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Envisioning the future of work to safeguard the safety, health, and well-being of the workforce: A perspective from the CDC's National Institute for Occupational Safety and Health

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Abstract

The future of work embodies changes to the workplace, work, and workforce, which require additional occupational safety and health (OSH) stakeholder attention. Examples include workplace developments in organizational design, technological job displacement, and work arrangements; work advances in artificial intelligence, robotics, and technologies; and workforce changes in demographics, economic security, and skills. This paper presents the Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health's Future of Work Initiative; suggests an integrated approach to address worker safety, health, and well-being; introduces priority topics and subtopics that confer a framework for upcoming future of work research directions and resultant practical applications; and discusses preliminary next steps. All future of work issues impact one another. Future of work transformations are contingent upon each of the standalone factors discussed in this paper and their combined effects. Occupational safety and health stakeholders are becoming more aware of the significance and necessity of these factors for the workplace, work, and workforce to flourish, merely survive, or disappear altogether as the future evolves. The future of work offers numerous opportunities, while also presenting critical but not clearly understood difficulties, exposures, and hazards. It is the responsibility of OSH researchers and other partners to understand the implications of future of work scenarios to translate effective interventions into practice for employers safeguarding the safety, health, and well-being of their workers.

KEYWORDS

future of work, occupational safety and health, Total Worker Health, worker well-being

1 | INTRODUCTION

The future of work is shaped by ongoing changes in the workplace, work, and workforce,[1] and by advances in technology connecting people, places, and things.[1,2] These changes have led to increased focus, prioritization efforts, and a call-to-action to address associated new and existing worker safety, health, and well-being determinants and outcomes with significant implications during these uncertain and evolving times.[3] Chiefly, continued developments in organizational design, technological job displacement, and work arrangements are affecting the workplace to a greater extent than ever before; advances in artificial intelligence, robotics, and technologies are influencing progressively more how work itself is conducted; and changes in demographics, economic security, and skills are increasingly impacting the workforce. Today, these future of work foci take on even greater meaning and importance due to worldwide emergency and disaster preparedness and response issues, which are reshaping the workplace, work, and workforce. Though doing so in ways yet to be fully understood, the COVID-19 pandemic is both highlighting already existing weaknesses and strengths, as well as potentially hastening additional unanticipated shifts related to the future of work.

Future of work-related changes offer many opportunities, while also posing challenges for both the workplace and work, with consequences for the safety, health, and well-being of the workforce. This necessitates an examination of issues and creation of new safety and health strategies to face them. To that end, the authors provide an overview of the Centers for Disease Control and Prevention (CDC), National Institute for Occupational Safety and Health (NIOSH) Future of Work Initiative: https://www.cdc.gov/niosh/topics/future-of-work/default.html[4]; describe an integrated approach to address worker safety, health, and well-being; prioritize topics and subtopics for forthcoming future of work research and resulting activities; and discuss preliminary next steps.

2 | THE CDC/NIOSH FUTURE OF WORK INITIATIVE

The overarching goals of the CDC/NIOSH Future of Work Initiative are to (1) compile existing studies on the future of work; (2) feature current future of work research projects; (3) promote research among new industries, technologies, organizational designs, job arrangements, risk profiles, and ways to control risks; and (4) connect trends in workplace, work, and workforce changes to prepare for future worker safety, health, and well-being. Steps to fulfill these goals include (a) developing, examining, and addressing future of work priority topics; (b) improving and generating sound taxonomy for terms used; (c) considering current and finding new research methods; (d) offering practical and tangible solutions to safeguard workers; and (e) surveilling, evaluating, and adjusting approaches and activities, as needed. Of note, the CDC/NIOSH Future of Work Initiative represents a new cross-cutting effort for the Institute's portfolio, rather than an abnegation of any of its traditional and long-standing programs still at the forefront of its mission.

3 | AN INTEGRATED APPROACH FOR ADDRESSING WORKER SAFETY, HEALTH, AND WELL-BEING

Studies have shown that integrating occupational safety and health (OSH) protection activities with health-enhancing ones—rather than delivering either of these activities alone—more effectively addresses the wide-ranging and increasingly complex concerns of workers.[5-8] Indeed, using an integrated and comprehensive approach to address work-related hazards and other exposures tackles the multifaceted risks that exist and leads to improved worker and organizational outcomes.[6] Experts have called for an expanded, holistic, and multi/transdisciplinary approach to confront these complex and novel concerns, sometimes referred to as OSH 4.0.[9] Consequently, the CDC/NIOSH Future of Work Initiative is addressing these challenges by implementing the *Total Worker Health*® (TWH) approach. TWH is defined as policies, programs, and practices that integrate protection from work-related safety and health hazards with the promotion of injury and illness prevention efforts to advanceworker well-being.[10] This approach—focused on how the workplace and work contribute and can be modified to improve workforce outcomes—also underscores the inextricable relationships that exist between these issues, both on- and off-the-job, including those which involve workers' families, communities, and society as a whole.

4 | CDC/NIOSH FUTURE OF WORK INITIATIVE PRIORITY TOPICS

The CDC/NIOSH Future of Work Group (comprising 28 researchers) developed a set of priority topics and subtopics (Figure 1)[4] to serve as a guiding framework for research and practice-based activities. The priority topics were based on an examination and synthesis of the literature to center on a list of top, salient issues. Nine topics divided among three groups capture central issues of particular relevance to the future of work. These groups include the workplace (topics: organizational design, technological displacement, work arrangements), work (topics: artificial intelligence, robotics, technologies), and workforce (topics: demographics, economic security, skills). Note that these topics are not meant to be exhaustive, imply a hierarchy, or be mutually exclusive. The authors also recognize the existence of other important issues impacting all topics, including emergency and disaster preparedness and response, exposures and hazards, extreme weather conditions, globalization, Industry 4.0, OSH 4.0, policies, politics, resources, and social disruption. There was no ethics review and approval and/or no informed consent given that no human subjects were involved.

