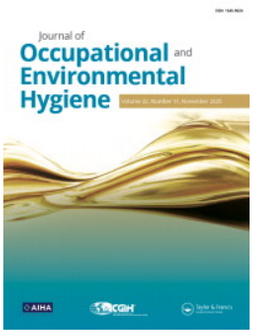

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REVIEW ARTICLE

Exploring the future of occupational safety research: A strategic foresight approach

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ABSTRACT

A team from the U.S. National Institute for Occupational Safety and Health conducted a strategic foresight project to explore the future of occupational safety research (OSR). Data collected via systematic horizon scanning and key informant interviews were synthesized into six drivers of OSR change: (1) technological advancement, (2) partnerships and public trust, (3) prioritizing research investments, (4) safety and health integration, (5) data and science quality, and (6) worker protections. These drivers served as the basis for envisioning four potential OSR futures. Analysis of the resulting scenarios identified opportunities to enhance and advance OSR methods and approaches, innovation, systems thinking, interpersonal networks and connections, and the ethical application of scientific findings as we move into the future of work.

KEYWORDS

Future of work; innovation; long-term planning; occupational safety; systems thinking; strategic action

Introduction

The Occupational Safety and Health (OSH) Act of 1970 established the U.S. National Institute for Occupational Safety and Health (NIOSH) and charged the federal agency with conducting research to advance OSH knowledge and inform the development of occupational standards (OSHA n.d.). A large part of the modern NIOSH portfolio focuses on occupational safety research (OSR), including basic, etiologic, surveillance, intervention, translation, and implementation studies designed to address occupational safety hazards across a variety of industries (NIOSH 2018; Stout and Linn 2001).

By definition, safety hazards include any "condition or activity that, if left uncontrolled, can result in an injury or illness" (OSHA 2002). Rapid changes affecting the landscape of work, including what constitutes work, who engages in the work, and where work can be performed, suggest we are experiencing an ongoing evolution of the work-related conditions and activities considered to be hazardous. For example, a recent comprehensive future of work review including a variety of industries and occupations found a heavy emphasis on the creation and exacerbation of psychosocial (e.g., organization of work, long or irregular work hours, fatigue, violence) hazards, with little mention of biological (e.g., viruses, bacteria), chemical (e.g., solvents, paints, toxic dusts), or physical (e.g., confined spaces, extreme temperatures, noise, vibrations) hazards (Schulte et al. 2020). While this does not necessarily suggest traditional safety hazards are expected to disappear completely, it does provide evidence of a potential shift in hazard-related priorities over time.

Considering this shifting hazard landscape, it seems shortsighted to assume today's standard OSR practices and priorities will remain effective as we move into the future of work. In recent years, NIOSH has developed a keen interest in understanding how to best position OSR for long-term success. To help inform robust preparation and planning for the future, a group of scientists from NIOSH engaged in a strategic foresight exercise to explore how unfolding changes may impact near-, mid-, and long-term approaches to OSR.

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Since 2021, NIOSH has leveraged the application of strategic foresight to better understand and prepare for the uncertain future and its implications for OSH (Felknor et al. 2023; Streit et al. 2021, 2024). Strategic foresight is a specialty practice within the realm of futures studies that is guided by systems thinking (Bishop and Hines 2012). It involves the collection of early evidence of potential change over the near-, mid-, and far-term futures and the application of findings to develop scenarios, or stories, about how the future might be different from today (Bishop et al. 2007; Policy Horizons Canada 2016). In-depth analysis of scenarios can uncover key implications and issues for organizational planning and responsive strategic action (Hines and Bishop 2015; IFTF 2021; Ramirez and Wilkinson 2016). Because strategic foresight considers and incorporates evidence while pushing us to think creatively about the future, these exercises help to combat the Achilles Heel of futures preparedness: the inherent human tendency to either over- or under-predict change (Iden et al. 2017; Schoemaker 1993).

Project purpose and objectives

The purpose of the NIOSH *Safety Research Foresight Project* was twofold: (1) to develop a long-term view of potential futures for OSR, and (2) to strengthen future planning and action for OSR. The specific project objectives were to: (1) gather early signals of how the future, as it relates to OSR, may be different from today; (2) identify critical uncertainties associated with the future design and implementation of OSR; (3) develop complementary evidence-based future scenarios for OSR; (4) articulate key implications and issues that may influence future approaches to OSR; and (5) generate a list of strategic actions to help the OSR community prepare for the future.

This project was reviewed by the CDC, deemed not to be research according to the definition of public health surveillance, and was conducted consistent with applicable federal law and CDC policy. See 45 CFR part 46.102(l)(2) for additional information (U.S. Code of Federal Regulations 2023).

