 4IR economic and social effects. 4IR government policy intervention success relies on aligning to *government* and *country context*. Effective policy optimizes potential while mitigating vulnerability. Thus, policymakers should analyze the 5Cs: culture, connectedness, capabilities, competitiveness, and complexity to understand context.

Culture

Culture determines the change space. Citizen views toward growth, equity, environment, and well-being with different notions of prosperity define perceptions of government effectiveness. Cultural analysis identifies improved success measures beyond traditional metrics like gross domestic product (GDP). Today, there are "soft" metrics like Gross National Happiness (used by the Government of Bhutan) and those from the World Happiness Report. The question policymakers must ask themselves is: will developing nation and emerging economy citizens reject 4IR policy interventions that grow economies at the expense of increased inequity, resource depletion, or mental stress?

Connectedness

Connectedness determines the global integration space. Countries have varying levels of "participation in international flows of products and services (trade), capital, information, and people."[6] Most developing nations and emerging economies have poor levels of global connectedness, meaning that many potential 4IR interventions will not be effective. Can policymakers in developing nations and emerging economies effectively leverage and improve current connectedness to leverage 4IR opportunities?

> *The question policymakers must ask themselves is: will developing nation and emerging economy citizens reject 4IR policy interventions that grow economies at the expense of increased inequity, resource depletion, or mental stress?*

Capabilities

Capabilities determine the knowledge space. Human capacity, supported by education systems and cultural norms, determines how countries can benefit from the knowledge economy and "future of work" changes resulting from automation. Educational outcomes are poor in most developing nations and emerging economies, giving advanced economies more opportunity to win the 4IR war for talent. Can policymakers in developing nations and emerging economies overhaul education systems "to support technology diffusion and innovation."[7]

Competitiveness

Competitiveness determines the productivity space. Competitiveness measures "an economy's level of productivity."[8] Competitiveness differs among countries and sectors. However, advanced economies have far higher levels of productivity. 4IR changes the nature of productivity through massive automation. Can policymakers in developing nations and emerging economies find ways to improve productivity through 4IR investments?

Complexity

Complexity determines the sector space. Economic complexity recognizes the "composition of a country's productive output and reflects the structures that emerge to hold and combine knowledge."[9] A country's economy leverages expertise to enter adjacent markets effectively, where advanced economies benefit from higher economic complexity. Can policymakers in developing nations and emerging economies effectively identify adjacent and more advanced markets for economic penetration, leveraging 4IR technologies?

The 4IR VUCA Disruptive Effects

Policymakers can use a VUCA analysis to identify the footprint of *potential* and *vulnerability*, based on country context.

Volatility

4IR changes the calculus of technology adoption that "until recently new economic activities more than compensated for technology-induced unemployment."[10] Current disruptive technology changes, however, raise concerns that this time could be different. There is an expectation of skills instability "given the wave of new technologies and trends disrupting business models and the changing division of labor between workers and machines transforming current job profiles."[11] This will result in employment volatility in developing nations and emerging economies.

Uncertainty

4IR reconfigures global supply chains with uncertain effects. Technological development uncertainty includes "where the likeliest prospects of monetizing particular innovations and sectors lie."[12] This uncertainty about employment and economic effects challenges policymakers in developing nations and emerging economies who rely on offshoring, including low-cost manufacturing and outsourcing.

Complexity

4IR alters global supply chains and increases job complexity. This represents a grand challenge to governments faced with the interconnection of technology disruptions. Technology complexity with automation of lower-skilled jobs challenges education system capabilities in developing nations and emerging economies. Policy is further complicated by "environmental threats like climate change, demographic, health and wellbeing concerns, as well as the difficulties of generating sustainable and inclusive growth."[13]

Ambiguity

4IR volatility, uncertainty, and complexity increase ambiguity for policymakers. According to the GSM Association, "Accurate knowledge of the value and perils that technologies can create for companies and countries is not widely diffused."[14] Ambiguity about the pace of technology innovation, acceptance, and adoption challenges all policymakers.

Potential VUCA Effects in Developing Nations and Emerging Economies

The country context and "national political and policy responses, along with geopolitics, are likely to play a major role in deciding IR 4.0's winners and losers."[15] Potential VUCA effects and vulnerability to those effects differ widely among developing nations and emerging economies. Labor substitution, offshoring, and sustainability are some common effects for policymakers to consider in a VUCA analysis.

Industrial Labor Substitution Impact

Developing nations and emerging economies benefit from labor arbitrage in global supply chains. According to global market strategist Arnab Das, "Unlike the first three industrial revolutions, IR 4.0 has elements that substitute capital for labor rather than complement labor."[16]

Potential: 4IR technology is affordable and available for "technology leapfrogging." Traditional industrial economies of scale no longer matter in Industry 4.0. Developing nations and emerging economies can compete through this technology democratization.

Vulnerability: 4IR disrupts employment, particularly in less-skilled jobs, burdening government social safety nets.

Offshoring Market Impact

Developing nations and emerging economies benefit from labor arbitrage in outsourcing services such as call centers, software development, and business process outsourcing (BPO). 4IR enables firms to "re-shore."

Potential: Technology may not have a negative impact in the outsourcing market. Outsourcing firms may be able to leverage both lower costs from outsourcing and improved automated services to grow.

Vulnerability: Chatbots, robotic process automation, and machine learning reduce BPO employment.

Sustainable Development Impact

4IR presents "significant opportunities as well as challenges for developing countries"[17] in achieving the United Nations' 17 Sustainable Development Goals (SDGs).

Potential: Technology promises to solve global wicked problems. 4IR can provide tools for countries to reduce consumption and pollution, improve resource usage and food security, and mitigate climate change.

Vulnerability: Technology also threatens to intensify global problems. Economic growth through 4IR can increase inequality, pollution, and poverty while making countries more susceptible to climate change, resource loss, and food insecurity.

Policy 4.0 Framework

Policy 4.0 frameworks are meant to be "coherent, consistent, and mutually enforcing"[18] "to build 4.0 institutions, 4.0 governance, 4.0 states, 4.0 labor forces, and 4.0 entrepreneurs."[19] An effective Policy 4.0 framework is designed to "(a) sustain overall industrial performance, (b) in a way that helps close the gap to the frontier in a constantly evolving technological landscape, (c) while mitigating the adverse consequences for society, in terms of employment, privacy and latent social fabric."[20] Developing nations and emerging economies have broad gaps to the frontier of leading-edge broadband connectivity and manufacturing sophistication.

Policymakers can heat map country contextual elements against potential VUCA effects for scenario planning. These scenarios enable medium-term planning strategies, typically over a three-year period, while providing the early warning necessary for agile adaptation.

Culture Context in Policy 4.0

The cultural context informs policymakers of citizen values and perceptions for the *change space*. This sets policy guide rails for change readiness, social protection, and sustainable growth.

> *Developing nation and emerging economy policymakers confront an overwhelming menu of recommended policy solutions from experts.*

Connectedness Context in Policy 4.0

The connectedness context informs policymakers of the positive effects of overcoming infrastructure gaps and enabling the *global integration space*. This sets policy guide rails for digital infrastructure, physical infrastructure, international cooperation, and government digital transformation.

Capabilities Context in Policy 4.0

The capabilities context informs policymakers of the impacts of leveraging existing human capacity and of the positive effects of skills development to enhance the *knowledge space*. This sets policy guide rails for education, health, and migration.

Competitiveness Context in Policy 4.0

The competitiveness context informs policymakers of priority sectors for investment to enhance the *productivity space*. This sets policy guide rails for business reform, innovation support, and country rebranding.

Complexity Context in Policy 4.0

The complexity context informs policymakers of adjacent *sector space* investment priorities. This sets policy guide rails for industrial policy, academic support, and cooperation with international financial institutions and major nongovernmental organizations.

4IR Public Policy Intervention Recommendations

Developing nation and emerging economy policymakers confront an overwhelming menu of recommended policy solutions from experts. Governments from these countries typically have long-term national development strategies and national visions to achieve middle- or high-income status. These strategies often combine so many policy interventions as to ensure failure.

In contrast, developed country governments tend to focus on more realistic, shorter-term, incremental approaches. However, developing nations and emerging economies are unlikely to optimize 4IR effects through incremental policy approaches. Moreover, traditional national development strategies from these countries often lack realism.

Policymakers in developing nations and emerging economies can adopt solutions aimed at exploiting potential while reducing vulnerability. These can be prioritized and sequenced based on heat mapping and scenario analysis to develop realistic national development plans. These scenarios project which policy interventions will have the most impact. Policymakers should assess the following areas:

- **Effectiveness** — improve government performance through anti-corruption and institutional reform to improve policy certainty and the rule of law
- **Regulatory** — adapt legal and regulatory frameworks by removing barriers to digital adoption, enabling competition, easing doing business, simplifying firm entrance and exit, and adapting to the realities of digital technology business models like the sharing economy
- **Social support** — develop social protection, including employment protection, improving social safety nets and employment equity

- **Digital infrastructure** — improve digital and ICT infrastructure development, enable digital payments, and reduce the digital divide
- **Skills** — develop human capacity through education reform, re-skilling, the use of digital education to foster lifelong learning, and methods to attract highly skilled expats to return
- **Innovation** — enable innovation through tax incentives, innovation districts, the leveraging of government buying power, research grants, and research and development credits
- **Globalization** — improve international economic integration through trade agreements, augmented with physical infrastructure for logistics and reduced tariffs on necessary digital technology
- **Financing** — leverage innovative financing models, including public-private partnerships, to increase innovation investments and leverage the use of data as a development asset by encouraging business to monetize open data for products and services through "government as a platform"[21]
- **Smart government** — improve service delivery and cost through e-government, digital citizen services, transparency, open data, Internet of Things integration, and participatory digital collaboration open government in support of other policy interventions listed above

Policy Cooperation and Coordination

Policy 4.0 requires unprecedented levels of cooperation and coordination among government, civil society, international financial institutions, and business organizations. Most governments function based on specialized sector silos that battle for budgets and preponderance of influence in government strategies. Realistic national development strategies that overcome specialist thinking benefit from program management.