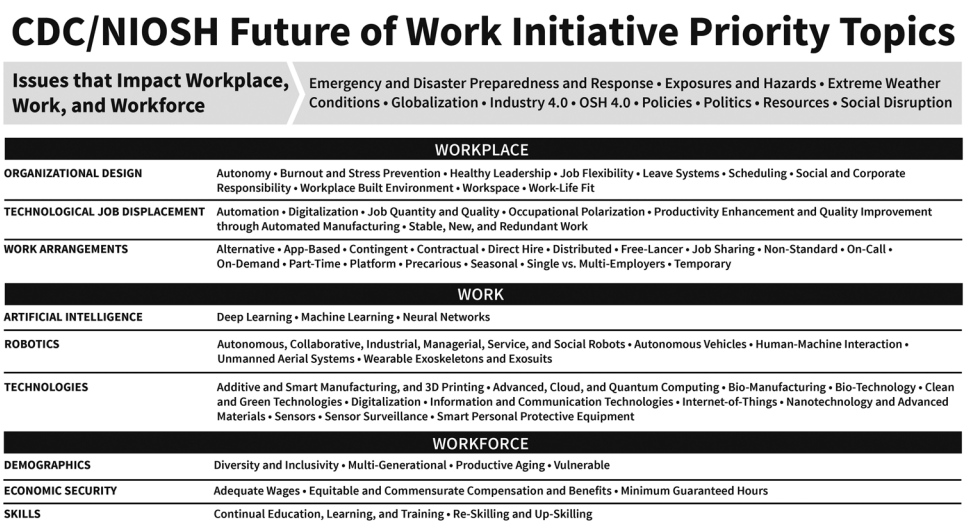

FIGURE 1 CDC/NIOSH Future of Work Initiative Priority Topics

4.1 | The future of the workplace

4.1.1 | Organizational design

The frequency of jobs with a fixed schedule, a dedicated location, and direct control by a single employer has decreased.[11] Indeed, over the past several decades, innovations in information communication technologies (ICTs) have radically shifted the design of work and, today, the use of ICTs such as Wi-Fi-enabled laptops, smartphones, and tablets make it possible to complete many jobs from nearly anywhere at practically any time of day.[12,13] As a result, remote work, telework, and virtual teams have become accepted ways of working.[14] According to pre-COVID-19 estimates, approximately 20% of U.S. workers were engaging in remote or mobile work at least some of the time, and the frequency and regularity of this type of work is anticipated to grow as new ICT-enabled jobs are created,[12] and as worldwide issues (e.g., pandemics) demand. In fact, though current estimates on teleworking frequency are variable, there appears to be a new willingness among certain employers to reorganize swiftly so that more eligible workers can work remotely during this precarious time and possibly moving forward. Further, recent estimates suggest that 37% of jobs in the United States could be performed completely at home, though wide disparities exist by geographic location and by occupations and industries.[15] As the workforce becomes an increasingly complex mix of workers engaged in traditional and flexible ways of working, many of today's design-related OSH concerns will remain relevant into the future. Work in this and related areas has been conducted at CDC/NIOSH since the early 2000s, now led by the CDC/NIOSH Healthy Work Design and Well-Being Program,[16] a tripartite effort which addresses the domains of TWH, work organization and stress-related disorders, and economics. Several salient examples of important organizational design factors are presented in this section.

The physical work environment influences both worker well-being and organizational performance.[17,18] Whether they work at a central facility, mobile site, home office, or in a different country or time zone, future workers across occupations and industries will continue to need access to ergonomically designed workstations and work tools, personal protective equipment (PPE), and hazard-free work environments.[19] Exactly how safe working environments will be provided and maintained as the physical boundaries of work become increasingly fluid, however, remains unclear. For instance, compared to their on-site counterparts, remote office workers may be at increased risk of injury because their home offices are frequently configured without employer guidance.[20] This has worker compensation and legal implications should accidents or injuries (whether occupational or not) occur in a personal space during work hours. In addition, evidence of the positive physical and psychological health effects of smart ventilation and environmental controls, automated safety mechanisms and controls, green buildings, sit–stand and active workstations, nutritious food options, and access to on-site exercise opportunities is growing.[21-24] As new workplace facilities are constructed, existing worksites are modernized, and workspaces become more flexible, employers will need to consider the many potential benefits of feasible mechanisms to make such safety- and health-enhancing amenities available for workers.

The need for workers to concurrently manage work and personal life responsibilities has also become a major organizational design topic, due in large part to globalization, technology advancements, and workforce demographic shifts.[25] Employer-sponsored leave (e.g., paid vacation, sick, parental, caregiving) frequently plays a central role in work–life fit (balance) considerations, which can become complicated for a workforce engaged in non-standard employment arrangements (detailed in the work arrangements section of this paper). Countries differ in their offerings of national paid leave policies, impacting workers employed by multinational companies. Access to paid leave can also vary within a country by several employment factors, including the worker's profession, status (full- or part-time), union presence and representation, occupation and industry, private versus government employment (federal, state, and

local), employer size, and geographic location.[26] Considering today's U.S. workers hold an average of 12.3 jobs by age 52[27] and the number is projected to grow, lack of or discontinuity in access to paid leave[28,29] will continue to have implications for well-being throughout the life course.

Relatedly, work–life interventions are vital for well-being and range from traditional integrative approaches (e.g., family-supportive supervisory behavior training, self-scheduling, and dependent care programs) to more progressive work–life supports (e.g., housing allowances, mindfulness training, and fertility assistance).[30] Flexible work arrangements have become one of the most popular mechanisms for enhancing work–life fit, under the premise that flexibility helps workers balance competing demands in a more positive and effective manner.[31] It should be noted that there is a distinction between flexibility that employers pursue (e.g., for on-call workers) and flexibility that workers control (e.g., their ability to vary their own schedules, and the access and ability to take leave when they need to do so), both of which may be offered with respect to work schedules, locations, and work assignments.[32] Research on flexibility's effects on workers has yielded mixed results. Flexible workplaces and work schedules may result in increased job performance, job satisfaction, autonomy, and creativity.[33-35] The increased utilization of remote work may also yield new employment opportunities for disadvantaged groups, such as those living with disabilities.[36] Other research found jobs consisting primarily of remote work may blur the boundaries between work and personal life, thereby increasing work–family conflict and work-related stress.[37] As ICT use intensifies and extended work availability becomes normalized, workers may also experience *telepressure*, an unhealthy internal state characterized by a constant preoccupation with work that is associated with increased burnout, elevated stress levels, and poor sleep practices.[38,39]

Work stress is another increasingly important safety, health, and well-being issue, and is highly affected by organizational design factors. Today, nearly two-thirds of adults identify work as a significant source of stress,[40] which has been linked to a myriad of negative health outcomes, including burnout, anxiety, depression, frustration, and physical complaints (e.g., back- and headaches, sleep disturbances, fatigue, and digestive issues).[41] Research suggests future workers will experience emotional and mental stress more frequently and more intensely as the result of increased blurring of work–life boundaries, greater demands for work availability and flexibility, and decreased human connections due to remote working and the use of robots in the workplace.[42] Since 1999, CDC/NIOSH guidance for preventing stress at work has called for comprehensive approaches that include both organizational change and stress management practices.[43] There is evidence that interventions which integrate primary and secondary stress prevention yield positive effects for both individuals (e.g., reduced perceived stress levels, depressive symptoms, negative affectivity, cardiovascular health risks, improved mental health, increased physical fitness) and organizations (e.g., reduced sickness and absenteeism, and presenteeism).[44] For maximum efficacy, future stress prevention interventions should be developed as a collaborative effort between managers and workers.[45]

As stress levels potentially rise as the future of work evolves, organizational leadership will play a pivotal role in protecting and promoting the safety, health, and well-being of workers. New ways of working must be matched with healthy leadership styles, and innovative approaches to health-promoting leadership will be needed.[46] Such leaders should strive to create conditions to support and enhance worker health and well-being by managing workloads and providing time for recovery; giving workers control over managing job demands and job decision-making; providing rewards to demonstrate appreciation; creating a respectful work community; imparting fairness and autonomy in decision-making; communicating and demonstrating values; and maintaining health awareness.[47]

Along similar lines, the importance of corporate social responsibility (CSR), which involves prioritizing societal interests over profits,[48] will continue to grow. CSR encompasses the economic, legal, ethical, and discretionary (philanthropic) expectations society has of organizations at a given time.[49] Traditionally, research has focused primarily on CSR's impact on an organization's financial performance,[50,51] but a growing body of research suggests it is an important psychosocial risk management strategy that can positively affect the quality of working life[52,53] through continuing education, safe working environments, diversity and inclusion policies, community engagement opportunities for workers, childcare programs, and ethical labor practices.[54] These and other mechanisms addressing workers' concerns around care (e.g., values, self-development), self (e.g., control, self-expression, safety), and relationships (e.g., belongingness and trust) may become critical organizational design issues in the future.[55]

Overall, organizational design constitutes and provides the basic, foundational physical and functional infrastructures influencing where, when, and how work is performed. As such, it is related to all future of work topics and is a critical consideration as time unfolds.