Methods

The project was completed over a period of eight months (March to December 2023). Activities were guided by the Foresight Framework for Occupational Safety and Health (OSH), a discipline-specific adaptation of the University of Houston's Framework Foresight (Hines and Bishop 2015; Streit et al. 2021). Figure 1 visually displays the six stages of the Foresight Framework for OSH in operational order: (1) *Framing*: identifying and defining the domain of interest, (2) *Scanning*: searching for and organizing futures-oriented information, (3) *Futuring*: synthesizing the information into evidence-based scenarios, (4) *Visioning*: exploring the implications and issues associated with the scenarios, (5) *Designing*: developing and implementing strategies to positively influence the future, and (6) *Monitoring*: watching for new indicators of potential future change. While a deeper dive into the structure and logistics of the Foresight Framework for OSH goes beyond the scope of the current paper, details are available in previous NIOSH publications (Felknor et al. 2023; Streit et al. 2021, 2024).

The Safety Research Foresight Project accomplished the first four stages of the framework. Each stage utilized a unique approach to meet its objective.

Framing approach

Framing was completed through a combination of independent and group brainstorming sessions. NIOSH senior leaders and strategic foresight practitioners spent several weeks collectively identifying and defining *occupational safety* as the project domain. A group of NIOSH OSR experts spent an additional three weeks summarizing relevant OSR conditions, identifying key interest groups for OSR, and providing salient examples of major OSR milestones from the past several decades.

Scanning approach

The interdisciplinary scanning team, recognized in the Acknowledgments section of this paper, reviewed traditional refereed publications, books, government reports, research reports, trade journals, popular news media, magazines, newspapers, newsletters, blogs, opinion pieces, podcasts, webpages, advertisements, and videos for information on the near-, mid-, and far-term future. NIOSH strategic planning cycles were used to identify the three future "horizons." The near-term future was defined by the current publicly available NIOSH Strategic Plan, which runs through 2026 (NIOSH 2023). The mid-term future was defined as the next planning decade (2027–2036), and the long-term future was defined as the years beyond (2037+).

Following standard foresight practice, a series of one-on-one semi-structured interviews was conducted

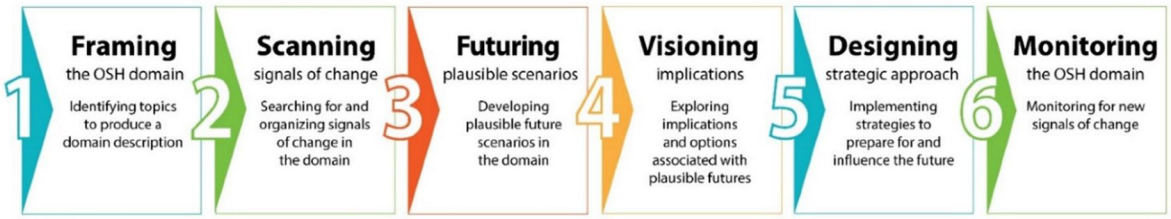

Figure 1. Foresight framework for Occupational Safety and Health.

with subject matter experts (SMEs) to complement the horizon scan. These conversations are beneficial to further elucidate key trends, opportunities, strengths, issues, and obstacles that may influence future planning and action (Policy Horizons Canada n.d.; Wilkinson 2017). Each interview was conducted on the Zoom for Government (Zoomgov) platform and lasted 30–45 min. Verbatim interview transcripts were manually analyzed using NVivo 12 Qualitative Research Data Analysis software (QSR International Pty Ltd 2018). Braun and Clarke's (2006) qualitative framework for identifying interview themes served as the blueprint for interview data reduction. Because foresight requires a forward focus, the coding also involved constant comparison of the interview themes for relevance to the future of OSR. A second analysis approach was then applied to extract key concepts from the coded scanning hits and interview passages and cluster those based on conceptual similarities (Saldana 2021). The clusters were discussed, refined, and finalized by the scanning team to become drivers of change for OSR.

Futuring and visioning approach

All interviewees were invited back to participate in a 4-hr virtual workshop to inform the futuring and visioning stages of the foresight process. The workshop was hosted on the Zoomgov platform and included polling, small group activities, and large group discussion. The workshop followed best practices for the matrix method of scenario development, which constructs and evaluates stories of the future built within a 2×2 grid (Rhydderch 2017; Schwartz 1996). After the workshop, two core team members with cross-training in OSH and foresight reviewed the notes and recordings to finalize the four scenarios and their implications for OSR. The results were secondarily reviewed by an external expert to confirm their fidelity and validity.

Findings from the Framing, Scanning, and Futuring stages of the Foresight Framework (Figure 1) are described in the Results section of the paper. Insights on Visioning, Designing, and Monitoring are presented in the Discussion and Conclusions, as appropriate.

Results

Frame and current assessment of OSR

Operationalizing occupational safety

For this project, the *occupational safety* domain was defined by five topics relevant to OSR:

- *Partners:* OSR collaborators, as well as the mechanisms and resources required for these relationships
- *Safety regulation:* The guidelines and laws that protect worker safety
- *Workforce:* Characteristics related to the people available to work in the U.S.
- *Technology:* The use of tangible machines and tools for work and OSR
- *Hazards and risks:* Work-related factors and conditions that can cause illness, injury, or death

As depicted in Figure 2, these topics were situated within the broader context of social, technological, economic, environmental, and political (STEEP) external factors that may influence the future. Figure 3 provides additional substance to each topic by highlighting the keywords that were initially used to guide information-gathering activities in subsequent project stages.