Program management and budgeting enable governments to align spending to a taxonomy of objectives across multiple years. This structure becomes embedded in financial management systems. Programs, projects, and activities can be coordinated across government ministries, departments, and agencies through financial systems. Program budgeting also enables integration with output and outcome performance measures, giving policymakers coordinated decision-making information. Outcomes can include SDG, governance, and well-being indicators.

Conclusion

Potential Industry 4.0 economic disruption challenges governments to transform policy making and governance. Developing nations and emerging economies are more susceptible to the VUCA effects of 4IR. Policymakers can optimize 4IR *potential* while mitigating *vulnerability* through articulating country context, analyzing potential scenarios based on this context, defining national strategies and interventions based on scenarios, and coordinating those strategies and interventions through program budgeting that enables decision making.

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The Skills Crisis 4.0: Accepting New Realities

by Barry O’Reilly

In the World Economic Forum’s “Future of Jobs Report 2018,”[1] a clear pattern emerges in desired skill sets — a shift toward critical thinking with a move away from skills relevant to industrial patterns of scale inherited from the Industrial Revolution, like modeling and perfecting processes. However, this shift may not be happening quickly enough in the workforce for Industry 4.0. This article examines the difficulties organizations experience when reskilling engineering teams to cope with the complexities of modern software development — as software moves center stage.

Industry 4.0 promises great riches to those who travel its path. Automation, better decision making, predicting the unpredictable — all of these promise the captains of industry that it is possible to squeeze more juice out of the same lemon one more time. Whether these lofty promises will ever be realized or they are simply a product of software vendors giving too much cash to their marketing departments to lavish on tall tales remains to be seen. One theme is common though: as companies move toward solving more of their critical everyday needs with advanced technology, almost all report suffering from a shortage of skills to handle wave after wave of new technologies.

As Industry 4.0 drives software to become a more central part of every business, the problems that businesses try to solve become less about automating old processes, as computing has been doing, and more about inventing a new world in which computing drives business rather than mirrors it. This means interfacing with the complexities of the real world; the focus shifts from automating simple processes and tasks to engaging with the uncertain, messy world of real business. It is this shift from simplistic engineering and time saving to engaging with real-world business complexity that causes most difficulty in software engineering today — and it is a key feature of Industry 4.0. Engaging with real-world complexity requires new skills outside of what the universities or vendor certifications are teaching today — the exact same set of skills noted by the World Economic Forum.[2] Critical thinking, complex problem solving, and anticipatory thinking are the necessary tools for navigating these problems.

What Is the Skills Shortage?

A skills shortage in the IT industry is not new; the problem is almost as old as the industry itself. Universities are not producing enough work-ready graduates to meet employer demand. This skills shortage is not just an irritation; it is something that threatens economic growth, and, for regions that manage to attract technical talent, this ability promises a lot in terms of economic upswing.

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So what makes the Industry 4.0 skills crisis different from previous skills crises? One aspect of Industry 4.0 is the Internet of Things (IoT). The journey since 2013 within IoT points to a new set of challenges that have not been present before. A sudden proliferation of ideas, patterns, tools, and protocols, coupled with very few case studies, provides a set of challenges that few software architects and engineers have ever dealt with. The combination of cloud computing, IoT connectivity demands, and the sheer size of the data sets creates a set of challenges that make succeeding difficult. Disruption of old industries, and of traditional business models, has caused fear and uncertainty in many large companies, and no solution has been the same twice over. There was not only difficulty in how to do IoT, there was also a huge amount of uncertainty around what to do on both a business and technical level. The rapid mobilization of software vendors around IoT and Industry 4.0 as drivers of cloud revenue meant that there was much encouragement and hype, but even today most industries are still finding their way through their first steps.

This rush of ideas and uncertainty has led to conflict and hesitance as old role descriptions no longer fit, and many feel unsure of how to proceed. Failed Industry 4.0 projects are stories of confusion, inertia, and small proof-of-concept projects that never make it any further. In terms of skill sets, the picture emerging from Industry 4.0 is constantly shifting and still not settled. Even for seasoned veterans in the IT industry, the pace of change has been intimidating. The cultural, political, and social impacts of this change are as difficult to navigate as the technical ones, and the herd instinct of the IT industry means that we are seeing constantly redefined trends as companies discover the truth behind the hype in tough lessons from pilot projects. Every project is a step into the unknown and requires skills not only in the rapid assimilation of new ideas and technologies, but also in navigating and managing this risk.

> *The IT skills shortage has been around long enough for some to have proposed solutions. Will these ideas work for Industry 4.0?*

Industry 4.0 requires experimentation and constant reinvention as everything changes, from business models to technology platforms to hype and social trends. Constant change requires a steady supply of engineers in an ever-growing field of products, protocols, and platforms — and there simply aren't enough to keep up. What's more, with the cultural and sociotechnical aspects of Industry 4.0 at play, these problems are not simply complicated, they're complex — and this requires a completely different set of skills to navigate, a set of skills not taught in any university computer science program. Navigating complexity and uncertainty in the face of ongoing technical reinvention is the core work of systems architects in Industry 4.0 projects. With all this in mind, a protracted and difficult skills shortage for Industry 4.0 seems in hindsight both inevitable and predictable.

Learning in Real Time

The current state of Industry 4.0 requires that innovators constantly learn technologies that haven't even been proven to work at scale and may never make it to production. This isn't lifelong learning; it's "just in time" learning. Unfortunately, this type of learning often clashes with our traditional view of skills acquisition. For many years, software engineers worked with platforms that changed every few years, with a constant feedback loop from vendors that allowed them to stay up to date with a disciplined approach to learning. Now, the release cadence of cloud platforms central to Industry 4.0 is four to six weeks, and there has been no wide-scale change in the approach to learning. The truth is that there cannot be a scalable version of the old ways of learning; it simply won't work. Industry 4.0 cannot be staffed using the educational theories of Industry 1.0. We do not need to learn faster, better, or cheaper; we need to learn in a completely different way. The challenge of working in these kinds of initiatives is that work cannot simply be reduced to factory-like machinations; engaging with Industry 4.0 requires a continuous cycle of probing and experimentation where learning is part of the job, not preparation for it.

The Never-Ending Skills Crisis: Lessons from the Past

The IT skills shortage has been around long enough for some to have proposed solutions. Will these ideas work for Industry 4.0?

A 2018 report from Almega shows that in Sweden alone, a shortfall of skilled people expects to leave 70,000 IT positions vacant by 2022, mostly in the areas of system architecture and programming.[3] Similar stories are familiar all over the globe. However, Sweden is especially relevant for a number of reasons: a long tradition of innovation and a willingness to embrace new technology, combined with universal free education right up to the master's degree level, should theoretically make it easy to produce computer science graduates. The continued existence of a shortfall, however, shows us that a technologically-enabled and educated workforce is not the sole solution to the problem.

Past Approaches to the Crisis

Let's look at some past approaches to the skills crisis and see if we can glean any lessons from them.

Government Initiatives

There is no shortage of government-funded initiatives, usually based around fast-paced reskilling programs and often sponsored by one or more vendors. This was a common approach even in the late 1990s when the first waves of e-commerce created a perceived skills gap. This hints at the fact that such measures are a Band-Aid on a much bigger wound — considering that we have tried and failed to manage a skills shortage over seven generations of university students.

MOOCs and Ease of Access to Education

The rise of MOOCs (massive open online courses) provided hope that we could mitigate the never-ending skills crisis by making education of software engineers cheap, easy, and accessible. The rise of companies like Pluralsight and the success of online education in artificial intelligence are positive anchors toward solving our shortage predicament; engineers now have access to a huge library of dynamic educational resources and can learn at their leisure for incredibly low fees (and they are doing so).

Offshoring

Another promising trend in solving the skills crisis was to move programming work to countries and regions with lower labor costs. However, offshoring, for multiple reasons, has declined in popularity in recent years. The shortfalls of offshoring become even more apparent when working with complex programs that cannot be described or managed in contractual terms.

Automated Candidate-Role Matching

The last few years have exposed the weakness of the concept of technology-driven recruitment at scale. LinkedIn ads seeking candidates with 10 years' experience in a technology that has only existed for two is not uncommon. Senior engineers receive job offers for junior or even unrelated roles on a daily basis. This simplification of the IT market in order to make recruitment scalable has not helped solve the skills shortage; in fact, it may be making things worse.

The reason for this is simple: we are still stuck in an age where IT roles are mapped to proficiency in vendor products. The recruitment model is not to blame for this but is a reflection of this mapping. The vendors like to keep it that way, as programmers who are well versed in their technology are pigeonholed and continue to support that vendor technology. This encourages a mindset of linking skills to tools, rather than ability.

Selling Computing to High School Students

Another approach is the marketing of careers in tech to prospective university students, selling the positive aspects of a career in this industry. However, a UK government report shows that 13% of computer science graduates remain out of work six months after graduating[4] — not exactly presenting a grand glimmer of hope. Despite having computer science degrees, graduates are not considered to be prepared for the practical aspects of delivering technology and not at all prepared for the constant flux in technology. On top of this, they experience barriers to entry caused by the recruitment industry's treatment of product knowledge as the measure of technology skill and an unwillingness of businesses to invest in relatively short periods of apprenticeship to learn these products.