4.1.2 | Technological job displacement

Technological advancements, including work automation, digitalization, robotics, artificial intelligence, advanced computing, and other innovations discussed in subsequent sections have become embedded in our everyday work environment, allowing for increased economic growth, development, and productivity. As these advancements take place and evolve, a prime issue to consider is their influence on our current and future workplaces. One key issue with significant downstream worker effects is technological job displacement.

Technological job displacement occurs when job tasks traditionally performed by human workers are replaced with technology, leading to the elimination of jobs; adversely impacting job quantity and quality; altering the existence of stable, new, and redundant (obsolete) work; and fundamentally changing many occupations and even entire industries. Currently, the CDC/NIOSH Healthy Work

Design and Well-Being Program explores the safety and health effects of work organization and external factors such as technology.[16] For instance, through the CDC/NIOSH's *Total Worker Health®* program and its affiliate partnerships, there are on-going research and workplace efforts for workers facing increased integration of technologies within their jobs, and the psychological and behavioral impacts with which these workers are confronted due to technological job displacement.[56,57]

Several estimates have been published about the extent to which job tasks could be automated across industry sectors. Studies by Oxford University[58] and by the McKinsey Global Institute[59] indicate that about half of all job tasks in the U.S. economy could be automated, but the extent of job losses are difficult to forecast. A study of occupations within the United States suggested that 46% of individuals work in jobs that could be performed by computers and algorithms. This said, some have argued that fears of technological disruption may be exaggerated as technology adoption is often slow, providing time for new task and job creation to offset job loss from automation.[60] Tasks such as the collection and processing of data may be accomplished faster and with fewer errors through automation and computing; such occupations include mortgage origination, paralegal work, accounting, and back-office transaction processing.[61] Less likely to be completely automated are occupations having nonroutine and interactive tasks, such as child and elder care, plumbing, and gardening.[61,62] Furthermore, some studies point to several economic, legal, or societal factors that could restrain an organization from adopting job-displacing technologies. For instance, fully autonomous vehicles, including freight trucks and taxis, will need an overall level of public acceptance of the technology, risk, and liability standards for them to be incorporated throughout the transportation industry.[63] Also, if the economic gains achieved from the productivity-enhancing technologies are not shared among society, political reactions could curtail or stop them from being adopted.[60]

New technologies will create new jobs, as has transpired in the past when similarly fundamental changes of work and the emergence of new industries occurred[64,65] (though differences may present in the pace between jobs being lost and the time it takes to acquire new skills). An example is the "gig" economy, in which individuals provide services through online platforms. Changes in work arrangements (detailed in the work arrangements section of this paper) may necessitate a portion of the displaced workforce to acquire new skills to compete in the new labor market. It is also possible that new technologies will decrease production and consumer costs, causing a higher consumer demand for certain products and services. This can lead to an increase in labor demand and additional job growth.

Another vital consequence of technological advancement and ensuing displacement is the likelihood of increased occupational polarization, whereby technology replaces routine work often performed by medium-skilled workers, effectively beginning to hollow out this class of workers.[66,67] Many higher-skill jobs require nonroutine tasks, with a higher order of thinking, problem solving, or unique social interaction that cannot yet be automated. In addition, many lower-skilled workers who perform nonroutine tasks, such as those in the service industry, cannot easily be substituted with technology. The effect is a decline in employment of middle-skilled workers, also disproportionately affecting certain socioeconomic status and demographic groups (e.g., women, immigrants, younger workers).[51] In recent years, there has been evidence to suggest technology may even be encroaching upon the higher-skilled workforce.[68] The disappearance of middle-skill jobs may lead to a more difficult path to convert lower-wage service jobs into better jobs and overall limited routes to improve careers.[69] Lower-skill jobs and new jobs may not have the same OSH safeguards in play. Moreover, with a glut of labor and an increasing risk of automation, it will be harder for those workers to demand that OSH needs are met, later discussed in the skills section of this paper. Public guidance, government action and training programs, and a demand for better CSR are essential.

Importantly, technological displacement and its effects on employment can negatively affect the mental and physical health of the workforce. The perception of a future lacking employment opportunity and creating anxiety over the need to acquire new job skills might be responsible for causing a public health crisis in some countries.[70] This can lead to an increase in depression, suicide, and alcohol and drug abuse, including opioid-related mortality.[71-73]

Though many benefits may ensue from new, emerging, and innovative technologies impacting the workplace and work, their potential displacement or unemployment consequences for workers (with downstream implications for safety and health) should be heeded no matter their skill levels, occupation, or industry, and steps taken to remedy such scenarios.

4.1.3 | Work arrangements

Work arrangements are important determinants of worker safety, health, and well-being. Therefore, it is imperative to understand the factors influencing them, the detailed aspects of each, and how these may change in the future. Activities leading to work arrangement research efforts at CDC/NIOSH were first spearheaded by CDC/NIOSH economists and others in OSH-related fields through various teams and working groups, over the course of roughly two decades. The CDC/NIOSH Economic Research and Support Office, which was established in 2014, continues to advance this study, along with the CDC/NIOSH Healthy Work Design and Well-Being Program referenced earlier.

There are no universally accepted or standardized definitions of work arrangements; rather, many terms are used to do so as depicted in Figure 1. The existing literature employs traditional surveys, such as the Bureau of Labor Statistics (BLS) supplements to Current Population Survey (CPS) and the General Social Survey (GSS),[74] to define and understand the prevalence of various but limited categories of work arrangements. Using very similar terminology, these categories of nonstandard work arrangements (also

referred to by some as "alternative") include independent contractors, on-call workers, temporary help agency workers, and workers provided by contract firms. Though data from the BLS and GSS surveys do not show significant increases in the prevalence of nonstandard work arrangements over the years, the limitations of the categories in current survey questions do not allow nuanced assessments. Further, an impactful issue not often considered is the need to evaluate a worker's overall work arrangements by assessing all jobs held at one time, the sequence of jobs held over time, the periods of unemployment, and the availability of another job should the worker need or want to change jobs. It is also vital to understand work arrangements in the context of all jobs held by the worker's family, to fully appreciate different individual-level needs and considerations affecting workers.

For these reasons—both now and as work continues to transform in the future—the work arrangement categories included in surveys need to be revised to increase our understanding of important details that can guide opportunities for improving worker well-being. Efforts are underway to improve these questions in future planned surveys using more precise definitions and taxonomy elements, which will in turn improve our comprehension moving forward. To address this gap, CDC/NIOSH begins by distinguishing nonstandard work arrangements from a standard arrangement. A standard work arrangement is secure or permanent (career).[75] Workers in such an arrangement have employee status; stable and adequate pay; access to health insurance; paid leave and retirement benefits; a regular, full-time work schedule; and the ability to negotiate their schedule and take time off.

Within non-standard work arrangements, CDC/NIOSH considers a taxonomy of elements.[75] One dimension of elements includes:

- Job security: permanent, open-ended, or limited term of years, months, weeks, or days;
- Work schedule: hours per week, shift-day, evening, night, rotating, predictability—ranging from unchanging schedule to informal on-call;
- Compensation type: wage, salary, piece rate, job rate, profit, commission, training experience, intrinsic reward;
- Pay level and security: annual, weekly, or hourly earnings, variability of earnings (predictable, or varying with hours or business);
- Benefits: health insurance, retirement benefits, fringe benefits; and
- Single versus dual or multiple employers: temporary help (or staffing) agency and client employer; subcontractor and general contractor.