Current assessment of OSR

Table 1 outlines the results of the baseline OSR assessment completed by NIOSH SMEs. Current OSR conditions are organized into five major topics: data and information quality and access, technology, the organization of work, work-related safety in the context of public health, and operational and budget considerations. Key parties and contributors are grouped by organization type to highlight OSR interest across academia; federal advisory committees; federal, state, and local agencies; insurers; organized labor; the nonprofit

sector; and standards-setting bodies. Select milestones are clustered by decade to demonstrate the evolution of OSR since the establishment of NIOSH in 1970.

It is important to remember that the completed current assessment is not intended to provide a comprehensive review of the history of occupational safety. Rather, its purpose is to establish a shared understanding of how OSR functions in the present day, particularly for NIOSH.

Scan for signals of future change and uncertainty

Signals on the horizon

The scanning team located 175 unique scanning hits relevant to the future of OSR. Thirty-six percent ($n = 64$) described continuations or accelerations of prevailing OSR-relevant practices or paradigms in the near-term future. Approximately half (51%; $n = 89$) identified changes that may take place and influence the mid-term future. The remaining 13% ($n = 22$) came from the far-term future.

Figure 2. Safety Research Foresight Project domain map, which organizes *occupational safety* into five research-oriented topics situated against a STEEP backdrop.

Key informant interview themes

A total of 27 semi-structured interviews were conducted to complement the scan for near-, mid-, and far-term signals of change. Eighteen interviewees were NIOSH OSR leaders (e.g., national experts in mining, agriculture, construction, Total Worker Health, traumatic injury, motor vehicle safety, or robotics). Nine were extramural experts affiliated with key safety interest groups (e.g., NIOSH grantees and councils, safety-related professional associations, or other government agencies active in occupational safety). The 2:1 ratio of NIOSH to non-NIOSH interviewees helped to ensure a breadth of perspectives on OSR were gathered, while remaining grounded within the purview of a federal agency.

Analysis of the interview transcripts identified nine primary themes. These themes, which served as an interim output of the foresight process, are presented in Table 2. The number of conversations containing interviewee-initiated comments or discussion relevant to each theme is included to provide a sense of each theme's prevalence. This should not, however, be interpreted as a quantified measure of the relative importance of any theme. All themes were strongly linked to the interview transcript data and equally considered as the foresight process continued.

Signal and theme synthesis

The collective synthesis of future signals and interview themes yielded a final set of six theme-based clusters. Each cluster defined a unique driver of change, or key factor, that could shape the future of OSR (Hines and

Partners	Safety Regulation	Workforce	Technology	Hazards and Risks	STEEP
• Industry • Workers • Labor unions • Mechanisms • Resource sharing	• Policies • Standards • Regulatory agencies • Reporting requirements • Compliance	• Training • Safety climate and culture • Demographics • Health communication	• Work tasks • Risk assessment • Hazard identification • Hazard control • Data collection • Instantaneous data availability • Data sharing	• New and Existing • Work environment • Work organization • Occupational injuries	• Global Economy • Sustainability • Climate • Values around work • Political (in)stability • Global and regional conflicts

Figure 3. Keywords used to facilitate exploration into each of the occupational safety domain map topics.

Table 1. Baseline assessment of occupational safety and related NIOSH activities, as of September 2023.

