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Emerging technology in agriculture: Opportunities and considerations for occupational safety and health researchers

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ABSTRACT

Introduction: A variety of factors are driving the development of robotics and automation in the agriculture industry including the nature of work, workforce shortages, and a variety of economic, climatic, technologic, political, and social factors. While some new robotics and automated machines are available commercially, most are still being developed. This provides occupational safety and health researchers an unprecedented opportunity to mitigate risks and benefit the health and safety of agriculture workers. *Method:* The NIOSH Office of Agriculture Safety and Health (OASH) is working to better understand how the advancements in automation and robotics is affecting workers. OASH is coordinating with the NIOSH Center of Occupational Robotics Research (CORR) to help to increase the understanding of human/machine interactions; improve the ability to identify injuries and fatalities involving automation/ robotics; and provide guidance on working safely with automation/ robotics. OASH also joined a small team of academics and industry to organize the SAfety For Emerging Robotics and Autonomous aGriculture or (SAFER AG) Workshop to identify gaps in knowledge and research needs that connect to issues related to risks and regulations/standards, occupational safety research, and impacts on workforce and society. This workshop was sponsored by USDA NIFA. *Practical Applications:* Occupational safety and health experts need to engage and collaborate with developers of technology. It is also increasingly important for occupational safety and health researchers and practitioners to not only become familiar with existing manufacturing safety standards, but also the lengthy standards development process. Joining consensus standards groups to help shape new standards for emerging technologies may help to mitigate adverse worker impacts. NIOSH's Office of Agriculture Safety and Health will continue to identify research gaps, support new research projects, education, outreach efforts and the development of best practices with our partners.

1. Introduction: Agriculture robots and automation

Many job tasks within agricultural work are commonly referred to as the 3-Ds: "dirty, dangerous, and demanding" (Quandt, et al., 2013), and one could add "dull" and "difficult." The "3-D" moniker is not without merit. Agriculture is consistently one of the most hazardous industries. In 2020, the U.S. Agriculture, Forestry, and Fishing industry had a rate of 21.5 fatal injuries per 100,000 full-time equivalent workers, or approximately six times the average rate (3.4) for all private industries (Bureau of Labor Statistics, 2021). Agriculture work takes place primarily outdoors, in all weather, with workers performing repetitive and physically demanding tasks for extended hours, especially during busy seasons such as planting and harvesting (Elliott, et al., 2022). Labor shortages are common within the sector, and programs like the H-2A temporary worker program have expanded from 75,000 certified jobs in 2010 to 275,000 in 2020 to partially fill increasing demand (Castillo, Martin, & Rutledge, 2022). Additionally, the average age of workers in agriculture is increasing, and despite the physical nature of agriculture work, in 2017, the average age of a farmer is 57.5 years and 38.8 for farm workers (USDA, 2022; USDA, 2019). However, it's not just the nature of agriculture work or the workforce that drives the development of robotics and automation.

A variety of outside factors including economic, climatic, technologic, political, and social factors are affecting the agriculture industry (Cong, 2021). The uncertainty of a changing climate as well as increased natural disasters such as floods, wildfires, and droughts has put an increased financial and psychological burden on agricultural producers (USDA, 2021). The industry is still determining the impacts of the COVID-19 pandemic on existing labor,

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economic, and environmental challenges. In the face of these challenges, the agriculture workplace, workforce, and how work is accomplished is changing (Howard & Lincoln, 2022). This is occurring not only to meet increased demand for food and other agricultural products, but also to adapt to a rapidly changing world.

The Fourth Industrial Revolution has been described not only by the velocity of transformation of how we work, but also by the integration of scientific and technical disciplines to a level in which digital, biological, and physical components communicate and collaborate seamlessly (Xu, David, & Kim, 2018). Technology in the fourth industrial revolution centers on robotics and automated machines and processes, artificial intelligence and data analytics, the Internet of Things (IoT) and smart sensors, as well as augmented reality and wearable technology. And while some new robotics and automated machines are available commercially, most are still being developed. For example, Olivera et al. (2021) found that around the world only 19% of new agricultural robots and automated machines were currently on the market, meaning more than 80% of were still in the development phase.