The second dimension of elements includes:

- Employee: permanent, temporary (e.g., day laborer, construction worker), and intern (college intern in summer);
- Self-employed: without business (e.g., driver, house cleaner), with business (e.g., dairy farm operator, law partner); and
- Volunteer (e.g., volunteer fire fighter).[75]

CDC/NIOSH has also adopted definitions for concepts related to nonstandard work arrangements that include contingent workers and precarious employment.[75] Contingent workers are those with a job that is not expected to last. Precarious employment has some degree of insecurity, temporariness, vulnerability to unfair treatment, lack of ability to negotiate pay, benefits, and work schedule, lack of ability to take leave, and lack of a social safety net including unemployment and workers' compensation insurance. That said, the definitions of work arrangements, contingent workers, and precarious employment are not mutually exclusive; for example, some workers in standard arrangements may experience unfair treatment, a characteristic of precarious employment.

In the absence of more detailed survey questions, the CDC/NIOSH taxonomy can be used to understand certain aspects of newer types of work arrangements, such as "gig" ones, which are temporary, short-term commitments. Recently, innovative technologies have given rise to "gig" work intermediated by a digital online platform (or apps), resulting in new issues for consideration. While many "gig" workers are classified as independent contractors, some may be employees who are improperly classified[76]; workers are also considered independent contractors if they are excluded from federal labor law protections and not legally recognized as employees.[77] Therefore, the status of workers as employees or nonemployees vitally matters for their OSH protections and for clarifying who is responsible for these protections. For instance, in an agency arrangement (e.g., temporary help agency), two employers share legal responsibilities for protecting the safety and health of employees.[78] To further complicate matters, many "gig" workers may hold other jobs, and the "gig" work may contribute to the safety and health issues experienced at the other job (e.g., fatigue from multiple jobs).

In addition to technology, other future of work factors such as demographics also affect work arrangements now and will continue to do so in time to come. The aging labor force, along with demand for newer skills and the blurring of work–home boundaries, are increasing the need for flexibility in work hours and in the location where work takes place. It is important to note flexibility (as discussed in the organizational design section) may refer to what employers or organizations need versus what workers need, which may not always correspond. Still, both employer and worker perspectives are affected by changes in demographics as certain nonstandard work arrangements are more prevalent among certain demographic groups. This may result in overlapping vulnerabilities for workers by race, gender, nativity, and less secure work arrangements.[79] These relationships are further discussed in the demographics section of this paper.

Different work arrangements variably affect worker safety, health, and well-being.[80,81] Indeed, a CDC/NIOSH study[80] using data from 2002 to 2014 concluded that for some workers in nonstandard work arrangements, such as independent contractors, increased job stress was associated with an increased number of self-reported unhealthy days. This was similarly observed with activity limitations,

whereby increased job stress was associated with increased reported days of activity limitations for workers in temporary help agency work arrangements. This example demonstrates the importance of studying and addressing each work arrangement separately and in-depth, in addition to the combination of existent factors, to more fully understand OSH implications.

Given the ongoing changes in technology, demographics, and other broad socioeconomic factors affecting employer and worker choices, the dimensions of work arrangements, the distribution of workers across arrangements, and the overall prevalence of non-standard work arrangements are likely to change in the future. Improved and detailed data collection on the many aspects of work arrangements will inform our understanding of these changes and their consequences.

4.2 | The future of work

4.2.1 | Artificial intelligence

One of CDC/NIOSH's earliest uses of machine learning (ML) occurred in its Center for Workers' Compensation Studies around 2016, when ML methods were used to code more than 1.2 million workers' compensation claims in a matter of hours instead of years. By way of the CDC/NIOSH Future of Work Initiative and other efforts such as its corresponding Artificial Intelligence (AI) Interest Group, much more AI-specific work will be conducted, given it is predicted to be a transformative influence across multiple industry sectors.[61,82,83] AI is a broad transdisciplinary field with roots in logic, statistics, cognitive psychology, decision theory, neuroscience, linguistics, cybernetics, and computer engineering. ML is the most prevalent AI method in use today, and is employed in internet searches, e-commerce sites, goods and services recommender systems, image and speech recognition, sensor technologies, robotic devices, and cognitive decision support systems (DSSs). Understanding how AI works can maximize its benefits to OSH as well as minimize its potential OSH challenges. Even though the application of AI in the workplace is still in its infancy, OSH professionals, practitioners, researchers, employers, and workers should develop a better understanding of workplace AI applications. Among the AI applications making their way into the workplace are those relating to sensor devices, robotic devices, and DSSs.

AI-enabled sensors can provide both promising benefits for the practice of OSH and potential challenges. For instance, large data sets produced by a 24/7 sensor network and analyzed by ML-enabled algorithms have the potential to improve surveillance of OSH effects, decrease uncertainty in risk assessment and management practices, and stimulate new avenues of OSH research. AI-enabled virtual reality training can also be used to create dynamic, high-fidelity immersive environments to simulate hazardous situations and enhance a worker's hazard recognition capabilities.[84] A prospective issue in AL-enabled sensor use, however, relates to privacy concerns given that more organizations are managing their workforces using sensor technology, cloud-based human resource systems, and ML-enabled data analytics in an approach called "people analytics."[85] To protect worker privacy, proposed best practices for employer-sponsored worker monitoring programs include using only validated sensor technologies; ensuring voluntary worker participation; ceasing data collection outside the workplace; disclosing all data uses; and ensuring secure data storage.

A shift is occurring from workplace robotic devices carrying out routine functions—automated robots—to more advanced robots able to interact with people and their environment—autonomous robots. AI methods also enable one robotic device to learn from the experience of other robotic devices, since the sensors in robotic devices can be connected to the cloud (a data center available to users over the internet), and the learning experience of one AI-enabled robotic device can be uploaded to all other connected robots by means of "cloud robotics."[86] To learn more, please refer to the robotics section in this paper.

Leveraging advanced computing capabilities, AI applications can mine knowledge from data for decision-making applications by using a DSS—a multipurpose informational AI-enabled tool—that employs neural networks and deep learning to aid humans in finding information or making decisions. As a result, organizations that collect and store large amounts of data(and have the technical capabilities and expertise)are using AI to support financial, operational, and organizational risk decision-making.[87] Though they may endanger behavioral and mental health by creating unemployment for those human workers whose jobs might be replaced (see the technological job displacement section for additional discussion), such tools and data could have important implications for the future of work and work-related health by promoting safety and health and reducing injuries. For example, AI-enabled DSSs have already shown promise in medicine and can be used to detect lung cancer in X-ray screening. They may also serve an important role in improving occupational risk assessment and risk management strategies. Indeed, AI-enabled DSSs may one day be able to prevent catastrophic safety- and health-related events, such as chemical plant explosions, by recognizing root causes of such events earlier. Likewise, they may aid in determining the optimal placement of firefighters during disasters, such as wildland fires, to prevent workers from being overtaken by the fires, and could potentially help make risk control decisions under conditions of uncertainty or even take control from a human to prevent a human action that would lead to severe injury or a fatality.

Some concerns relating specifically to ML-enabled DSSs (including algorithm transparency and algorithm bias, further described in the demographics section of this paper), have arisen as they have been introduced across industry sectors. The lack of methodological transparency inherent in ML methods ("black box") can impair user trust in the outputs produced by a DSS,[88] while negative consequences can occur when system controls are not fully understandable to humans, or fully responsive in practice as they were in design. The introduction of AI-enabled technologies in self-driving vehicles, at a nuclear power plant, or in the avionics systems of a jet airliner, raises issues of how to manage the

uncertainties associated with human–machine interactions with AI-enabled systems, and the readiness of the workforce to handle these. As such, managing risk as AI-enabled technologies are introduced to the workplace should start with a systems safety approach that focuses on system operation and controls to ensure the reliability and safety of AI technologies enabling autonomous systems.[89] Similarly, human–machine interactions must be addressed when considering AI in the workplace.