It is apparent that we cannot simply continue as we have in the past. Educating engineers faster, matching them to jobs more easily, and simply doing "the same old thing" has not solved the earlier skills crises — and Industry 4.0 presents even tougher challenges than what we have experienced thus far.

A Crisis of Perception?

Despite the impression that software is rapidly changing, with wave after wave of new ideas and technology, the truth is that it is very static. Modern ideas driving the technical focus of Industry 4.0 are perceived as revolutionary, even though ideas such as the actor model were conceived in 1972. Machine learning is the application of algorithms to statistics, which has theoretically been established for several generations. Such is the disconnect between academia and industry that after 20 years of practical software engineering, most professionals' daily work is far removed from the lectures they attended, so when these subjects resurface, they appear brand new! The theoretical basis for Industry 4.0 already exists and can be made available to anyone through MOOCs and online platforms; only the experience of practical application in changing contexts is missing.

For this reason, talk of a skills crisis in IoT a few years ago was plainly ridiculous — the market or engineering foundations are still not established enough for a more formal emergence of expertise to exist so trying to hire that expertise by searching a skills database will lead to a perpetual sense of crisis. Instead of seeking expertise from the beginning, accepting emergence of expertise over time may be the best way to combat a crisis that possibly exists more in our perception than in reality. Perhaps the skills gap is not a gap in *knowledge of platforms and products*, but a gap in the *ability to navigate the unknown* without the comfort blanket of product or platform expertise. Many see the solution as a workforce trained in the latest and greatest technologies and call the gap between the solution and reality a crisis, but perhaps the assumption that such a workforce can exist in this environment is the cause of the problem?

Government initiatives to teach coding miss the point, as successful software engineering in complex environments is going to need skills outside of coding to be successful.

Viewing the Skills Crisis Anew

The information presented above provides a clearer view of the skills shortage. The ability to navigate complex situations and problems is the major issue, not knowledge of specific languages, frameworks, or vendor tooling.

Government initiatives to teach coding miss the point, as successful software engineering in complex environments is going to need skills outside of coding to be successful. Current thinking and policy focus on producing more people who can code, not who can think in a way that allows coding to be used properly.

The basics of computer science are still important, but these are easy to master if taught in context and shown to be relevant to the everyday work of software engineering, rather than a separate rite of passage that seems to bear little relation to the working world graduates are released into — a world that leaves 13% of them unemployed six months after graduating!

If we are to abandon the simplistic idea that the skills crisis can be solved by increasing the number of people entering the field or who know the platforms we are working with, we need to propose new solutions.

However, employers are keen to see graduates who are work-ready,[5] and in many cases this means already knowing the latest trends and tools. This is an impossible task for universities to meet, given the never-ending pace of change; even if they succeeded, students graduating with relevant skills today will still need to retrain in a few months as new patterns and tools emerge. Regardless of what universities do or how accessible government or industry programs make IT education, every single graduate will eventually face a choice between self-sustaining renewal or career stagnation.

Alternative Solutions

The tech industry also suffers from another, remarkably well-hidden problem: age discrimination. Over the age of 45, many in the industry feel dispensable and struggle to find work if they should find themselves unemployed. Having been through many waves of technology before, this group of people undoubtably contains the critical-thinking skills needed by Industry 4.0. However, these resources possess only out-of-date skills, with little weight being given to the critical faculties developed over a career. Allowing for easy mid-career transitions to different areas of specializations would make this group a powerful remedy to skills shortages but requires a shift in thinking from employers.

A huge number of software projects still fail and multiplying the number of people who do the *same old things* will not change this failure rate. Today's skills gap is probably smaller than the number of talented developers currently wasting their time on failing projects or dedicating their time to overhyped trends with no basis in economic reality. Teaching programmers and their extended teams to think critically would allow for much faster abandonment of failing projects and acceptance of this as a natural way of doing business with technology will free up resources and ease the workload.

Industry 4.0's predilection for hype is also an issue. For example, many technologies form their own skills crisis as businesses seek resources who know this specific toolset — only for that toolset to be retired after a few years with few tangible benefits. These resources are also wasted, with specialist knowledge gained now useless.

If we could leverage the huge pool of older resources, waste less time on failed projects and hyped projects, and encourage the acceptance of emergence, we would at least reduce the number of resources needed. This solution, however, requires organizations to be more critical in their navigation of Industry 4.0.

Teaching Critical Thinking

Some theories on critical thinking view the skills of critical thinking as separate from contextual knowledge, while others see the two as inseparable.[6] There is little consensus. Regardless, Industry 4.0 is pushing the fields of business and technology so close that they are becoming a single context and thinking critically about one is impossible without knowledge of the other. This is a defining characteristic of Industry 4.0, and one that creates problems but also provides opportunities. This alignment of the two fields demands that many engineers and associated business roles on Industry 4.0 projects need to broaden their context to cover both business and technology specializations, another step toward becoming generalists. By exposing more computing graduates to business studies, and more business people to computing, we increase the size of the pool that can engage in critical thinking around delivering technology into business environments and make more effective decisions that reduce issues of resource wastage on hype-driven projects or ill-defined initiatives.

Research shows that there are four techniques that have specific impact on a student's critical thinking, and while we leave the debate about how to better produce critical thinking in K-12 education to those that work in that area, one important point was the impact of mentoring in combination with dialogue and real-world problem solving.[7] Encouraging this kind of mentoring within a company could have a significant impact on how critical thinking is spread through an organization, making it easier for technologists to tackle shifting technology landscapes with confidence.

Conclusion

We currently live in a world where we need the knowledge and experience built up over a career to navigate the complexity involved in most fields. In the technology industry, we have come to expect this experience to simply appear despite constant technological change. The seemingly obvious solution of educating faster and cheaper and wider has been shown to be ineffective — and the obvious next step is to question how we can better navigate this crisis in the future. Assuming that we must learn in the same way is a mistake, and we limit ourselves by consigning solutions to copies of what has worked in the past. Rather than learning faster, one option is simply to learn better. A field of software engineering where knowledge of a platform or technology is not a prerequisite to working on a project would solve the perception of a skills crisis overnight. Equipping engineers with the necessary skills to handle complexity, transition, and breadth, with a real and solid grounding in practical computer science that stays with them throughout their careers, is essential.

In Industry 4.0 we see a glimpse of the future: technology will always change faster than education, so learning how to cope with change and complexity is the only feasible alternative to learning technologies as they appear. A new set of heuristics is necessary; the role of the modern technologist will be similar to that of the emergency medical field teams that deal with virus outbreaks and who do not need to know the exact nature of the virus to begin with containment as they learn more. Creating just-in-time units of software delivery capacity will become a key skill, and at the root of all this will be the developer, free from vendor branding, a critical thinker with the confidence to tackle new problems without prior knowledge of relevant products. Learning how to leverage the critical-thinking skills acquired in other disciplines to allow transition to technology careers for those that already have the (much harder to establish) soft skills in place would also help.

In conclusion, the perception of a skills crisis makes realizing the vision of Industry 4.0 difficult for many organizations. Those that encourage critical thinking to drive skills transition as part of the job will gain ground on those that wait for government agencies and universities to solve the problem for them. We can take some simple steps in both the short and the long term to combat this skills crisis. In the short term, ensuring that a culture of lifelong learning is established and encouraged, both financially and organizationally, will go a long way to making sure that organizations can build the necessary flexibility in their workforce to avoid desperate recruitment drives. Combining this with a culture of acceptance around late-career transitions will provide a steady flow of talent from existing pools of older employees currently being assigned to the scrap heap.

In the longer term, reassessing our view of skills will be necessary. Instead of focusing on narrow platform and vendor-focused skill sets that make for easy searches in recruitment databases, we need to focus on the core skills that make employees able to consistently embrace new technologies successfully: critical thinking, computer science basics, a broader exposure to the humanities, and an ability to combine digital skills with industry experience. Developing these core skills requires changes to the educational system at all levels, which should not be unexpected given the huge transitions to the way in which our society uses knowledge today compared to when our educational systems were designed. By using mentoring, critical dialogue, and project-based learning for junior engineers, we can help nurture a critical-thinking culture that reduces wasted resources and risk-filled vanity projects, making more resources available. In short, we can do more with less, which is one of the driving forces behind Industry 4.0 in general!

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Challenges of Cybersecurity Management in Industry 4.0

by Feng Xu and Xin (Robert) Luo

With the ever-increasing integration of information technology, services, and advanced manufacturing, we are in the midst of a paradigmatic transformation toward Industry 4.0. Through the diffusion of digitally automated technologies, Industry 4.0 can combine operational technology, such as industrial control systems (ICSs), with information technology to enable smart manufacturing.[1] By optimizing the computerization of its predecessor (Industry 3.0), Industry 4.0 triggers a huge number of digital connections between devices and networks. In fact, *Forbes* estimates that there will be more than 75.4 billion devices connected to the Internet by 2025.[2]

The concept of Industry 4.0, first coined by Germany Trade & Invest (GTAI) in 2011,[3] was considered an evolution of manufacturing that transfers embedded systems to cyber-physical systems (CPSs). To illustrate the concept of Industry 4.0, GTAI invoked two crucial elements of Industry 4.0: the Internet of Things (IoT) and CPSs. Recent research has extended the concept to include other technology, such as wireless sensor networks[4] and the cloud.[5] While IoT and CPSs are deemed the most important technology components of Industry 4.0, this new wave of technology also relies on IoT device networking[6] and data networking.[7] These technology components form the foundation of Industry 4.0.

