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REVIEW ARTICLE

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Adapting the T0-T4 implementation science model to occupational health and safety in agriculture, forestry, and fishing: A scoping review

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Background: Despite much research to develop life-saving innovations for the agriculture, forestry, and fishing workforce, these populations continue to face the highest fatal and non-fatal injury rates in the United States, as many of these solutions are not fully adopted.

Methods: A scoping review was conducted to provide an overview of research to practice efforts in this field. The language used to describe these initiatives, the utility of the NIH T0-T4 model, and the progress along the research to practice continuum were examined.

Results: Fourteen eligible references demonstrated that progress in implementation science is lacking and that there is little consistency in how researchers apply the T0-T4 model; thus, a new model is presented.

Conclusions: Researchers in this field face several challenges when moving from research to practice. While some challenges are addressed with the proposed model, additional resources and infrastructure to support such initiatives are necessary.

KEYWORDS
diffusion, dissemination, implementation, occupational health and safety, research to practice, research translation, T0-T4, widespread adoption

1 | INTRODUCTION

The agriculture, forestry, and fishing (AgFF) workforce faces the highest risk of fatal injury: 25.3 fatalities per 100 000 full time workers, compared to the US all-worker fatality rate of 3.4 fatalities per 100 000 full time workers.[1] Although much research has been conducted to identify viable solutions for preventing these events, examples of successful and complete adoption of these solutions among target populations are rare.

The primary funder of AgFF occupational health and safety research in the US, the National Institute for Occupational Safety and Health (NIOSH), encourages researchers to "develop new knowledge in the field of occupational safety and health and to transfer that knowledge into practice," in order to improve health and safety outcomes for the workforce.[2,3] To advance the mission of putting research knowledge into worker practice, NIOSH launched the Research to Practice (R2P) initiative in 2004 to encourage intramural and extramural researchers to increase the reach of effective and efficacious research (which are referred to as evidence-based solutions in this manuscript). The R2P initiative focuses on "the use, adoption, and adaptation of NIOSH knowledge, interventions, and technologies," as well as the evaluation of these activities.[4] Based on the descriptions of this effort, we understand R2P as efforts involving: 1) sharing knowledge through diffusion, dissemination, or

implementation, with target populations so that they may benefit from it, and 2) actively seeking to ensure that evidence-based solutions are widely adopted in the workplace.

1.1 | Measuring progress along the R2P continuum

AgFF populations are often well aware of the risks associated with their chosen occupations; however, the wide array of life-saving technologies and interventions designed by research teams to address these risks have yet to be fully accepted or made widely accessible to the workforce.[5–9]

Unfortunately, various researchers have demonstrated that health and safety initiatives are a low priority for this workforce as a result of myriad obstacles, including those related to finances, environmental conditions, and increasing regulations (which can have unintended consequences such as increasing workflow complexity, stress, or other factors relating to safety).[10–14] In order to meet the goals of both NIOSH and the R2P initiative and make a significant impact on measured health and safety outcomes within these populations, researchers must find ways to increase the widespread adoption of evidence-based solutions, have meaningful dialogues about the translation process, and evaluate progress toward this goal.[3,15,16]

In the past, AgFF health and safety researchers have most commonly referred to the National Institute of Health's (NIH) clinically based T0-T4 model of translational research[17–19] (Table 1) to discuss the implementation process and evaluate where they are along the R2P continuum.[20] Within the NIH T0-T4 model, the T0 and T1 phases start with the identification, development, and application of disease-focused interventions in controlled settings. This is followed by the T2 phase, which involves experimental applications with patients and the T3 phase which involves patient trials in less restrictive, real world settings. In the T4 phase, research innovations are finally rolled out to the population level, at which point meaningful health impacts can be measured.[17]

TABLE 1 Descriptions of the NIH T0-T4 translational research model stages[17–19]

	NIH T0-T4 model
T0	• Scientific discovery and identification of risk factors
	○ Surveillance
T1	• Discovery to candidate health application
	○ Phase I clinical trial (assess safety)
	○ Observational trial
T2	• Health application to evidence-based practice guidelines
	○ Phase II clinical trial (assess efficacy)
	○ Phase III clinical trials (confirm findings in large population)
	○ Observational studies
	○ Evidence synthesis
	○ Guideline development
T3	• Practice guidelines to health practice
	○ Dissemination, diffusion, and implementation research
	○ Phase IV clinical trials (long-term safety)
T4	• Practice to population health impact
	○ Outcomes research (monitoring of benefits, risks, and morbidity)

1.2 | T3: A gap in public health and AgFF research

The authors of this manuscript are interested specifically in the T3 or implementation phase, which appears to be the most significant gap in AgFF health and safety and public health research.[3,16,21,22] The T3 phase of the NIH T0-T4 model is a crucial phase for ensuring worker adoption and application of evidence-based solutions in practice, as this phase focuses on the diffusion, dissemination, and implementation of research findings.[17] Further explanation of these terms, as well as examples of each, can be found in Figure 1. Throughout this manuscript, we include both employers and employees within the AgFF sector in the term "workforce." This is with the understanding that in most cases, adoption of evidence-based solutions requires buy in and acceptance from both groups.