Assessment category	Description
Current conditions	**Data and Information** • Increasingly stringent laws around when and how federal agencies can collect information from the public make it increasingly difficult to conduct OSR in timely and meaningful ways (General Services Administration n.d.-b). • The Bureau of Labor Statistics, which serves as the remaining major source of national surveillance data on nonfatal occupational injuries, is incomplete and has acknowledged issues with underreporting (Rogers 2020). • New data governance and information technology requirements for federal agencies has significantly challenged and constrained forward progress on research studies, including data access, data collection, data sharing, and data analysis (General Services Administration n.d.-a). • The United States lacks a unified system to capture nonfatal work-related injuries. Instead, researchers rely on multiple sources of data, which are ever-changing and becoming increasingly difficult to access and utilize (The National Academies of Sciences, Engineering, and Medicine 2018). **Technology** • Industry 4.0 and the Industrial Internet of Things have brought both new safety opportunities and new risks and hazards for workers (Bloom et al. 2018). • Largely unregulated uses of artificial intelligence impact occupational safety in the workplace (e.g., automation of hazardous jobs) and associated research (e.g., synthesizing large amounts of literature and writing synopses) (van Dis et al. 2023; Wisskirchen et al. 2017). • Machine learning is increasingly used to code, manage, and forecast occupational injury surveillance data (Khairuddin et al. 2022). **Organization of Work** • The evolution of the gig economy creates challenges for reaching nonstandard workers for research, translation, and implementation purposes (Bates et al. 2020; Taylor et al. 2023). • Industry 'disruptors' introduce new business models and practices related to safety (e.g., hours of service regulations, safety equipment in vehicles, etc.) that directly affect worker pay, work schedules, hours worked, and time spent engaging in risk-enhancing behaviors (Schremmer 2023). **Broader Public Health Context** • The future of work arrived faster than expected due to significant changes in work organization and the nature of work resulting from the COVID-19 pandemic (Alfes et al. 2022). • The U.S. Surgeon General prioritizes mental health as a national public health issue, providing new opportunities for workplace safety efforts and initiatives (U.S. Surgeon General n.d.). • Social determinants of health that exacerbate risk of injury are embedded in public health and occupational safety.(Silver et al. 2024) • Mass shootings have become increasingly common, affecting safety in the workplace (Fowler et al. 2021). • There are ongoing efforts to integrate standardized, self-reported, patient work information into electronic health records (Wallace et al. 2021). **Operational and Budgetary Considerations** • Federal and state budgets underinvest in public health staffing, including occupational safety staffing (Leider et al. 2023). • In general, federal agencies face broad challenges related to budgets and staffing (OMB 2022).
Exemplar safety research key interest groups	• **Academia:** colleges and universities with active occupational safety portfolios, including the NIOSH Extramural Research and Training Programs • **Federal Advisory Committees:** Advisory Committee on Construction Safety and Health; Board of Scientific Counselors; National Advisory Committee on Occupational Safety and Health • **Federal Agencies:** Agency for Healthcare Research and Quality (AHRQ); Bureau of Justice Statistics; Bureau of Labor Statistics (BLS); Consumer Product Safety Commission; CDC's National Center for Injury Prevention and Control Department of Defense (DOD); Department of Labor; Department of Transportation; Federal Highway Administration; Federal Motor Carrier Safety Administration; Mine Safety and Health Administration (MSHA); National Highway Traffic Safety Administration (NHTSA); National Institute for Occupational Safety and Health; National Institute of Justice; National Transportation Safety Board; Occupational Safety and Health Administration (OSHA); US Coast Guard; US Fire Administration • **Insurers:** Liberty Mutual Insurance • **Labor Unions**: International Association of Fire Fighters, Teamsters, AFL-CIO • **National Academies of Sciences, Engineering, and Medicine:** Transportation Research Board • **Nonprofit Organizations:** The Center for Construction Research and Training (CPWR); Council of State and Territorial Epidemiologists (CSTE); Insurance Institute for Highway Safety; National Safety Council

(*Continued*)

Table 1. Continued.

Assessment category	Description
	• **Professional Associations:** American Society of Safety Professionals (ASSP; formerly ASSE); American Public Health Association Occupational Health and Safety member section • **Public-Private Partnerships:** Network of Employers for Traffic Safety • **Standards Committees and Organizations:** American National Standards Institute; American Society for Testing and Materials; International Organization for Standardization • **State and Local Partners:** State Occupational Safety & Health Surveillance Program; Workers' Compensation Cooperative Agreement States • **Trade Associations:** American Road & Transportation Builders Association; Associated General Contractors of America; International Association of Fire Chiefs; International Safety Equipment Association (ISEA); National Fire Protection Association (NFPA)
Select highlights from safety research recent history, by decade	**1970s** • Survey of Occupational Injuries and Illnesses: To address a mandate in the OSH Act of 1970, the Bureau of Labor Statistics begins publishing estimates of injury and illness incidence rates by industry. This provided one of the earliest chances for NIOSH and others to explore workplace hazards that lead to injuries and illnesses. **1980s** • The Fatality Assessment and Control Evaluation (FACE) program is created to identify factors contributing to traumatic fatal injuries at work and inform the development of comprehensive recommendations to prevent similar deaths. • Creation of the National Traumatic Occupational Fatalities (NTOF) Surveillance System. These data were extensively used to describe fatal workplace injuries and to identify specific research priorities for many high-risk worker populations. **1990s** • BLS begins to publish detailed information on the circumstances and demographics of injured or ill workers in the Survey of Occupational Injuries and Illnesses. • The BLS Census of Fatal Occupational Injuries (CFOI) was created as a multi-source system of traumatic occupational fatalities. • The first decade of the National Occupational Research Agenda (NORA) was initiated. NORA was developed as a partnership program to stimulate innovative research and improve workplace practices. • NIOSH launched a National Childhood Agricultural Injury Prevention Initiative, including research, public education, and professional training. • Based on external partner interest and high numbers of fatalities occurring among firefighters, NIOSH was mandated to develop the NIOSH Fire Fighter Fatality Investigation and Prevention Program (FFFIPP). To date, this program has completed more than 350 investigations of traumatic firefighter line-of-duty deaths, which have resulted in recommendations to prevent similar deaths and injuries in the fire service. • NIOSH began collecting occupational injury data from emergency departments using the occupational supplement to the National Electronic Injury Surveillance system (NEISS-Work). This became the second national surveillance system of nonfatal occupational injuries and served as the basis for much of NIOSH's nonfatal occupational injury research for approximately 25 years. **2000s** • Advent of social media influences communication about occupational safety to a variety of audiences (Lagoe and Newcomer 2023). • Foundational paper describing conceptual filters of occupational injury underreporting is published. The paper identifies various reasons for incomplete occupational injury data and helps frame the strengths and weaknesses of any occupational injury data collection effort. To date, it has been cited nearly 700 times. **2010s** • NIOSH apps (e.g., Ladder Safety app, Maine Department of Labor, HEAT Safety Tool app (OSHA-NIOSH), Lifting Equation App: NLE Calc) provide safety information to a broader audience in a more accessible format. • NIOSH established the Center for Workers' Compensation Studies (CWCS) to integrate NIOSH's traditional research efforts with workers' compensation efforts aimed at providing medical care and wage benefits to workers with a work-connected injury or illness. This increased NIOSH access to and use of an alternate occupational injury data source. • The NORA Traumatic Injury Prevention Council was formed and includes members who are internal and external to NIOSH. • A Smarter National Surveillance System for Occupational Safety and Health in the 21st Century is released, providing a comprehensive assessment of and recommendations to improve OSH surveillance. This led to discussions between NIOSH, OSHA, and the BLS on how to develop more coordinated, cost-effective approaches for OSH surveillance.