While enhancing digital transformation, Industry 4.0 inevitably ushers in new potential cyberrisks to manufacturing and its associated supply networks. Indeed, 31% of more than 3,600 respondents interviewed for the Cisco 2018 annual cybersecurity study reported that they had experienced cyberattacks affecting their industrial equipment.[8] The physical-to-digital-to-physical connection allows participants to access real-time data instantly, but at the same time, possible attackers can gain unparalleled access to the IoT network and disrupt physical devices. Therefore, it becomes imperative to understand how to identify and manage cybersecurity issues in the emerging era of Industry 4.0.

This article attempts to identify the challenges of cybersecurity management in Industry 4.0. We first examine the specific characteristics of security challenges and then discuss the challenges of cybersecurity management in Industry 4.0. Based on these discussions, we present actionable insights that can effectively protect industrial assets.

While enhancing digital transformation, Industry 4.0 inevitably ushers in new potential cyberrisks to manufacturing and its associated supply networks.

Cybersecurity Issues in Industry 4.0

The three conventional essential security requirements are confidentiality, integrity, and availability, which present somewhat different issues in the age of Industry 4.0 (see Table 1). The essence of security in Industry 4.0 is to protect the confidentiality, integrity, and availability of two critical assets: industrial control systems and CPSs. The critical element of Industry 4.0 is the IoT, which requires integration and cooperation across these systems. However, security objectives across systems are rarely aligned.[9] For example, a control system engineer is not concerned about data loss, but an IT system administrator cares about information assurance. In addition, increasing connectivity leads to greater and farther-reaching risks. Attackers might attack the targeted systems by intruding into the weakest parts of other connected systems.

Confidentiality

As manufacturing evolves, it requires real-time information sharing among all participants in the digital supply network. However, information sharing creates significant cyberrisk; balancing confidentiality and data sharing is difficult. The protection of confidentiality

CIA Triad	Objective	Issue in Industry 4.0
Confidentiality	Keep information protected from unauthorized access.	Real-time information sharing increases the difficulty of protecting confidentiality. A combination of technical methods with other governance approaches becomes necessary.
Integrity	Only authorized subjects modify information.	Integration of operational technologies with IT infrastructure increases the risk of integrity violation. It is easy to attack unprotected control systems. Thus, it is critical to build cybersecurity into the design process.
Availability	Information is timely and accessible to subjects.	Increasing connectivity increases the risk of exposure. The impact of availability violation becomes greater and more significant. Security management must be part of the entire product lifecycle.

Table 1 — Confidentiality, integrity, and availability in Industry 4.0.

becomes more complex and dynamic in Industry 4.0 as the violation of confidentiality might destroy the entire industrial supply chain. Plus, techniques that solely address confidentiality risks are inadequate. They must be combined with other approaches, such as data governance, to ensure the confidentiality of industrial systems.

Integrity

The integrity of industrial systems is easily violated due to tighter integration of operational technologies with the IT infrastructure. It is important to maintain the integrity of the information flow throughout the industrial supply chain. Compared to traditional integrity protection, integrity in Industry 4.0 requires consistency and trustworthiness of both the information flow and the physical components. However, a recent security report found that the physical systems of a third of manufacturers have not been protected.[10] Organizations need to adopt advanced risk management to preserve integrity and remain secure.

Availability

The mounting number of network-connected devices leads to a variety of exposure points, which can be targets for attackers. Compared with Industry 3.0, this situation would have a broader and more significant impact on stakeholders, such as customers, producers, or manufacturers, in Industry 4.0. For example, increasing connectivity might cause the entire industrial supply chain to be out of service if components of the chain are attacked. Organizations need to focus more on the availability of a physical process, such as temperature control or energy consumption, and pay attention to the whole product lifecycle.

Cybersecurity Management in Industry 4.0

Cybersecurity incidents lead to huge loss or severe damage to industrial assets. To mitigate cybersecurity threats, it is essential to understand the cycle of information security governance and control: preparation, prevention, detection, response, and learning.[11] This information security management cycle provides important guidance to organizations dealing with security incidents. However, in the context of Industry 4.0, these five tasks present different challenges. Table 2 lists the challenges of cybersecurity management.

The Security Management Cycle

Preparation

Preparation is the first step in information security management. It emphasizes risk identification and understanding attackers' motivations. For example, opportunist attackers do not have a specific target and

Cycle Phases	Tasks	Challenges in Industry 4.0
Preparation	Understand motivations, tactics of external and internal attackers, and vulnerability and risks.	Denial of service is one of the most common attacks in Industry 4.0. The motivations of attackers and internal risks are difficult to understand. Attackers can attack targeted systems indirectly through other connected systems.
Prevention	Identify emerging methods and security practices to prevent external and internal threats.	Technical methods alone are inadequate to counter threats. Technical methods must be integrated with a security governance approach.
Detection	Combine automated and human cybersecurity detection.	The IoT is making cybersecurity incidents more dynamic and complex. Artificial intelligence needs to be leveraged for threat detection.
Response	Identify and respond to stakeholders; adopt effective response plan.	All participants throughout the industrial supply chain are potential stakeholders. Attacks that occur in one system may lead to damage to other systems, whether they belong to manufacturers, customers, or factories.
Learning	Learn from incidents.	Organizations that have experienced security incidents must learn both their internal risks and their vulnerability throughout the industrial supply chain. Guidance or advice should be proposed at a cooperative and industrial level.

Table 2 — Cybersecurity management in Industry 4.0.

are more likely to attack organizations that have known vulnerabilities. Rogue employees might be emotionally motivated to access sensitive systems or data. Understanding attackers' motivations can help an organization adopt proper security management mechanisms. The organization might, for example, build response teams, provide checklists, or develop contingency plans. In Industry 4.0, it takes more effort to understand the motivations of attackers, who can successfully attack a target indirectly through the connected systems, making understanding their initial motivations a hard and complex task.

Prevention

The prevention phase aims to identify emerging threats and methods to counter them and to provide security training and education. Due to the rapid evolution of cybersecurity threats, it is critical to identify new methods and tools to prevent threats. In addition, organizations should take efforts to prevent insider security threats, such as providing security countermeasure training. The purpose of prevention is to reduce the occurrence probability of security incidents. In Industry 4.0, the ramifications of insecure IoT devices increase threat occurrence probability. Organizations must not only take measures to prevent threats to themselves; they also need to protect distributed systems. Advanced technical methods alone cannot adequately prevent threats, making an integrated approach necessary.

Detection

With the rapid increase in data volume, information security incident detection requires more automated mechanisms to improve the efficiency of detection. Human cybersecurity detection will be supplementary to automated incident detection, and the combination will maximally protect organizational security. Despite the addition of improved automated incident detection, security threats in Industry 4.0 become more dynamic and complex due to the IoT, making the leveraging of artificial intelligence to detect cybersecurity threats necessary.

Response

Once a security incident is detected, an organization should respond quickly to analyze and deal with it. For example, organizations should hire specialists to analyze security incidents. According to the US Securities and Exchange Commission (SEC), after detection of an incident, organizations must identify and respond to stakeholders.[12] In an industrial supply chain, an attack might intrude on one of the weakest systems in order to destroy the entire supply chain. Thus, a concerted effort is necessary in this process because all members of the industrial supply chain may be stakeholders in the attack response.

Insiders have become one of the most perilous threats to organizational security.

Learning

Organizations should learn from any incident they experience and must recognize the value of post-incident reviews. They need to compare different incidents, identify their system vulnerabilities, and strategize how to reduce the number and impact of future security incidents. In the context of Industry 4.0, advice and guidance must be provided at an industrial and cooperative level. Organizations need to consider not only their own systems but also those of the entire industrial supply chain.

Recommendations for Cybersecurity Management in Industry 4.0

Based on our discussion and analysis of cybersecurity features in Industry 4.0 and the challenges of cybersecurity management in Industry 4.0, we offer five recommendations for protecting cybersecurity in Industry 4.0.

1. Build a 360-Degree Focus of Information Security Management

In Industry 4.0, connected systems will likely create and expose new cyberchallenges. Due to these connected systems, security threats occurring in any part of the supply chain may lead to a catastrophic loss. Thus, information security management in Industry 4.0 requires a 360-degree orientation. Organizations should focus on a broad range of security issues across the entire industrial supply chain. For example, they need to coordinate and cooperate with all ecosystem constituents, such as suppliers, retailers, and customers. Traditional security management generally focuses on vulnerability, whereas security management in Industry 4.0 should consider the characteristics of interconnections and concern itself with the entire industrial supply chain.

2. Build Cybersecurity into the Design Process

In Industry 4.0, connected objects extend cyberrisks to physical objects. With the IoT, a huge number of physical devices, designed without concern for security, are connected to the Internet. Most of these systems have a low level of security protection, creating a higher likelihood of attack. Cybersecurity should be considered from the beginning to the end of the development lifecycle for IoT devices. It is essential that organizations build security into the design process, assess the effectiveness of security controls, and implement security practices to produce secure devices.

3. Develop an Integrated and Cooperative Approach to Cybersecurity

The cyberrisks of sharing data across the digital supply network increase with Industry 4.0. Cybersecurity now extends beyond the isolated organization. In Industry 4.0, cyberattacks can threaten any interconnected physical system, and an attack occurring in any component of the industrial supply chain will influence the security protection of the entire industrial supply chain. An organization's focus on threats to internal systems is no longer sufficient to protect security. An integrated and cooperative approach, requiring cooperation across organizations and responsibility to the entire industry and all stakeholders, is now a necessity.