Moving forward, OSH stakeholders should conduct a thorough review and systems testing of the worker safety, health, and well-being benefits and costs of AI-enabled applications, before such devices or systems are introduced into the workplace.

4.2.2 | Robotics

There are multiple and evolving definitions of robots. Definitions in standard dictionaries frequently include references to science fiction and humanoid characteristics,[90] while the International Organization for Standardization, which provides safety requirements to promote safe human–robot collaboration has a stricter definition that includes parameters such as axes of movement.[91] Common features of these definitions include the robot programmed to carry out physical actions and/or make decisions. That said, increases in sensors, computing power, and AI (discussed earlier) are contributing to robotic design in such a way that goes beyond the standard definitions of specific industrial robots and is moving toward making the robots imagined in science fiction a reality.

CDC/NIOSH is distinctively positioned to evaluate prospective benefits and risks of robots in the workplace, conduct workplace interventions to prevent robot-related worker injuries, and create recommendations for safe interactions between humans and robots. The CDC/NIOSH Center for Occupational Robotics Research, birthed in 2017, has taken a broad view of the definition of robots.[92] This includes the traditional industrial robot used for decades in manufacturing settings to perform a limited number of tasks while physically separated from human workers, for which sales have been steadily increasing since 2011.[93] It also includes new types of robots being developed or envisioned for future workplaces that can sense their environment, make informed decisions, work more autonomously, work in conjunction with or in the same space as human workers (i.e., collaborative robots or "co-bots"), and robotic devices such as industrial exoskeletons that are designed to be worn by human workers. These new types of robots are designed for use across industry sectors and often in environments that are minimally controlled or uncontrolled, such as in community settings (both workers and the general public), outdoor worksites, and disaster sites. Examples include:

- Service robots that perform specific tasks (e.g., clean public spaces; deliver items in hospitals and hotels; fight fires; and perform inspections, maintenance, and repair in confined spaces);
- Social robots that sense and express human emotion under development for healthcare and social services;
- Automated industrial vehicles such as driverless forklifts and tractors;
- Fully automated vehicles currently used to haul materials in mining and being piloted for transit of people and commercial goods delivery;
- Unmanned aerial vehicles (UAVs or drones) increasingly being used to evaluate worksites and structures,[94] and being piloted for delivery of goods;
- Wearable robotics, such as exoskeletons and exosuits designed to reduce stress on some body parts and augment human workers' physical capacity[95]; and
- Digital and managerial robots that conduct complex tasks such as writing, data and information synthesis, and project management.

Robots hold tremendous potential for improving work for human workers by negating or reducing the need for human workers to do "dirty, dangerous, and dull (or monotonous)" work, including in future of work scenarios such as extreme situations associated with weather conditions, and emergency and disaster preparedness and response. Still, robot developers and the OSH community need to proactively address the potential for harm to human workers in their interaction with robots.[94-97]

Many benefits have already arisen from the increased use of robots, but important consequences also exist. Workers can be physically injured from unexpected contact with robots,[94-96] and if they lose situational awareness, they may be unable to adequately react to hazards as has occurred in fatal crashes involving highly automated vehicles.[98] Potential psychological harm includes worker stress from changes in how work is conducted; the pace at which work is conducted; and working with robots they may misunderstand, mistrust, and/or fear. And, as discussed in other parts of this paper, psychosocial harm to workers can also be anticipated from concerns about job loss or displacement due to robots. Not only will robots displace workers, they will also contribute to a rise in nonstandard work arrangements as more displaced workers find work in the "gig" economy, as highlighted previously.

The pace at which robots are being developed is speedily increasing, and with little experience with new types of robots, there is the potential for unanticipated harm to human workers' safety, health, and well-being, all of which must be carefully weighed as the future of work is traversed.

4.2.3 | Technologies

Rapid and dramatic advances and changes in material science, industrial processes, and computing capability have all contributed to the evolution of what is referred to as Industry 4.0 or the Fourth Industrial Revolution—characterized by the fusion and growing utilization of innovative technologies, beginning in the early 2000s. New technologies are not merely another iterative step in the maturation of traditional technologies, but advances that enable fundamental restructuring and reorganization of work itself.

While the CDC/NIOSH Future of Work Initiative is still relatively new, the Institute has conducted research on material science technology since the early 2000s.[99] Indeed, the Institute's portfolio of nanotechnology research brought it into the present state of tracking advances in industrial materials and responding to rapidly evolving manufacturing technologies. Material science continues to advance as nanotechnology, smart materials, and other developments place new capabilities into the hands of manufacturers and engineers. The work of developing and creating these materials is ever-changing and places great demand on employers and workers to keep up with supply and safety practices for the most recent developments.

The most prototypical example of a game-changing technology may be additive manufacturing, also known as three-dimensional (3D) printing.[100-102] This technology can create highly complex shapes and structures on a single machine, starting from a computer-aided design (CAD) template and through the successive joining of small amounts of material in an iterative process.[100-102] This can improve design optimization, ease collaboration, and allow faster design iteration. The capability of a single machine can reduce the need for or simplify assembly lines; the combination of both may make it easier to produce and to then subsequently meet demand and enable just-in-time fulfillment, making production more approachable.[100-102] Additive manufacturing represents a different type of work than traditional machining, with greater emphasis on computer and engineering skills, and tasks that may be more intellectually dynamic but physically static. As manufacturing capacity scales down to single tools with more complex requirements, the work environments will change as well, as may the safety and health hazards workers face.

Another key enabling technology for the future of work is advanced sensing.[103] Advanced or "smart" sensors exhibit greater functionality than traditional sensors. Smart sensors can be surgically placed in the body (i.e., implantables); worn on the body or embedded in safety clothing (i.e., wearables); or attached to a workplace object to monitor different parameters (i.e., placeables).[104-107] One benefit of these could be the availability of continuous data provided from workplace sensors instead of a reliance on slower, episodic sampling, enabling early intervention to prevent toxic exposures. Among the challenges though, as discussed previously, is the privacy dilemma associated with the use of AI-enabled sensor technology to monitor and track all aspects of worker performance.

Moreover, devices that previously had only local sensors and controls are now designed to connect to the Internet or another network, forming an Internet of Things (IoT).[103] A cloud-based IoT platform can collect, integrate, and analyze data from a distributed industrial network of IoT sensors to improve assessment of different workplace safety and health hazards.[108] One benefit to productivity is that a single person can remotely monitor and control large numbers of devices at different locations, transforming many jobs and tasks to a single set of computer tasks. Automation of such devices can also create cyber-physical systems, which further enhance efficiency.[103,109] However, although operating at a distance may protect workers from immediate physical hazards, it may be difficult to contextualize decision-making and avoid creating hazards for others, which is the case with all technologies, including AI and robotics. Additionally, while physical hazards may be reduced, cognitive overload and resulting psychosocial issues could become a factor if workers are forced to manage too many different devices at once. This is the case when there is a lack of fit between the pace imposed by the device (lots of information in very short time periods) and human capability to assimilate this information, especially during a crisis or emergency.