Table 2. Future of safety research themes from key informant interviews ($n = 27$).

Theme	Codes clustered to create theme	n[a]
Topics for future research	Health and well-being outcomes related to safety; advanced technology; new research methods and approaches; safety risk factors	27
Partnerships	Importance of partnerships; responding to partner wants and needs; internal collaboration; new ways to build partnerships; changing partner roles; creating opportunities for collaboration and idea exchange	27
Establishing priorities	Emphasizing research-to-practice and translational research; sunsetting legacy research that is no longer critical; focusing research priorities; innovate or become irrelevant; capitalizing on organizational advantage; allocating resources based on the safety burden addressed; using top-down or bottom-up approaches to identify research needs; coordinating diverse national safety research portfolios; incentivizing researchers to focus on new and nontraditional issues; ensuring cumulative injuries receive as much attention as isolated 'dramatic' events	26
Organizational characteristics	Agility; credibility; territoriality; rigidity; risk aversion stifles innovation; limitations of traditional personnel advancement approaches for scientists; creating evidence vs. using evidence created by others	26
Administrative processes	Information technology; administrative burdens of conducting science; budgetary constraints; review and clearance processes required to disseminate science; stuck in old ways, methods, and approaches	20
Workforce development	Attracting new talent; retaining existing talent; training for new OSH professionals; importance of unique perspectives in OSH science; metatraining – learning to learn and change; developing geographically dispersed workforces; dynamic learning; interdisciplinarity; workforce pipeline	19
Communication needs	Widely communicating the importance of OSH; offering practical solutions for industry; overcoming industry resistance to guidance; increasing demand for microlearning; OSH advocacy	17
Policy and governance	Standards and regulation development; politicized safety and health; governance effects on business operations	14
Resources	More resources needed for safety research	12

[a]Number of interviews containing content coded to the theme.

Bishop 2015; Policy Horizons Canada 2016). The drivers included technological advancement, partnerships and public trust, prioritizing research investments, safety and health integration, data and science quality, and worker protections. These are defined in more detail in Table 3.

To prepare them for use in constructing scenarios, the drivers were restated as key questions about the future for which there is currently no definitive answer. This 'uncertainty' format is intended to inspire critical reflection about how the drivers of change may impact the future within the domain of interest (Rhydderch 2017). The six OSR uncertainties pertinent to this project are presented in Table 4. For each question, a pair of extreme polarized outcomes has been identified. In foresight, the extremes are used to spur discussion about future possibilities; it is understood that the actualized future will unfold somewhere along the continuum that exists between them (Rhydderch 2017).

Four future scenarios for OSR

Twenty-one (78%) of the interviewed SMEs returned to participate in the workshop and construct a 2×2 scenario matrix. Through a polling exercise, the SMEs selected the *technological advancements* and *safety and health integration* uncertainties to serve as the 2×2 matrix axes. The remaining drivers and their associated uncertainties were used to generate the storyline within each scenario quadrant. The final four scenarios, each approximately 400 words long, were titled *Technological Utopianism, Limited Utility, Ineffectual OSH,* and *Unintended Consequences.*

Figure 4 shows how the scenarios were positioned within the 2×2 matrix and includes a brief description for each quadrant. Table 5, a shorthand scenario map, provides greater detail for each story. The structure of the map allows exploration of driver combinations *within* each scenario to create a cohesive potential future for OSR. It also facilitates cross-scenario comparison to show how each driver unfolds differently *across* the four scenarios. The final row of the table highlights the key topics for strategic reflection that were extracted from each scenario. Collectively, the topics relate to building collaborations; generating and translating safety-related evidence; enhancing communications; exploring emerging technologies and other OSR priorities; utilizing new types of data; addressing barriers to safety

Table 3. Six drivers of change for the future of safety research.