4. Recognize That Insiders Are the Weakest Link

Insiders have become one of the most perilous threats to organizational security. The potential impacts of insider attacks on industrial supply chains are becoming increasingly significant. With IoT-enabled connections, information becomes easily available through remote access mechanisms. Insiders are more likely to be motivated to attack CPSs in order to achieve huge benefits. All participants can access the information that flows throughout an entire industry, creating a huge challenge to control insiders so as to protect industrial assets.

5. Establish Strategic Information Security Governance

Implementing cybersecurity as part of an organization's strategy is critical to strengthen the new industrial ecosystem. In Industry 4.0, cyberrisks occur due to vulnerabilities in physical devices, insecure transmission of data, embedded application risk, and so forth. It is insufficient to base organizational information security only on siloed technical methods. Establishing strategic information security governance has become an indispensable way to protect an entire industry. This strategic governance considers not only security governance at the organizational board level but also security cooperation at the industrial strategy level. Leaders must recognize opportunities and risks associated with industrial supply chain systems.

Conclusion

This article described cybersecurity issues in Industry 4.0, identified the challenges for cybersecurity management, and presented five strategic recommendations for security protection in Industry 4.0. We believe that a better understanding of cybersecurity requirements will help organizations strengthen their defenses against potential attacks. Organizations should pay more attention to the challenges of cybersecurity management in Industry 4.0 and adopt effective and proper approaches or mechanisms to mitigate cybersecurity risk.

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Industry 4.0: Ethical and Moral Predicaments

by Weiyu Wang and Keng Siau

The advancements in software technology and data science are enabling Industry 4.0, aka the Fourth Industrial Revolution or the Industrial Internet of Things (IIoT). While the first three industrial revolutions have brought about immense change, the impact of Industry 4.0 will be much wider and far greater, especially with regard to the easily overlooked ethical and moral aspects. Widening wealth gaps between countries and among classes of people within countries, a potential growing unemployment rate, data privacy and accessibility issues, and the treatment of intelligent agents (e.g., military robots) present new and complex ethical and moral dilemmas.

In this article, we discuss Industry 4.0 ethical and moral predicaments from the perspective of different business and technical forces. We present ethical and moral issues related to data privacy, data ownership, system accessibility, cybersecurity, the future of work, and the future of humanity. Our aim is to present various challenges and discuss ethical and moral considerations from different perspectives. We hope this discussion will give business executives and technical designers/developers a better understanding and appreciation of the ethical and moral challenges Industry 4.0 presents.

Industry 4.0's opportunities and benefits can be seen in more efficiently used resources, more personalized customer service, and easier-to-use and more cost-efficient upgraded equipment.

Industry 4.0

Industry 4.0 collectively refers to a wide range of concepts, including cyber-physical systems (CPSs), the Internet of Things (IoT), artificial intelligence (AI), cloud computing, smart manufacturing, decentralized self-organization, and advanced analysis techniques. It focuses primarily on the establishment of smart factories, smart products, and smart services embedded in the IoT and the conversion of established factories into smart manufacturing environments. Industry 4.0 allows for continuous interaction and information exchange among humans (consumers), between humans and machines, and between the machines themselves.

In 2013, Morgan Stanley predicted that more than 75 billion objects will connect to the IoT by 2020.[1] New, flexible business models that enable personalized and digital products and services will need large amounts of high-quality data in the near future. Highly automated and even autonomous machine tools and robots will be widely available. By 2025, the rate of automation (division of labor as share of hours spent) will be 52%,[2] a sharp contrast to the 2018 rate of 29%. Indeed, unless there's a creation of new industries not yet present, the number of workers will likely decrease. New and remaining jobs may require more knowledge than current ones and may also demand new skill sets. This will necessitate retraining and retooling of existing workers. Consequently, the education paradigm will have to be reengineered. Also, with Industry 4.0, the organization will be more decentralized rather than centralized, which not only leads to management complexity but also challenges existing management theories and practices.

Industry 4.0's opportunities and benefits can be seen in more efficiently used resources, more personalized customer service, and easier-to-use and more cost-efficient upgraded equipment. More intelligent agents in CPSs will release humans from laborious tasks, allowing people to dedicate time to more meaningful work. However, we cannot overlook the challenges and risks Industry 4.0 presents. The main challenges revolve around technological, organizational, strategic, legal, and ethical and moral issues. Our focus here is on the ethical and moral issues that have thus far received little attention.

Ethics

Ethics is a complex, complicated, and convoluted concept, which we will not attempt to define in detail in

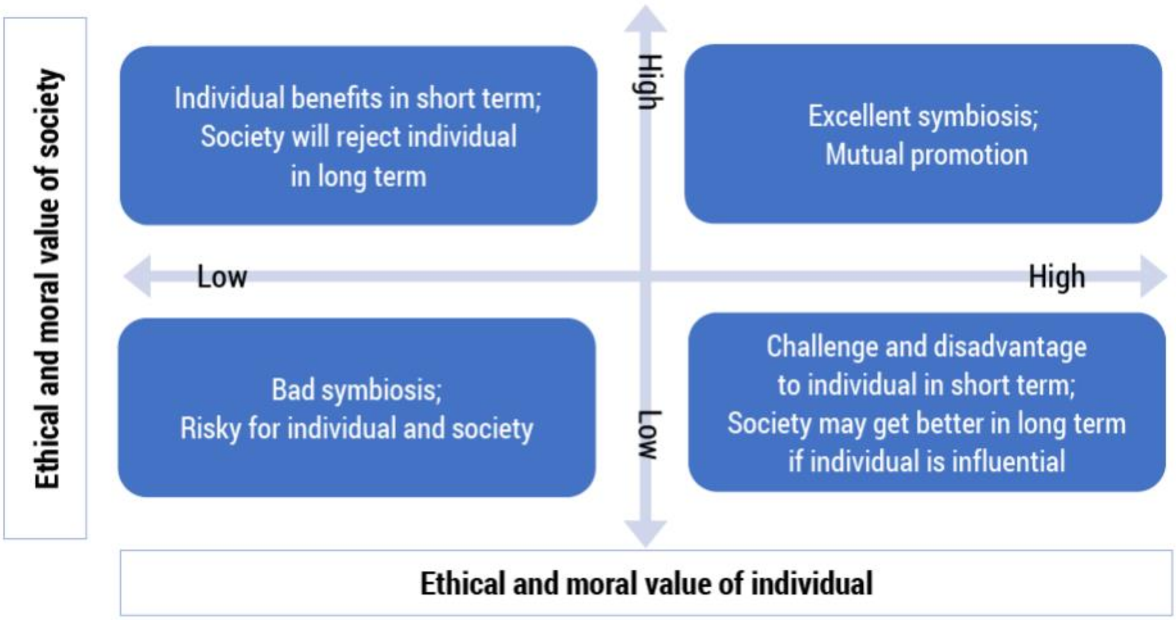

Figure 1 — Symbiosis of society and individual (ethical and moral values).

this article. Briefly, ethics refers to the moral principles that govern behavior, and the study of ethics involves what constitutes ideal conduct in various situations.

Ethics affect both individuals and society as a whole, as illustrated in Figure 1. A highly ethical society and a highly ethical individual can mutually promote ethics, establishing a good symbiosis. In a society with high ethical values, an individual with low ethical values may benefit in the short term, but in the long term, society will reject that individual. If the individual has high ethical values but the society has low ethical values, it will be challenging for the individual to survive in this society; if the individual is influential, the societal ethics may improve over the long term. The worst situation is when both society and the individual have low ethical values.

To study ethical issues is to examine the moral aspects of conduct and the actions deemed "morally acceptable." Table 1 provides an overview of some established ethical frameworks. The framework examples provide background knowledge to aid in understanding ethical issues. Some scholars believe that classic ethical principles can and should be used to deal with new technology, which, as an example, should not bring any harm to users. Others argue that new dimensions of ethical issues, such as the responsibility of machines, should be considered and included in the discussion. For instance, the involvement of intelligent agents in manufacturing enables some tasks to proceed without human participation. But if an agent makes the wrong decision and causes severe damage (e.g., kills somebody), is the agent solely responsible? What about the designers and builders of the agent? In the next few sections, we will analyze potential ethical issues in Industry 4.0 from different perspectives.

Ethical and Moral Forces in Industry 4.0

The ethical forces of Industry 4.0 exert their influence over different stages in value chain activities — from design, development, and production to application. Tracing the ethical responsibility and decision making of each stakeholder associated with value chain activities is very important and poses a major challenge. AI and autonomous systems make the tracing of ethical responsibility more pressing because some of those functions may be performed without human intervention. A lack of ethical and moral standards in those autonomous agents and decision-making software is a problem, and a lack of experience and guidance in formulating ethical and moral standards in Industry 4.0 exacerbate the problem.