A further feature of new, emerging, and innovative technologies is advanced computing. The ability to harness vast amounts of data and leverage them to either improve decision-making or directly undertake actions has influenced almost every industry to some degree. The data flow in from ever-increasing numbers of sensors available at ever-decreasing costs, and more data of varied types are being digitalized each day.[103,109] ICTs enable data collection, aggregation, processing, and decision-making to occur in disparate locations, which is increasingly vital as more companies become global, with each facility's operations potentially dependent on other facilities located hundreds or thousands of miles away. As such, information and computing technology could be a significant boon to both productivity and safety by alerting workers to hazards, maintaining processes within tolerance limits, or enabling risk management decisions based on previously uncollectable information.[109] Still, data have their own hazards and ICTs have created a work demand all on their own. Workers may feel pressured by omnipresent monitoring to take risks to maintain productivity or to find ways to thwart specific data collection.[110] Collected information might also be misused, such as by using early indicators of chronic disease for discriminatory employment practices, and security is essential to ensure data breaches do not jeopardize worker information. Ultimately, it is important for employers and other parties engaged in data collection and retention to responsibly use and protect worker data.

What is more, breakthroughs in computing, cheaper equipment, and new techniques such as synthetic biology have motivated the development of biology-based processes to replace traditional manufacturing.[111,112] Beyond pharmaceuticals and medical advances, other breakthroughs are anticipated in technology such as CRISPR,[51] a technological innovation affecting many industries such as forestry and farming, and pervasive across many areas including biofuels, genetics, food technology (e.g., consumer-accessible artificial meats and yoghurts), and other products, which may also have an added benefit of helping enable a greener economy.[111-113] Such work by a biomanufacturer may look far different than that of a traditional manufacturer, as might the space in which they operate, with organizational design implications. As a result, biosafety practices designed for the laboratory might need to be fundamentally rethought as they are expanded to an entirely new scale for workers with different education and experience.

While the technologies mentioned here are likely to be impactful, this set is neither exhaustive nor necessarily representative; to be sure, if recent history is any guide, it has shown disruptive

technologies are difficult to anticipate and detect before their effects are realized. Keeping pace with the future of work will require more than cataloging the present, it will require being both reactive and proactive as future technologies become reality, to safeguard the safety, health, and well-being of workers.

4.3 | The future of the workforce

4.3.1 | Demographics

As workers experience changes to their workplaces and work, changing workforce demographics will continue to present both opportunities and challenges for OSH, as well as impact how work is performed. Asymmetrical power relationships can result in differential employment opportunities, disparate exposure and susceptibility to workplace hazards, and an inequitable distribution of occupational illness or injury.[79] Such power inequities often occur in society along axes such as age, class, gender identity, nativity, neurodiversity, race/ethnicity, sexual orientation, and visible and invisible disabilities. Workers may also be members of multiple vulnerable groups and therefore experience overlapping structural vulnerabilities.[79] As such, a central challenge to the future of work is ensuring the equitable distribution of OSH benefits and risks that accompany transformations in organizational design, work arrangements, and technology, discussed previously.

In preparing for the future, it is important to identify, eliminate, and/or minimize institutionalized bias that contributes to existing occupational health inequities and ensure these structural exclusions are not repeated moving forward. Changes resulting from future of work issues (e.g., technological job displacement) may also increase existing disparities and must be addressed. To that end, through the Occupational Health Equity program launched in 2005, CDC/NIOSH leads research, outreach, and prevention activities to tackle inequities.[114] These efforts help to identify and reduce the influence that social and economic structures historically linked to discrimination or exclusion have on the distribution of work-related risk and negative health outcomes. Occupational health inequities refer to avoidable differences in work-related fatalities, injuries, and illnesses closely linked with social, economic, and/or environmental disadvantages. Since institutional efforts to document and improve OSH outcomes often do not adequately include the experiences and perspectives of socially marginalized groups, it is critical that OSH surveillance systems, new technologies, and work arrangements do a better job of addressing the needs of historically excluded social groups to ensure that the future is an equitable one for all workers.

There is a dearth of data on OSH outcomes for vulnerable groups such as racial/ethnic minorities and immigrant workers, who constitute an increasing share of the U.S. workforce. Consequently, a National Academies of Sciences report called for the better collection of demographic variables such as race, ethnicity, and nativity in OSH systems.[115] Fortunately, advances in AI, computing capability, and data (highlighted previously) have the potential to advance OSH surveillance. Improved data will allow researchers, practitioners, and organizations to better identify which groups are at increased risk for specific conditions, so that they may subsequently identify and tailor interventions for them.[116] The paragraphs below describe OSH issues workers of various demographics—especially vulnerable ones—face now and will likely continue to in the future.

Gender remains an important demographic consideration as the future of work unfolds. Though women comprised over half of the U.S. workforce in 2018, they still face disparities in workplace policies and payment scales.[117] Indeed, while working mothers are one of the fastest-growing segments of the U.S. workforce, many struggle to balance workplace demands with reproductive plans and caregiving, especially if they fall within a lower socioeconomic status bracket and/or are employed by unsupportive workplaces.[118-121] In addition, women workers are disproportionately affected by workplace violence—a key priority area for achieving occupational health equity—with homicides persisting as a leading cause of occupational fatalities for women.[122] The #MeToo movement further highlighted another form of workplace violence (i.e., sexual harassment in the workplace), which most commonly involves men harassing women; women of color and immigrant women may also face additional forms of harassment and discrimination.[123-126] Relatedly, workers may experience exclusion, discrimination, and violence based on their gender identity and sexual orientation.[127-130] This is an increasingly important consideration in the coming years, given the percentage of U.S. adults identifying as lesbian, gay, bisexual, transgender, and queer is increasing, primarily among the millennial cohort.[131]

The multigenerational and aging workforce may also confront and create disproportionate challenges moving forward. In particular, the proportion of older workers has risen and is expected to grow through 2050.[132,133] While older workers tend to experience fewer injuries than their younger counterparts, when injury and illness incidents do occur, they often require more time to heal or are more likely to be fatal.[134,135] Moreover, though the aging workforce offers a wealth of experience, invaluable institutional knowledge, higher job satisfaction, and a strong work ethic, it also faces additional challenges including managing possible (or the potential for) diminished physical capacity, slowing cognition and decreased working memory, more difficulty with hearing and vision, higher rates of musculoskeletal conditions, and chronic diseases.[136]

As indicated previously, different work arrangements will be of increased importance in years to come, with demographic implications. Namely, racial minorities (comprising 22% of the total U.S. workforce) and foreign-born workers in the United States (comprising 17% of the total U.S. workforce) are highly concentrated in contingent work and nonstandard work arrangements, including day-laborers, seasonal workers, independent contractors, and leased workers.[137] Immigrant workers and those of lower socioeconomic status are frequently employed in higher-risk occupations (e.g., construction, agriculture, transportation, and emergency work), which are often subject to outdoor extreme weather conditions, predicted to continue to present OSH hazards.[138-140] As such,

immigrant workers face a combination of risk factors for heat-related illnesses, including lack of OSH knowledge and quality training, poverty, seasonality of jobs, and extreme work conditions.[141-145]

As new technologies are developed and evaluated, changing demographics must be taken into consideration to guarantee these technologies are inclusive of the workforce's diversity and equitably benefit and provide protections for all. For example, protecting the workforce requires that workers have properly fitting tools, machines, workspaces, and PPE. With respect to PPE, the full range of workers' body sizes and shapes across the United States has not often been considered during the design process. Historically, PPE was designed based on anthropometric data from U.S. military recruits during the 1950s to 1970s, translating into poorer fit for women and ethnic/racial minorities.[146] Improperly fitting PPE is a major and growing challenge for women in the modern workplace, especially as they move into "nontraditional" and more hazardous occupations (e.g., construction).[147] This is particularly problematic because poor fitting PPE can prevent the equipment from functioning correctly, be a safety hazard, and discourage its use by workers[148]; even when alternative-sized PPE is produced, it is often not well-marketed, making it difficult to find.[149] Thus, to avoid the mistakes of the past, CDC/NIOSH anthropometry efforts are prioritizing the future design of PPE, cobots, and exoskeletons to account for a wider range of body shapes and sizes, ensuring that they are accessible and effective for all workers.