Driver name	Description
Technological advancement	Rapid technological advances continue to complicate the occupational safety landscape. The research community is tasked with examining both the benefits and the hazards that new and emerging workplace technologies bring for industries, organizations, and individual workers.
Partnerships and public trust	It is important for safety researchers to continuously look for new ways to build relationships, facilitate and strengthen collaborations, and promote the exchange of ideas to advance safety knowledge while combating public mis- and distrust of science.
Prioritizing research investments	Research institutions face difficult decisions regarding what streams of activity to advance or conclude, including when to generate new evidence or translate existing knowledge into industry solutions.
Safety and health integration	The interplay among safety, health, and well-being suggests the need for more holistic and integrated approaches to identify and explore risk factors and outcomes to adequately meet the health and safety needs of a diverse labor force.
Data and science quality	A push toward open science and an uptick in industry-generated data (due in part to advancing technologies) have expanded the amount of information available for safety research purposes. These data bring new issues around access, information quality, and ethical concerns for safety research.
Worker protections	Workers are left vulnerable to risks and hazards as occupational safety regulations struggle to keep pace with change and disruption in the future of work. The role of regulations is further called into question with the rise of nonstandard work arrangements, where the responsibility for worker safety is often unclear.

Table 4. Key uncertainties for the future of safety research, with polarized response options.

Driver	Key uncertainty question	Response A	Response B
Technological advancement	Do technological advancements bring more benefits and solutions or more hazards to the workplace?	More benefits	More hazards
Partnerships and public trust	Will labor and industry remain trusting partners of occupational safety research, or will public mis- and distrust of science lead labor and industry to become distrusting of occupational safety research?	Trusting	Distrusting
Prioritizing research investments	Will occupational safety investments be prioritized to support studies that generate new knowledge or activities that translate research to practice?	New knowledge	Research to practice
Safety and health integration	Will there be widespread acceptance for holistic approaches to integrate occupational safety and health, or will the field remain loyal to traditional approaches to occupational safety?	Holistic	Traditional
Data and science quality	Will the use of new information sources for research result in high-quality or poor-quality safety science?	High quality	Poor quality
Worker protections	Do regulations and standards adapt to protect workers anywhere work happens, or do they apply only to traditional workplaces?	Anywhere work happens	Traditional workplaces only

progress; safeguarding against the misuse of OSR findings to create disparate treatment across worker groups; and supporting a variety of professional and lived experiences across the OSR workforce.

Discussion of strategic visioning

Strategic implications for OSR

During the final activity of the workshop, all SMEs came together as a large group to compare the four scenarios and agree on their implications for OSR. The following discussion summarizes the implications identified for each scenario.

Key implications from the *Technological Utopianism* scenario include the need for new types of research to inform the development of work protections; a stronger emphasis on implementation of safety science; and increased need for expertise in social and behavioral sciences and Total Worker Health methods to achieve a more integrated, holistic approach to OSR.

The *Limited Utility* scenario showcases how the promising safety-enhancing benefits of evolving technologies may create new tensions related to job security and the incidence of injury, illness, morbidity, and mortality. While these may include concerns related to work precarity and worker displacement due to the