In general, the difference between Industry 4.0 and previous industrialization comes from the wide application of CPSs, which connect the physical and virtual worlds and realize real-time information interaction among different stakeholders. In past industrial revolutions, technology supplemented and replaced the limited physical strength and speed of humans. In Industry 4.0, advanced technology can supplement and replace humans' limited cognitive processing space/scope, along with speed. This is at

Reference	Ethical Framework
"The Belmont Report: Ethical Principles and Guidelines for the Protection of Human Subjects of Research." US Department of Health, Education, and Welfare. Publication No. (OS) 78-0014, 18 April 1979.	**Ethical principles:** respect for subject (the right to decide whether to participate); beneficence (do no harm to participants); and justice (fairly distribute costs and benefits of research)
Mason, Richard O. "Four Ethical Issues of the Information Age." *MIS Quarterly*, March 1986.	**PAPA issues:** privacy, accuracy, property, and accessibility
Bentham, Jeremy. *The Collected Works of Jeremy Bentham: An Introduction to the Principles of Morals and Legislation*. Clarendon Press, 1996.	**Act utilitarianism:** tally the consequences of each action first and then determine on a case-by-case basis whether an action is morally right or wrong; **hedonistic utilitarianism:** pleasure and pain are the only consequences that matter in determining whether the conduct is moral or not
Wallach, Hanna. "Big Data, Machine Learning, and the Social Sciences: Fairness, Accountability, and Transparency." Medium, 19 December 2014.	**Ethical principles:** fairness (bias, fairness, and inclusion), accountability, and transparency
Sinnott-Armstrong, Walter. "Consequentialism." In *The Stanford Encyclopedia of Philosophy*, edited by Edward N. Zalta. Stanford University, Summer 2019.	**Consequentialism:** engaging in action that causes more good than harm
Hursthouse, Rosalind, and Glen Pettigrove. "Virtue Ethics." In *The Stanford Encyclopedia of Philosophy*, edited by Edward N. Zalta. Stanford University, Winter 2018.	**Virtue ethics:** having ethical thoughts and ethical character
Alexander, Larry, and Michael Moore. "Deontological Ethics." In *The Stanford Encyclopedia of Philosophy*, edited by Edward N. Zalta. Stanford University, Winter 2016.	**Deontological ethics:** conforming to rules, laws, and other statements of ethical duty (e.g., religious texts, industry codes of ethics, and laws)

Table 1 — Examples of ethical frameworks.

the same time both exciting and frightening. Humans are not the strongest in the animal kingdom, but our cognitive superiority has enabled our dominance as a species on this planet. If our cognitive superiority is challenged, the future of humanity is uncertain.

We use "force" to describe any agent that may interact with CPSs and can take responsibility (or be responsible). Based on the roles each force plays, we classify the forces into two groups: (1) technical-oriented and (2) business-oriented. Figure 2 shows the forces and the interactions and communication among them, which is the collective responsibility of the business- and technical-oriented forces. Next, we discuss the responsibilities of the various forces in promoting an Industry 4.0 that subscribes to high ethical and moral values.

Business-Oriented Forces

In today's competitive business environment, ethical issues arise frequently. Business partners may not respect contracts, or competitors may attempt to steal business secrets. With Industry 4.0, the situation becomes much more complex. Consider the trend to personalized production, which benefits individuals who receive personalized services. Achieving personalized services, however, involves big data, data science, AI, machine learning (ML), and automation. This raises complex organizational and social issues. For example, the adoption of more autonomous systems and automation will likely lower the employment rate, hurting human motivation, well-being, and livelihoods. Let's further explore these issues.

Shareholders and Business Executives

Business executives typically act in the interest of shareholders and for the purpose of maximizing shareholder value. In accordance with this belief in the predominance of shareholder value, business executives would replace employees with automation if that seemed to be in the best interest of the sharehold-

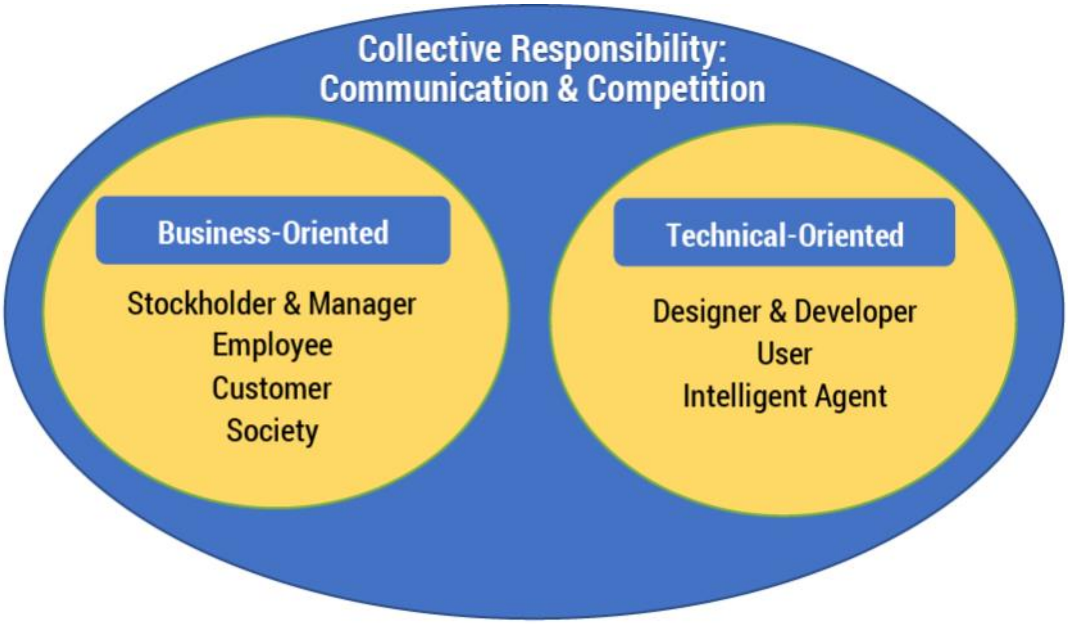

Figure 2 — Ethical and moral forces of Industry 4.0.

ers. Walmart, among many other retailers, has added robots to its stores to scan shelves, unload boxes, and mop up floors in an effort to reduce costs. In addition to the loss of jobs, automation may decrease human contact and interaction, weakening human relationships in the workplace. Profit maximization may also result in ignoring or downplaying security and safety considerations, such as employee safety, data security, and customer privacy. Business executives should ensure that sufficient resources and efforts are expended to establish a safe culture in the company, with, for example, employee safety training and data security education.

Employees

In the new business models, intelligent agents and autonomous systems will affect employment. Laborious and repetitive jobs will be restructured or even eliminated. The structure of the jobs that remain may also change significantly. New jobs may be created, but specialized knowledge and more complex skill sets will likely be needed. To adapt to the new working environment, major transformation in education as well as on-the-job retraining will be necessary.

The main concern is those groups of workers who will be left behind by Industry 4.0. To face the possibility of technological unemployment in an ethical manner, some people have suggested a universal basic income (UBI).[3] On the bright side, people can survive with a UBI. On the other hand, how can people realize their esteem and self-actualization needs, which usually come from accomplishments in their works or jobs? Social fairness would be another ethical concern with a UBI: why should all individuals receive the same UBI? For example, some individuals will be more highly educated, and some individuals may be in ill health and require more financial support.

Customers/Clients

Personalization or customization has a long history and has long been desired by customers. In the early 20th century, for example, a trend that favored the wearing of bird feathers, beaks, and even bodies on hats pushed several species almost to extinction. With Industry 4.0, personalized products and services will be more accessible to the masses and more widespread. Customers' peculiar preferences and requests can be integrated into the design/development/production of the product. However, if customers are not well educated on the impact of their requirements and wishes, blindly meeting their demands may also lead to issues. For instance, a customer's desire to have a smartphone that can analyze the personality of a caller may lead to privacy and ethical issues. In that case, should this smartphone be produced?

Society

The social contract theory places responsibility on business executives to consider the needs of the society in which a corporation is embedded. Social contract theorists ask what conditions would have to be met for the members of a society to agree to allow a corporation to be formed. In other words, society bestows legal recognition on a corporation to allow it to utilize social resources toward some given end. Under the social contract theory, a society may not want a corporation to continue to function if the corporation is replacing employees with automation and forcing society members into unemployment. Labor unions may demand to dialogue with industry and government for job adjustments for remaining or new employees (e.g., the establishment of workload policies) to protect the rights of those workers. Local communities also play an important role in protecting local jobs and the environment. Government should ensure that industries take responsibility on major social and labor issues in tripartite social agreements (among employer organizations, trade unions, and the government). It is noteworthy that some communities and organizations (e.g., AI Global, the IEEE Global Initiative on Ethics of Autonomous and Intelligent Systems, and the Open Roboethics Institute) are dedicated to addressing ethical and moral issues in these areas.

Technical-Oriented Forces

The responsibility of each technical force stakeholder should be clear and transparent. Each stakeholder must maintain the highest ethical standards to prevent risky behaviors and harmful consequences. For instance, the failure of safety-critical systems may lead to loss of human life and other catastrophic consequences.

Designers and Developers

It is important that designers and developers know the ethical implications of the high-tech products or services that they design and build. The rapid development of computing technology, however, has resulted in policy vacuums. When different technologies from different companies are coupled or integrated, it can be difficult to assign responsibility. For example, if a self-driving car has an accident, who is responsible? Ambiguous responsibility may weaken the designers' sense of responsibility, but it is very important that all products are designed to be safe. Designers and developers should be held responsible for safety-related accidents that are a result of ignoring safety considerations in the design and development of new technology. The process of addressing ethical issues is a continuous one; ethical policies associated with computing technology should evolve as technology advances. Although rapid advances in technology make it harder to study ethical issues and establish ethical standards and policies particular to a technology, general guidelines and policies can be developed as a basis for a framework for ethical assessment in Industry 4.0.