In addition, there must be an effort to address the racism, sexism, and other forms of discrimination that may be built into machine-learning algorithms underlying AI systems, which could exacerbate occupational health inequities, if left unchecked.[150] Fortunately, there lie opportunities to leverage technology to support workforce diversity; specifically, assistive technologies, AI, and universal design can increase job opportunities and economic security for those living with visible and invisible disabilities that may affect a worker's vision, movement, thinking, remembering, learning, communicating, hearing, mental health, and social relationships.

Many steps can be taken by OSH professionals to remedy workplace and work issues impacting workers across demographics. More explicitly, these include improving data collection to better elucidate OSH disparities; developing inclusive technology; implementing policies and programs to reduce occupational health inequities; improving awareness of the social determinants of OSH; and fostering workplace inclusivity and worker empowerment. Well-designed, worker-centered safety and health approaches (e.g., work schedule flexibility, investments in worker training and skill-building, supportive supervision, and ergonomic and lifestyle interventions) will also benefit all workers in the future, to the degree they are inclusive of the workforce's growing diversity.[151] Complementing traditional approaches to OSH with new conceptual and methodological perspectives that can better account for the social aspects of health and well-being is similarly essential to ensuring that these benefits reach all workers. Stakeholders taking such actions will ensure that, regardless of changing demographic characteristics, all workers have safe and healthy jobs.

4.3.2 | Economic security

Economic security is a vital determinant of worker health and well-being[152,153] and, much like work arrangement efforts, for decades, related research activities have been chiefly led by CDC/NIOSH economists and others in OSH-related disciplines. The CDC/NIOSH Economic Research and Support Office carries on this study in conjunction with the CDC/NIOSH Healthy Work Design and Well-Being Program.

While there is no single, universally accepted standard definition of economic security, the International Labour Organization provides a broad definition that includes seven components[154]:

- Income security (adequate income and benefits);
- Representation security (individual and collective rights);
- Labor market security (opportunity for income-earning activities);
- Employment security (protection of income-earning work);
- Job security (opportunity for some control over the content of the job and to build a career);
- Work security (working conditions that are safe and promote well-being); and
- Skill reproduction security (opportunity to gain and retain skills).

According to a narrower and more commonly used definition of economic security, its components include income (or wage) and asset adequacy, benefits (e.g., paid leave, health insurance) adequacy, and job security.[155] The ability to earn adequate income and have access to adequate benefits is affected by adequate work hours. Adequate work hours mostly affect hourly workers who face additional, overlapping vulnerabilities. Income and benefits adequacy can be measured in relation to mean or median income, while job security can be measured by the unemployment rate and surveys asking workers how likely they are to lose their job over a specified period in the future. In simple terms, economic security refers to conditions that allow workers to maintain an adequate standard of living in the foreseeable future.

Several studies, including CDC/NIOSH-sponsored ones, have demonstrated the well-being effects of the components of economic security. For instance, low wages negatively affect behavioral health and psychological well-being,[156-158] while the risk of unemployment negatively affects physical and emotional health among the unemployed, underemployed, and employed.[28,159,160] Access to paid sick leave reduces the probability of suffering an occupational injury, improves the ability to seek preventive healthcare for family members, and reduces the transmission of infectious diseases at work.[161] Additionally, perceived job insecurity, which is associated with reduced engagement, impacts worker well-being and has economic consequences for employers.

Economic security is particularly critical to the future of work as it is related to many other CDC/NIOSH Future of Work Initiative priority topics discussed in this paper, including technologies, technological job displacement, aspects of organizational design such as job flexibility, work arrangements, and demographics.

For example, changes in the relationship between the technology and labor needed to produce goods and services are rather complex and have both positive and negative implications for the economic security of workers. Technological advancements increase productivity, resulting in higher income, while technological displacement of workers due to automation negatively affects the economic security of impacted workers; however, this negative impact can be mitigated by social services or training programs that help displaced workers develop new skills that match the evolving needs of employers and organizations. What is more, job flexibility, which is associated with the work arrangements that organizations adopt to adjust to market fluctuations (resulting in job insecurity with economic security implications) provides opportunities for workers to better manage their lives at and outside work. Lastly, the proliferation of some types of nonstandard work arrangements in the future may unfavorably affect the economic security of workers, further negatively affecting their well-being. Indeed, groups such as lower-income workers and workers of color (particularly women) may be disproportionately marked by the negative impact of unstable and unpredictable work scheduling practices on the rise. This leads to job instability and increased household economic insecurity, resulting in food insecurity.

Another reason to consider the allocation of economic security among workers now and in the future is that not only is income level a major determinant of worker health and well-being, but its distribution is as well.[162] Income inequalities are often reinforced by workers' specific occupations and work arrangements, as evidenced by organizational design factors. The flexibility to work remotely, for instance, is associated with relatively higher levels of education and income. The so-called "digital divide" exacerbates the overlapping vulnerabilities of certain groups of workers, including increasing their economic insecurity. As a result, some have proposed establishing a universal basic income,[163] which is gaining momentum in parts of the world, and which might serve to lessen the impact of low economic security among low wage/higher-risk worker groups.

Similar to other determinants of well-being, both perceived and revealed metrics of economic security are vital—as is tracking them over time—and economic and worker well-being spill-over effects and changes should be assessed over time for employers, and workers and their families.

4.3.3 | Skills

Over the past several decades, advances in technology have increased the demand for more skilled workers in the United States[164] and globally. Against this backdrop, concerns about the purported skills gap (a mismatch between the skills workers have and the skills prospective employers want and need) have been persistent, widespread, and controversial.[65,165-170] Although the skills gap is contested terrain, it is generally recognized that globalization and innovative technologies have generated new and urgent demands for the knowledge and skills required for job and life success.[171] As such, in 2013, CDC/NIOSH launched the Safe • Skilled • Ready Workforce Program to build on more than two decades of young worker research—including in the area of OSH skill development[172,173]—and to advance science for the design, implementation, and evaluation of OSH programs that prepare vulnerable workers for safe and healthy employment.

To keep pace in a rapidly changing global economy, workers must continually upgrade their skills, maintain their employability, pursue career advancement, and respond to unexpected changes in demand for their current skill set.[174] More precisely, the future workforce will engage more comprehensively with machines and will thus need to gain in-demand skills to keep pace with the new automation age.[61] To that end, the World Economic Forum launched a multistakeholder initiative of national governments and private-sector companies to prepare the global workforce—a billion people by 2030—with the skills needed to "future-proof" their jobs against displacement resulting from rapid technological change.[175] A skilled workforce is truly the essential input to a productive and competitive economy and enhancing the skills of the workforce is imperative for promoting long-term economic growth and social development.

More than ever, skills are a vitally important future of work consideration. A multi-country survey of adult skills concluded that the use of skills in the workplace has an influence on important labor market phenomena, including productivity, and the wage gap between temporary and permanent employees.[176] Lower-skilled workers may be hindered in their ability to contribute to and benefit from a dynamic economy. These workers may have difficulty attaining the additional education and training needed to respond to structural changes that require adaptation to new methods and processes, possibly creating a kind of poverty trap or a self-reinforcing trend.