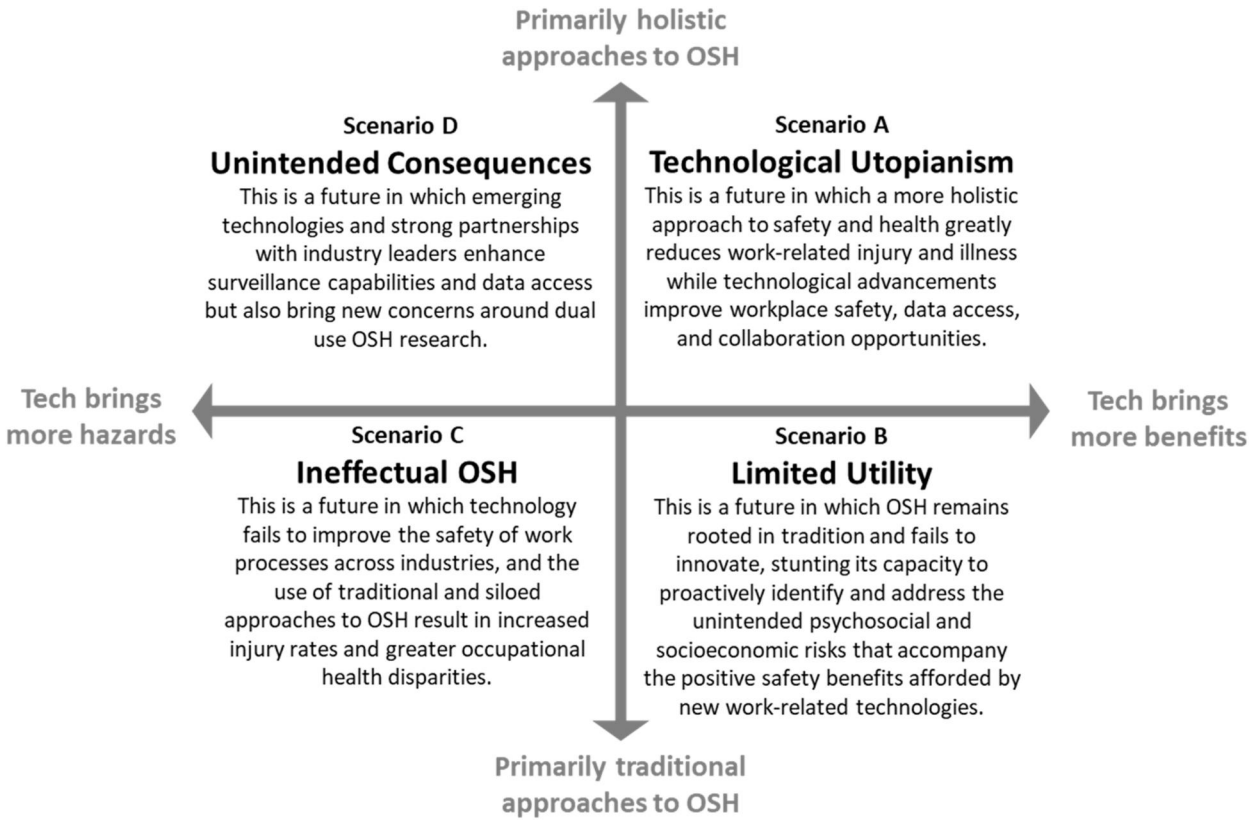

Figure 4. Final 2×2 matrix for safety research future scenarios. The x-axis was defined by the uncertainty for *technological advancements*, and the y-axis was defined by the uncertainty for *safety and health integration*.

Table 5. Comparative overview of the future of safety research scenarios.

	Scenario A: Technological Utopianism	Scenario B: Limited Utility	Scenario C: Ineffectual OSH	Scenario D: Unintended Consequences
Technological advancement	Integration with OSH	New challenges emerge	Growing disproportionality of OSH burdens	Risks remain unmanaged
Partnerships and public trust	Advancing trust and truth	Divided and semi-functional	Broken and irreparable	Influenced by industry
Prioritizing research investments	Balanced and responsive	Heavy technology focus	Constantly changing	Surveillance reigns supreme
Safety and health integration	Comprehensive and effective	Trying, not thriving	Stale and outdated	Dual-use research concerns[a]
Data and science quality	Enhanced and accelerated	Plentiful but unusable	Limited and questionable	High accuracy, low participation
Worker protections	Universal protections and leading indicators	Nontraditional workers lack coverage	No evidence, No protections	Silent on technology
Key topics for strategic reflection	Building collaborations that enhance trust in OSH science Achieving balance between generating evidence and translating evidence Enhancing communication capacity	Implementing research methods for emerging technologies Establishing research priorities Utilizing new data types Expanding research on nontraditional employment arrangements	Enhancing OSH connection to small business and historically disadvantaged workers Addressing challenges and barriers to progress Transcending OSH research siloes Ensuring regulations are evidence-based and informed by research	Remaining a neutral arbiter of OSH information while being responsive to industry and labor needs and interests Safeguarding against misuse of OSH scientific findings Increasing and sustaining interest in research participation across diverse worker groups

[a]Concerns that research methods, materials, or results could be used to cause harm (National Institutes of Health 2023).

implementation of technology, the rate and magnitude of these concerns may be disproportionately felt by historically vulnerable worker groups (e.g., racial and ethnic minorities, women, and older workers). In addition, follow-on OSR assessments may be needed to identify opportunities where the greatest impact can initially be made, particularly with respect to strengthening trust in OSH.

The *Ineffectual OSH* scenario demonstrates that OSR will need a clear understanding of the factors that influence industry acceptance of hazardous technologies. Important concerns may be raised if OSH methods and approaches fail to empower small businesses and protect workers at disproportionate risk of injury.

The *Unintended Consequences* scenario reveals how new methods of surveillance may be a critical first step in understanding technology-related hazards. Risk prevention strategies may also benefit from the identification and pilot testing of innovative research methods and approaches. Expanding concerns around the misinterpretation and misapplication of OSR results (e.g., justifying workforce downsizing based on population vulnerabilities or comorbidities of adverse safety-related outcomes) may bring the need for revisiting the scope of OSR ethical guidelines. Collaboration with public health partners and concepts may help to more holistically address new hazards associated with technological advancements.

The team identified six additional shared insights that collectively apply to all four scenarios:

- All OSR scientists could benefit from having a fundamental working knowledge of technology.
- Partnerships will likely be key to advancing OSR on work-related technologies in the near-, mid-, and far-term future.
- It would be beneficial to more officially monitor the broader set of external STEEP factors that can accelerate and decelerate industry change.
- Research that not only identifies but also critically considers facilitators and barriers to the adoption of new technologies and technology-related worker protections may enhance current OSR approaches and the implementation of findings.
- New, more sophisticated analytic methods and skills will likely be needed to maximize the use of data collected by new technologies.
- Clear and skilled communication of OSR results may be critical in preventing the misapplication of safety science findings.