Users

Separating design error from users' decisions is also crucial. Users should be aware of the impact of their decisions. As an example, police officers (users) deploying autonomous drones to destroy drug plantations must assess the environmental impact (e.g., to avoid starting a forest fire). In addition, users should be well trained to work with CPSs and other intelligent agents; if not, users working with new artifacts and intelligent devices may be exposed to a potentially hazardous environment without a full understanding of the technology. New and unexpected behavior resulting from new technology will increase the risk of error and wrong decisions. Almost all computer and smart devices are now Internet- and social media–enabled. On the one hand, this provides convenience and accessibility for the users. On the other hand, this exposes many computers and devices to cyberattack because of user carelessness or unfamiliarity with cyberthreats. Many organizations currently have mandatory cybersecurity training, which was not required five or 10 years ago. Some high-security government agencies have even cut off access to the Internet in the workplace. In many cases, users are not fully aware of the interactions that take place in current smart environments, such as the IoT. This lack of user awareness can exacerbate the ethical and moral issues Industry 4.0 raises.

Intelligent Agents

Assigning responsibility to intelligent agents is contentious. Critics believe that designers and developers should take responsibility for the decisions of intelligent agents. However, AI and ML present new challenges. While designers and developers may build the base model, the system will continue to learn and evolve. During the learning and evolving process, the intelligent system may pick up bad examples and produce erroneous outcomes. Thus, some argue that intelligent systems may need to be assigned responsibility. Not assigning responsibility to intelligent agents may create a hazardous policy and ethics vacuum with unforeseeable negative consequences. Furthermore, developers may be reluctant to develop advanced technology if they fear being assigned responsibility for the bad decisions intelligent agents make. Such reluctance would seriously hinder technological progress.

Collective Responsibility

Because multiple stakeholders rather than only one stakeholder will typically be involved in an action/behavior, organizations need to consider collective responsibility. Ethical behavior and safe operation require each stakeholder to interact responsibly with all other stakeholders. The hardest part of collective responsibility is communication and information integration. At times, some stakeholders may not want to disclose certain information, making it necessary to investigate the ethical aspects of communication, and establishing what information should be disclosed for ethical reasons without exposing business secrets.

Competition may induce another ethical risk. Industry 4.0 will generate strong output globally, as well as increased competition in the marketplace. To adapt to new technology, companies need to update their skills and knowledge, invest appropriately, and change their business processes. For small and medium-sized enterprises, it will be challenging to compete with the leaders in these areas. Major players in a market can monopolize a market, and the result is often higher prices for consumers. Although antitrust is one of those academic business ethics topics that is usually left to the lawyers, some scholars have advocated that business schools should cover antitrust ethics. Furthermore, the ability to adopt and invest in new technology may create a division between companies that successfully adapt to Industry 4.0 and those that do not. Industry 4.0 may also enlarge the gap between developed and developing economies.

Business and technical forces have an impact on the ethical world. In Figure 3, we depict the possible interactions between them. Highly ethical business-oriented and technical-oriented forces can mutually promote ethical behaviors and moral values, which is excellent symbiosis. If only business-oriented forces have high ethical values, the new technology and systems may be risky to human life. For instance, if self-driving cars are not very well developed because of irresponsible developers, accidents with human casualties may occur. In this case, business forces may compel technical forces to behave ethically, through contracts and legal procedures. If only technical-oriented forces have high ethical values, corporations may compete with each other using unethical methods. As an example, people reveal a great deal of personal information on social media, via smart home systems, and in online shops. If that information is not adequately protected or is sold to third parties for financial gain, people may suffer financial losses and emotional harm. If all forces exhibit low ethical values,

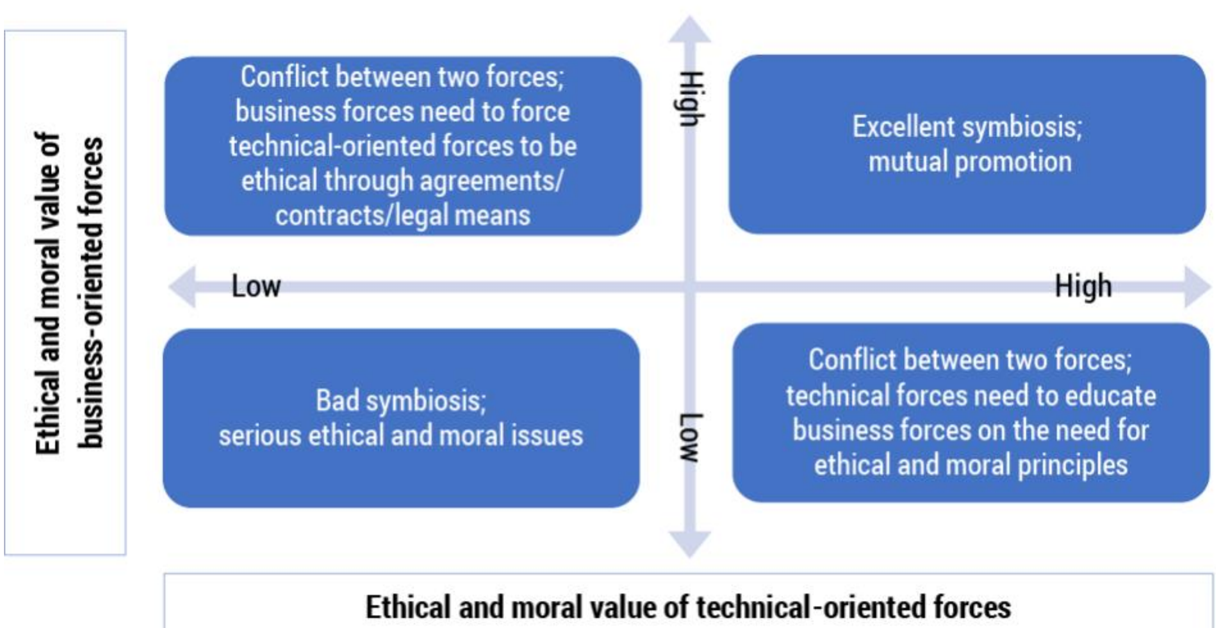

Figure 3 — Symbiosis among ethical and moral forces of Industry 4.0.

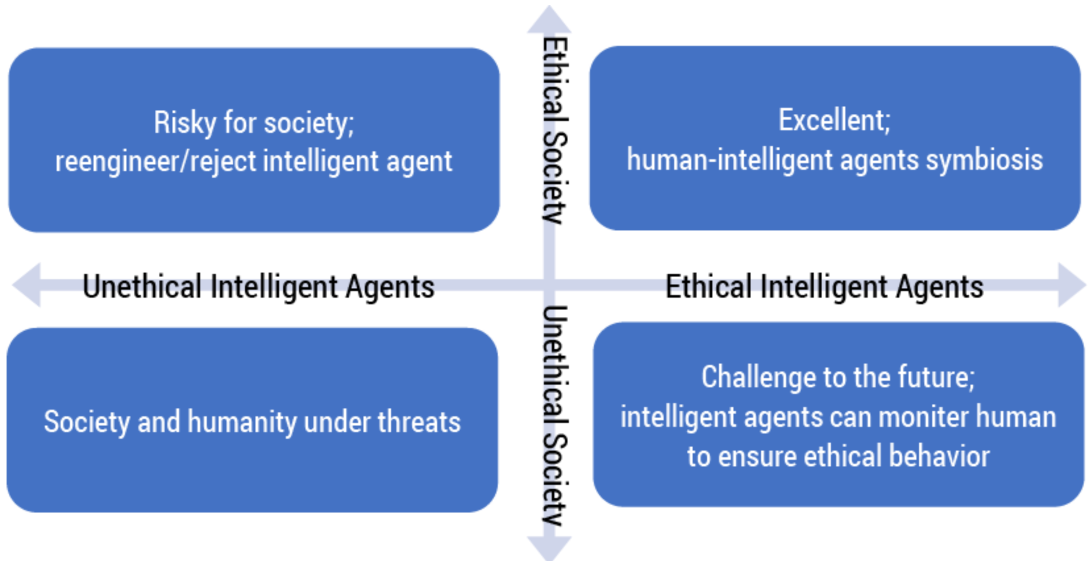

Figure 4 — Symbiosis of human society and intelligent agents.

it would be a bad symbiosis, creating serious ethical and moral issues across society.

In addition to interactions between technical-oriented and business-oriented forces, we can examine the interaction of intelligent agents and human society. As shown in Figure 4, only when both human society and intelligent agents are highly ethical can we have healthy human-intelligent agent symbiosis. If only human society is ethical, humans should reengineer or even reject the intelligent agents. If only intelligent agents are ethical, unethical human society may produce unethical agents, which is very risky for the future of humanity. However, developing and implementing ethical and moral intelligent agents can help to monitor humans to ensure ethical behavior. For instance, ethical intelligent agents would not comply with an unethical human command. If no party is ethical, society and humanity will be under great threat.

Ethical Framework in Industry 4.0

Data, new technology, and systems are crucial in Industry 4.0. Taking good advantage of them can benefit human society and enhance people's lives. However, it is very easy to overlook the potential ethical and moral impacts when using technology. In this section, we introduce the potential ethical issues in Industry 4.0. We look at them from two aspects: (1) ethical issues related to data and (2) ethical issues related to systems, technology products, and services. Figure 5 shows the basic framework of ethical issues in Industry 4.0.

Ethical Issues Related to Data

Data plays an important role in Industry 4.0. Data is collected from the human environment and analyzed to drive a new economy/new business models, increase profits, and improve services. Industry 4.0–related technology generates, stores, and uses highly sensitive data, which needs adequate security and privacy on a global scale. Ownership of the data needs to be clarified, too. It is challenging to formulate standards to encourage data sharing and yet provide appropriate protection.