These findings also suggest lower-skilled workers have poorer health outcomes.[174,176] The absence of skills reduces the employability of workers, leading to underemployment and unemployment, which have substantial, adverse health and well-being impacts.[177-180] Undeniably, skills and access to training are inextricably linked with health equity, addressed in the demographics section. For instance, lack of job opportunities and an increase in hopelessness and despair have been implicated in the marked increase in mortality among middle-aged, white Americans[181]; an increased risk of depression among young people[182] and adults[180]; and an increased likelihood of health problems among African Americans.[182] Depression rates in the United States have been shown to be higher among non-Hispanic Blacks and Hispanics, who are more likely to be in lower-wage (lower-skilled) jobs.[183] Conversely, employability—the ability of a person to find and maintain employment, measured by proxies such as the skills of the worker—has been demonstrated to substantially moderate the effects of unemployment and job insecurity on life satisfaction and mental health.[184] This said, the association between health status and skills is complex and has many confounders. For one, healthier workers may be more likely to have the wherewithal to engage in additional training or education to enhance their skill sets than do those in poorer health.[174]

Moreover, higher-skilled workers may also be more likely to find employment in occupations and industries that minimize their exposure to safety and health hazards.

Knowing which skills are critically important for the future workforce is a necessary next step as the future of work unfolds. What the new, in-demand, and robust skills are and how they are acquired and measured is a subject of on-going deliberation. Typically, employers seek workers with not only greater proficiency in literacy and numeracy (so-called hard, technical, and cognitive skills) but also strong interpersonal and problem-solving abilities.[59] Also referred to as soft skills, work-readiness, employability skills, noncognitive skills, 21st century skills, and transversal competencies, they are commonly accepted to be a wide range of knowledge, skills, abilities, and dispositions that are vital to citizenship in a modern society and workforce.[185,186] Cross-sector competencies are also in higher demand by employers than are more narrow technical skills. These competencies are usually considered to be portable as they can be taken from job to job, and transferable or transversal as they can be applied across multiple situations and social contexts as well as span cognitive domains.[187,188] Top 21st century skills and competencies required to succeed in high-growth/high-demand jobs include critical thinking and active listening, while communication, creativity, critical thinking, and problem-solving are the four most frequently identified, high-demand skills within national policy documents of 152 countries surveyed.

Critically, most of the current frameworks and initiatives to prepare the emerging workforce do not consist of essential cross-sector competencies, which include knowledge, skills, and abilities for safe and healthy work. To promote the safety and health of the future workforce, foundational competencies in OSH should be integrated into existing programs and activities aimed at preparing the emerging labor force to compete and succeed.[172,189] These competencies[172,190-192] would provide a foundation on which job-specific, safety skills are built and could be integrated into the work readiness skills delivered to secondary school students before they enter the workforce so that they are prepared for the dynamic risks and hazard scenarios they may encounter.

Developing and maintaining the skills proficiency of the workforce is vital to innovation and competitiveness and to the creation and retention of high-paying, high quality, and high-status jobs.[174] In turn, ensuring skills related to OSH are included in and are central to this vision is essential for ensuring today's and tomorrow's workers are safe, healthy, and productive.

5 | DISCUSSION AND NEXT STEPS

The importance of many of the CDC/NIOSH Future of Work Initiative priority topics introduced in these pages for the safety, health, and well-being of workers is not new. The scientific literature is filled with evidence on the vitalness of issues such as health insurance,[193] paid leave (e.g., vacation, sick, family, parental),[26,28,29,119,119,161] job flexibility (e.g., telework, virtual, non-fixed hours, work–life balance),[194] adequate living wages,[157,158,183] job stability,[153,195] and healthy leadership[47] to not only meet workers' basic human needs, but also that of their families, communities, and society as a whole. What may be newer, however, is the heightened awareness as to the significance and necessity of these existing and emerging future of work issues for the workplace, work, and workforce to flourish, merely survive, or disappear altogether in today's world. This more recent cognizance may serve as motivation for stakeholders to harness what they already do that is successful, modify what is needed to become so, or endure consequences from a lack of needed change. And, based on varied leadership decision-making, time will reveal both the negative implications and positive benefits for employers and workers regarding safety, health, and well-being issues long marginalized, as predicted world scenarios ensue.

Ultimately, all future of work priority topics impact one another in some capacity. Basic, foundational workplace topics, such as organizational design, are modified by technology (enabling flexibility), demographics (seeking flexibility), and global market needs. In turn, these will affect work regulations, which will then contribute to other relevant issues such as work arrangements, economic security, work–family balance, and the overall safety, health, and well-being of the workforce. The future of work will depend on each of the standalone factors discussed in this paper and their combined effects. Given this, through cross-fertilization efforts and by way of the CDC/NIOSH Future of Work Initiative, the Institute will continue exploring these future of work factors, including examining the central interrelationships among them. Undeniably, the interactive, cross-cutting, and interdependent issues of all elements displayed in Figure 1 are critical to address in-depth. As such, CDC/NIOSH and others will engage in subsequent activities to fulfill earlier highlighted goals, which also include exploring the intricate nature of the relationships among future of work foci.

Another noteworthy step will be to use a process guided by strategic foresight, an action-oriented planning discipline,[196] which involves the practice of both seeing and acting ahead based on inputs that explore and organize signals of change to identify alternative future scenarios for which an organization should be prepared. Foresight involves six stages of activity to help prepare for change: framing, scanning, forecasting/futuring, visioning, planning/designing, and acting/adapting. Organizations can use data subsequently garnered to influence a preferred future and generate options to alternative futures.[197] Such actions lead to a deeper understanding of potential disruptions on the horizon and an enhanced capacity to think strategically and act proactively to influence the emerging future.[197,198] To that end, CDC/NIOSH will launch several activities to develop a futures-oriented capacity in research prioritization and planning to shape the future by helping to anticipate possible scenarios and their impact and offer recommendations. Along with external stakeholders and partners, CDC/NIOSH will further use the TWH framework to conduct collaborative Institute-wide activities with extramural partners to develop an expanded focus for OSH.[199] The goal is development of a transdisciplinary field that embraces new disciplines expanding the traditional OSH approach[199] by considering work, nonwork, personal, and socioeconomic risk factors, along the working life continuum.

6 | CONCLUSION

The future of work presents many new opportunities for the workplace, work, and workforce, while also posing significant but not yet fully understood challenges, exposures, and hazards.[200] Examining and addressing these is an imperative effort as the future of work is further shaped by both anticipated and unanticipated national and global issues such as extreme weather conditions and pandemics that require emergency and disaster preparedness and response, and with potential, long-lasting implications. Such worldwide life events and developments may impact workers across all occupations and industries at an accelerated rate as changes in the workplace, work, and workforce take hold. This will require new and flexible ways of perceiving and confronting risks. It is the responsibility of CDC/NIOSH and its OSH stakeholders to prepare employers and workers by providing sound, evidence-based recommendations on how to best safeguard and promote the safety, health, and well-being of workers facing uncertain futures.

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AUTHOR CONTRIBUTIONS

Sara L. Tamers, PhD, MPH, participated in (a) conception or design of the work; (b) the acquisition, analysis, or interpretation of data for the work; (c) drafting the work or revising it critically for important intellectual content; (d) final approval of the version to be published; and (e) agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Jessica Streit, PhD, MS, participated in (a) conception or design of the work; (b) the acquisition, analysis, or interpretation of data for the work; (c) drafting the work or revising it critically for important intellectual content; (d) final approval of the version to be published; and (e) agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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The work was performed at the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention. There was no ethics review and approval and/or no informed consent given that no human subjects were involved.

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