This provides occupational safety and health researchers an unprecedented opportunity to assess the risks that these new technologies may pose, make evidence-based recommendations on what additional tasks to automate in 3-D work, and collaborate to ensure emerging technologies will mitigate risks and benefit the health, safety, and well-being of agriculture workers. Researchers can also anticipate the safety and health training/education needs of the future workforce. To this end, NIOSH is undertaking efforts to facilitate dialog and address potential benefits/hazards of emerging technologies in agriculture.

2. What is NIOSH Doing?

2.1. NIOSH office of agriculture safety and health

The NIOSH Office of Agriculture Safety and Health (OASH) is working to better understand how the advancements in automation and robotics is affecting the occupational safety and health and well-being of workers in the agriculture industry. This is being accomplished by reviewing existing research, setting occupational safety and health research priorities through the Center for Robotics Research, and creating opportunities such as workshops for researchers to understand the need for projects in agriculture and to connect with industry developing these technologies.

In 2020, we partnered with other NIOSH colleagues and conducted a literature review to identify research related to emerging agriculture technologies. Our aims were to: (1) determine which technologies are being developed and used in an agriculture setting; (2) investigate the safety and health risks associated with these technologies; and (3) identify ways in which occupational safety and health researchers and experts can better collaborate with current efforts focused on the development of robotics and automated technologies. We reported separate summary findings for technologies related to "animals/livestock" and "crop/harvesting" since these work settings and hazards are very different (Hayden, et al., 2022; Weaver, et al., 2022). This literature review revealed a wide variety of robotics and automation being developed in planting and seeding, weed control, and harvesting crops. Other articles revealed innovations in automated milking machines, milk and pallet feeders, and automated cleaners/scrapers. Technology is also being created to monitor not only the location of animals but also animals' health (e.g., monitoring cattle health, disease detection, lameness, and animal behavior).

Authors found the primary focus of articles included in the review was on the development of the technology itself as well as any potential productivity increases. However, little research described potential impacts (positive or negative) to workers safety and health should the technology be adopted. Robotics and automation can be used to reduce occupational safety and health risks among workers by removing workers from job tasks that are high-risk. For example, automating tasks inside of a grain bin or assigning these tasks to robots would reduce the risk of workers entering confined spaces, which accounted for 21 deaths in 2021 (Cheng, Nour, Field, Ambrose, & Sheldon, 2022). On the other hand, there is also the potential for injuries due to contact with robots, increased distraction in workers, and distrust or uncertainty/stress of using a robot at work are hazards to be considered. However, in the scientific literature published during 2015–2020, very few articles evaluated the impact of occupational health and safety of workers after adopting the technology, and future research is needed to identify hazards and potential benefits to workers in an agricultural setting.

2.2. NIOSH center for occupational robotic research

The NIOSH Center of Occupational Robotics Research (CORR) provides scientific leadership to guide the development and use of occupational robots that enhance worker safety health and well-being. The Center helps to increase the understanding of human and automation machine/robot interactions to ensure human worker safety; improving the ability to identify and track injuries and fatalities involving automation/robotics; and providing guidance on working safely with automation/robotics in all industries (NIOSH, 2022). Several areas of research are needed to understand the benefits these technologies have on reducing worker safety and health risk as well as whether hazards have been introduced.

The NIOSH OASH plans to use the research needs the NIOSH CORR has developed to advance research in the agriculture industry. This includes:

1. Surveillance research focusing on the methods and techniques for systematic collection, analysis, and interpretation of data on injuries associated with robots.
2. Basic/etiologic research to use data to identify patterns, to understand risk factors contributing to robot-related injuries, such as the human-robot interface.
3. Intervention research to evaluate robotics technologies as interventions to improve worker safety, and evaluation of control technologies to improve worker safety around robots.
4. Translation research to understand the aids and barriers to translating occupational robotics research findings into practice.