Privacy and Data Security

There is always a tradeoff between creating smart services and maintaining privacy. For instance, to provide personalized customer service, as much knowledge about the person as possible should be collected. That, in turn, increases the risk to privacy. As evidenced by recent data breaches, information is increasingly exposed to hacking, resulting in information security and privacy issues. For example, data privacy is very important in the context of healthcare and social media, which involve sensitive private records. Indeed, the Facebook-Cambridge Analytica data scandal and many other data breaches expose the urgency of building a protection system for private data and information. Without clear ethical and moral guidelines and policies, management of collected personal information can be challenging. For example, all parties in an organization, business-oriented as well as technical-oriented, need to subscribe to the same ethical and moral standards. With proper ethical and

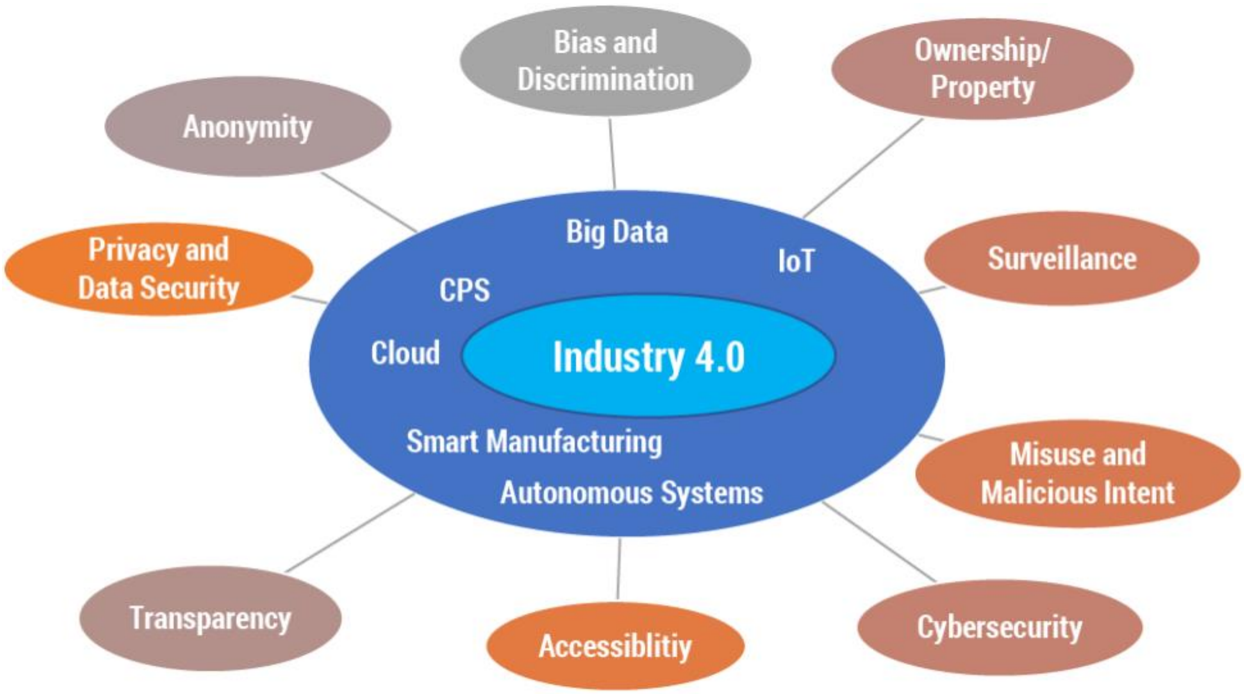

Figure 5 — Ethical framework in Industry 4.0.

moral education, we can reduce the number of hackers that explore a system's vulnerabilities and knowingly or unknowingly violate others' rights just for fun or for their own entertainment.

Anonymity

In the virtual world, people can use fake identities to remain anonymous. Anonymity, in itself, is neither unethical nor immoral. How anonymity is used, however, can create ethical and moral issues. For example, malicious attacks such as cyberbullying can be carried out anonymously. On the other hand, anonymity enables participants to generate more comments and contribute more ideas during anonymous brainstorming sessions. Studies have shown that de-anonymizing data is possible when the data in one data set is paired with that in other data sets.[4] Sensors in the environment, for example, can recognize real objects that people wear and use, and collaborating many data points together can have a de-anonymizing effect. All these technologies will result in the loss of anonymity in many cases. In Industry 4.0, there are more and more sensors available and more data collected about individuals. Recognizing when to provide anonymity and when to de-anonymize data requires ethical and moral judgments. Companies possessing such data must have clear ethical and moral guidelines on when to release the data to any third party (including government agencies).

Bias and Discrimination

Many scholars have suggested bias and fairness as ethical principles.[5] Autonomous systems make decisions based on the data they can access, which raises concerns regarding bias and discrimination. ML uses existing data, some of which may be biased. One example of an ethical concern is that predictive insurance analytics may increase costs for, and therefore hinder, services to individuals prone to illness. In another example, Tay was an AI Twitter bot released by Microsoft in 2016. Tay, learning from its conversations with humans, became racist and tweeted many nasty utterances within a day and was eventually taken down. ML and autonomous systems will be widely available in Industry 4.0. Ensuring that autonomous systems maintain a high ethical and moral standard is a challenge.

Ownership/Property

IoT collects a lot of data about individuals. Correctly identifying data ownership and property is still an ongoing debate. Who owns the data collected by sensors connected to the IoT (e.g., Google Home or

Amazon Echo)? Data collected in the public domain may be arguably data owned by the collectors. What about data collected in one's home (e.g., what food is in the fridge)? What about data collected from one's surfing of the Internet using one's own computers? The IoT risks making the boundaries between public and private space invisible, creating privacy and ethical issues.

Surveillance

Another major concern is Big Brother–type surveillance, with people being monitored without their consent or even, in some cases, without being aware of being monitored. Smart assistants, such as Google Home and Amazon Echo, listen to their hosts all the time, waiting for a command. Having an assistant makes life easier, but if those assistants are misused, people are at risk of unauthorized surveillance, which is both an ethical and legal issue. Systems of protection from unauthorized remote intrusions should be elaborate and comprehensive. The legal systems need to catch up with the developments in Industry 4.0.

Misuse and Malicious Use

The amount of transferred data increases greatly in Industry 4.0. Big data comes from social media, online accounts, medical information, electronic communication, online searching, and many other sources. Among that data, inevitably, personal and private information, such as leisure time activities, medical conditions, or family information, will be disclosed. If the information is maliciously used or disclosed by some third party, negative consequences are possible. Again, this has ethical, moral, and legal implications.

Ethical Issues Related to Systems, Products, and Services

Accessibility

Accessibility, as an ethical principle, refers to whether systems, products, and services are suitable for all people, including the elderly, the handicapped, and the disabled.[6] Considering the complexity of new technology and high-tech products, as well as the aging populations of some countries, the accessibility of new technology will directly affect human well-being. The purpose of developing technology is to benefit humans. But if only a portion of people benefit, is it ethical and fair? Consideration must be given to developing systems, products, and services that are accessible to all, and the benefits of advanced technology should be fairly distributed to all.

Transparency

Transparency helps promote ethical and moral behavior.[7] Transparency of systems can clarify responsibility and make outcomes understandable. Users can better understand the underlying processes the system used to arrive at an outcome and use that knowledge to make correct decisions. Without transparency, it is much easier to maliciously use and control systems. Moreover, insufficient transparency may jeopardize human trust in autonomous systems.[8]

Cybersecurity

Cyberattacks are geographically unconstrained compared to physical attacks. The original designers of cyberweapons are hard to identify, while vulnerable systems are countless, including healthcare systems, transport networks, traffic light systems, and food distribution systems. Cybersecurity affects system reliability, which, in turn, affects user trust in these systems. Enhanced cybersecurity and better protection of data will reduce ethical and moral problems and complications. This is in line with one of the ethical principles suggested by the US Department of Health, Education, and Welfare's "Belmont Report": do no harm to participants.[9]

Conclusion

Keeping ethics and moral values high in Industry 4.0 has become more critical than ever. Although there is no one-size-fits-all approach to solving ethical issues, basic frameworks to guide behavior must be explored and formulated. In this article, we have discussed potential ethical issues from three perspectives: (1) ethical forces in Industry 4.0; (2) ethical issues related to big data; and (3) ethical issues related to systems, products, and services. Only when we establish and follow ethical and moral principles for various aspects of Industry 4.0 can we achieve a society that will truly benefit from Industry 4.0.

The educational system must train students, especially those studying computing and software engineering, in ethical principles. The educational system must also be reengineered to educate students and workers to become more qualified in Industry 4.0, where the release of platforms/systems is much faster than we have seen to date and the skill sets required are constantly changing. Graduates are expected to be work-ready and know the latest technology trends and tools. The ability to think critically and the embracing of lifelong learning are extremely important,[10] as those who have these characteristics can adapt to the challenges of Industry 4.0 and be less subject to replacement by machines and intelligent agents.

Organizations must set up governance systems to ensure protection of operations and business ethics. Data privacy policies should integrate into business operations. The European Union has responded to the data misuse threat through the issuance of the General Data Protection Regulation; failure to comply with the regulation is subject to a fine of up to either 4% of an organization's global turnover or €20 million. Similar regulations should be implemented in other regions to protect data privacy and security.

Understanding and addressing ethical and moral issues related to Industry 4.0 is still in its infancy stage.[11] Addressing ethical and moral issues is not a simple discussion of "right or wrong," "good or bad," or "virtue to vice." It is not even a problem solvable by a small group of people. However, formulating and developing ethical and moral principles related to Industry 4.0 are critical. Industry 4.0 is transforming jobs, societies, and humanity. The future development of Industry 4.0 needs to be guided by sound ethical and moral principles.

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