Strategic action in OSR

The implications extracted from the four scenarios coalesced around five key areas where strategic planning and action may help NIOSH and the broader OSH community prepare for future changes impacting the practice and priorities of OSR:

1. **Enhancing OSR methods and approaches.** Amplifying the occupational safety toolbox may include considering new types of research and surveillance, expanding implementation science, and pilot testing new risk prevention strategies.
2. **Building capacity to conduct innovative OSR.** Improving researchers' capacity to innovate may involve increasing the representation of the social and behavioral sciences in its OSR staff; investing in advanced training for research data analysts and statisticians; and providing all OSR staff with foundational knowledge in work-related technologies and their safety risks, hazards, and benefits.
3. **Implementing systems thinking in OSR.** The principles of systems thinking may help address the complexities of occupational safety. Systems-based approaches may be incorporated into OSR by designing research activities that identify and address both the challenges and benefits associated with new safety solutions; explore the factors that lead to disproportionate rates of injury, illness, morbidity, and mortality; investigate facilitators and barriers to decision-making; and explore the external factors that influence change at the individual, organizational, industrial, and societal levels.
4. **Networking and connecting.** OSR scientists may collaborate with public health to address safety issues; build and maintain new and existing OSR partnerships, particularly in emerging technologies; and identify salient opportunities to strengthen public trust.
5. **Preventing the misuse of science.** Scientific communities in general would benefit from working together to determine whether policies are being appropriately applied to protect workers against the misuse of science. Skilled communication strategies within OSH may help prevent the misapplication of published OSR findings.

Limitations

The Safety Research Foresight Project was conceptualized as a non-research public health surveillance activity to develop inputs for future planning and action to enhance the robustness of the NIOSH OSR portfolio. Because of this, the *occupational safety* domain was framed by experts from NIOSH to focus on key areas of specific Institute interest. Other organizations may prefer to define occupational safety and its key topics differently for their unique explorations of future impacts to OSR. However, the demonstrable value of the results of this project should not be undersold. The data collection (signals scanning and key

informant interviewing) and analysis were thorough and rigorous, and the four scenarios provide broad descriptions of potential near-, mid-, and far-term future contexts in which OSR might be conducted by many diverse organizations.

In addition, this project was designed to explore the future of OSR in the U.S., primarily at the federal level. This should be recognized when interpreting the results, as there may be an underrepresentation of international and nongovernmental policies, practices, and perspectives. At the same time, it is worth noting that data collected for this project did include the review of domestic and international resources and the interviewing of both federal and nonfederal OSR experts to help minimize this gap.

Conclusions and considerations

The Safety Research Foresight Project followed the NIOSH Foresight Framework for OSH to systematically explore possible futures impacting OSR. Signals of emerging change related to partnerships, safety regulation, workforce composition and development, technology, and work-related hazards and risks were combined with SME input to identify six overarching drivers of change for OSR. These drivers were used as the basis for constructing four possible future scenarios and extracting their implications for OSR. Expert assessment of the challenges and opportunities implied by the scenarios elucidated five major areas for strategic action that may help safety researchers better prepare for the future. These include enhancing OSR methods and approaches, building capacity to conduct innovative occupational safety research, implementing systems thinking in OSR, networking and connecting, and preventing the misuse of science. Concerning the systematic practice of strategic foresight, outlined in Figure 1, the project completed the stages of Framing, Scanning, Futuring, and Visioning the future of OSR.

The Designing stage of the foresight process is the point at which foresight becomes actionable. Here, the results of a foresight exercise are integrated into organizational planning and decision-making to allow for the development of futures-informed strategies and plans, which can bolster organizational preparedness, advantage, innovation, and performance (Rohrbeck and Kum 2018; Ruff 2015). As such, organizations that conduct occupational safety research, practice, and education are encouraged to consider the results as input during their own planning and decision-making processes. The key topics for strategic reflection presented in Table 5, as well as the key areas for strategic action noted in the Discussion, can provide a roadmap for these organizations to stress test their own programs and planning approaches. This can, in turn, help to identify specific preparedness gaps and opportunities that can be addressed to strategically enhance their future readiness. Safety researchers, practitioners, and educators can also use the drivers and uncertainties to construct their occupational safety-relevant scenarios. These can then be assessed to either corroborate the results or shed light on additional implications and opportunities for strategic action. In addition to expanding evidence-based insights related to OSR, spinoff exercises can also enhance systems thinking capacity at the individual and organizational level. This is particularly important for building a futures-ready organization, as systems thinking is considered fundamental to strategic foresight and futures studies (Bishop and Hines 2012).

It is important to note that completion of this project, along with any spinoff activities, should not be the end of the OSR foresight process. In contrast, strategic foresight is considered most effective when it is embedded into the fabric of an organization as an ongoing activity (Hines and Bishop 2015; Ramirez and Wilkinson 2016). To normalize strategic foresight and systematic futures thinking for the OSR community, organizations are encouraged to develop their own internal signal scanning capacity over the near-, mid-, and far-term horizons. Ongoing scanning is the main component of monitoring for signals of change relevant to the future. Having early insights into what may be coming and how it might affect work, workers, and workplaces can help occupational safety-minded organizations become nimbler and more proactive in their efforts to understand and prevent work-related injuries, illnesses, and fatalities.

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Disclaimer

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Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

Study data are not openly available to protect the confidentiality of the participating experts. Data are stored at NIOSH in accordance with the CDC Records Control Schedule, which specifies NIOSH's legal authority for retaining and destroying Institute records, including project data.

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