After finishing the literature review, OASH identified other interested extramural researchers to create the Robotics in Agriculture Workgroup in 2021. The workgroup began by reviewing existing applicable standards and existing guidance related to automation and robotics in the agriculture industry. The workgroup then quickly identified the need for a multidisciplinary approach and identified an opportunity to organize a workshop focusing specifically on automation and robotics in agriculture.

2.3. SAFER AG workshop

The SAfety For Emerging Robotics and Autonomous aGriculture or (SAFER AG) Workshop took place November 9–10, 2022 (http://go.illinois.edu/SAFERAG). This workshop was sponsored by USDA NIFA, while the original concept to develop the conference was from the IRAS (intelligent robotics and autonomous systems) Interagency Working Group (IWG) of the Networking and Information Technology Research and Development Program (NITRD). A small team of academics, industry, and NIOSH personnel organized the

SAFER AG workshop to identify gaps in knowledge and research needs that connect to issues related to risks and regulations/standards, occupational safety research, and impacts on workforce and society.

Understanding the risk associated with agricultural robotic technology is very broad. This includes risk of injury, financial risks, insurability, risk potential for different scales of technology, and evaluating risk due to continuous software improvements. The area of risk is also related to the role that regulation and standards play in the development and adoption of safe digital technologies. This includes examining all policies to understand how they could affect (positively or negatively) the adoption of new technologies in agriculture. Likewise, understanding existing regulations, standards, existing gaps, as well as the lengthy standards process allows insight into how manufacturers are factoring the safety and health of workers in the development of technology. Additionally, the workshop sought to understand the impacts of robotics and automation on the occupational safety, health, and well-being of the agriculture workforce. The organizing group wanted to identify additional existing research efforts and enumerate the gaps in research needs, including exactly what existing hazards could be reduced, what known hazards are introduced with the adoption of technologies, and how can we best identify and mitigate adverse outcomes related to adoption of technology before its implemented? Finally, the workshop planned to explore the workforce and societal implications of new technology adoption including training needs for displaced workers, identification of new skillsets and educational needs, infrastructure and technology support in rural areas, as well as cultural and consumer implications that are anticipated due to these advancements.

The vision for the workshop was to create a community of practice around issues related to agriculture automation and robots informed by the diverse expertise, experience, and perspective of the participants. The expected output of the workshop is a list of priorities in three areas: (1) Risk management/regulations and standards, (2) Occupational safety research needs, and (3) Anticipated worker impacts/societal implications. Currently, white papers are planned for each priority area with companion articles published in the *Journal of Agricultural Safety and Health*.

3. Future directions

There is a unique opportunity for occupational safety and health research related to the development and adoption of agricultural robots and automation of job tasks. Since many technologies are currently under development, researchers can work to provide evidence-based recommendations. For example, through surveillance data, we can identify tasks that are high risk and model the 3-D's (dirty, dangerous, demanding) as potential candidates for automation. Occupational safety and health research can also point out potential unintended consequences of automation for workers safety. For example, an automated job task may save workers time and labor, but now may leave workers with less time to rest as there's now less down time, causing mental fatigue and distraction. Likewise, we can share research and best practices we've learned regarding barriers to adoption of safety interventions, as these emerging technologies may face some of the same barriers.

However, advancements in technology in agriculture are not waiting for occupational safety and health research to be completed. Therefore, robotics manufacturers and integrators are encouraged to develop consensus standards groups and best practices and to follow Prevention through Design principles. This includes the efforts to anticipate and design out hazards to workers in the agriculture setting during the development and implementation of these novel robots and automated tasks.

Occupational safety and health experts need to engage and collaborate with developers of technology to learn about what emerging technologies are available, what is being developed, and what may be possible with time. Education and training of the next generation of safety and health professionals will need to focus on how automation and robots impact worker safety and health in agriculture. Partnerships (and ideally research) is needed to develop curriculum and resources needed for the future occupational safety and health workforce. It is also increasingly important for occupational safety and health researchers and practitioners to not only become familiar with existing manufacturing safety standards and gaps within those standards, but also the lengthy standards development process, if only to better understand how manufacturers are implementing standards. Better still, joining consensus standards groups to help shape new standards for emerging technologies may help to mitigate adverse worker impacts.

NIOSH's Office of Agriculture Safety and Health will continue to identify research gaps, support new research projects, education, outreach efforts and the development of best practices with our partners. As we move though the Fourth Industrial Revolution, with all its connectivity and uncertainty, we invite you to join us in proactively addressing the future needs of worker safety and health.

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References

Bureau of Labor Statistics. (2021). Hours-based fatal injury rates by industry, occupation, and selected demographic characteristics, 2020. https://www.bls.gov/iif/oshcfoi1.Htm.

Castillo, M., Martin, P., & Rutledge, Z. (2022). The H-2A Temporary Agricultural Worker Program in 2020. *USDA Economic Information Bulletin*. EIB-238.

Cheng, Y. H., Nour, M., Field, B., Ambrose, K., & Sheldon, E. (2022). *2021 Summary of U.S. Agricultural Confined Space-Related Injuries and Fatalities*. West Lafayette, IN: Agricultural Safety and Health Program Purdue University.

Cong, S. (2021). Factors affecting agriculture. *Joural of Plant Biology and Agriculture Sciences, 3*(2), 9.

Elliott, K., Lincoln, J., Flynn, M., Levin, J., Smidt, M., Dzugan, J., & Ramos, A. (2022). Working hours, sleep, and fatigue in the agriculture, forestry, and fishing sector: A scoping review. *American Journal of Industrial Medicine, 65*(11), 898–912.

Hayden, M., Barim, M., Weaver, D., Elliott, K., Flynn, M., & Lincoln, J. (2022). Occupational safety and health with technological developments in livestock farms: A literature review. *International Journal of Environmental Research and Public Health*. https://doi.org/10.3390/ijerph192416440.

Howard, J., & Lincoln, J. M. (2022). Future of work in agriculture. *Journal of Agromedicine*.

NIOSH. (2022). *Center for Occupational Robotics Research.* https://www.cdc.gov/niosh/programs/ppops/corr.html: Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health.

Oliveria, L., Moreira, A., & Silva, M. (2021). Advances in agriculture robotics: A state-of-the-art review and challenges ahead. *Robotics, 10*(52). https://doi.org/10.3390/robotics10020052.

Quandt, S., Arcury-Quandt, A., Lawlor, E., Carrillo, L., Marín, A., Grzywacz, J., & Acury, T. (2013). 3-D jobs and health disparities: The health implications of latino chicken catchers' working conditions. *American Journal of Industrial Medicine, 56*(2), 206–215.

USDA. (2019). Farm Producers. *Census of Agriculture Highlights*, https://www.nass.usda.gov/Publications/Highlights/2019/2017Census_Farm_Producers.pdf.

USDA. (2021). *USDA Action Plan for Climate Adaptation and Resilience.* Washington, DC: U.S. Department of Agriculture.

USDA. (2022). Average age of U.S. farm laborers/graders/sorters by place of birth, 2006-19. *Annual American Community Survey*, https://www.ers.usda.gov/topics/farm-economy/farm-labor/.

Weaver, D., Barim, M., Hayden, M., Elliott, K., Lincoln, J, & Flynn, M. (2022). Literature review: Does improved agriculture technologies mean improved

safety? *National Occupational Injury Research Symposium (NOIRS) 2022.* Morgantown, West Virgina/Virtual.
Xu, M., David, J. M., & Kim, S. H. (2018). The fourth industrial revolution: Opportunities and challenge. *International journal of financial research, 9*(2), 90–95.

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