Although the T3 phase includes diffusion, dissemination, and implementation, previous work has shown that more "hands-off" approaches such as diffusion and dissemination can make it difficult to ensure that public health and AgFF health and safety research is adopted by target populations, who are less likely to be engaged in diffusion and dissemination than in implementation efforts.[16,23,24] This can be seen, for example, within the agricultural population where rollover protective structures (ROPS) were made standard on new tractors in 1985.[25] At the same time, retrofit ROPS kits became available and were initially promoted by manufacturers (dissemination); however, after a short time, little was done to actively encourage farmers to retrofit (diffusion).[26] Despite predictions that 75% of US tractors would be retrofitted with ROPS kits by 2015,[27] this has not been the case; nearly 50% of US tractors remain unprotected today[28,29] demonstrating the strong need for more intensive approaches to increasing worker adoption. In addition to difficulties engaging target populations through diffusion and dissemination, it can also be difficult to evaluate the health and safety impacts of these efforts.[16,23,24] For example, although the "Simple Solutions: Ergonomics for Farmworkers," program is available freely,[30] no impact evaluation of the program was found. It is likely that this is related to the difficulties in tracking how materials are passed throughout a population.

In addition, the use and fit of the NIH T0-T4 model in AgFF health and safety efforts has yet to be fully examined. This literature review aims to fill these gaps by: 1) providing an overview of R2P efforts in the AgFF health and safety sector; 2) comparing the way R2P, and specifically T3 research, is defined and discussed in AgFF health and safety literature; 3) determining progress along the R2P continuum in AgFF health and safety published research; and 4) examining the utility of the NIH T0-T4 model for use in AgFF health and safety efforts.

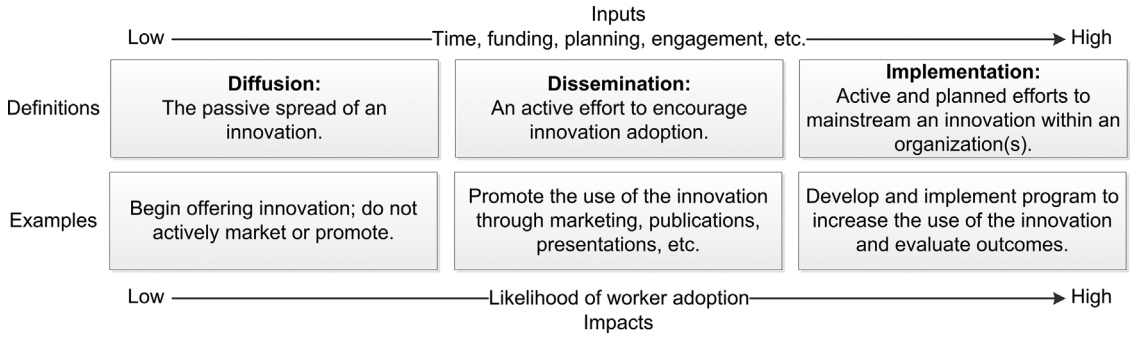

FIGURE 1 Definitions and examples of diffusion, dissemination, and implementation. Definitions were chosen based on those provided by Sundberg, as they succinctly highlight the key differences between each method of increasing the adoption of evidence-based research[62]

2 | METHODS

A scoping review of the literature, using the PIECES method,[31] which involves defining the research question, identifying key search terms, and meticulously tracking the search and analysis process, was followed.

2.1 | Definitions

The 2012 North American Industry Classification System (NAICS) was used to specifically define and set boundaries for each of the industry groups included in this study: agriculture, forestry, and fishing.[32,33] Occupational health and safety is defined as "the science of the anticipation, recognition, evaluation and control of hazards arising in or from the workplace that could impair the health and well-being of the workforce."[34]

2.2 | Search terms

Prior to beginning the literature search, the lead author and an information specialist with a focus in health and safety research worked to determine the most appropriate search terms using pilot searches through PubMed, Scopus, and Medline. Based on these searches, the authors and information specialist found that in order to effectively conduct the literature review, searches needed to utilize a combination of three term categories: 1) research translation and related terms; 2) occupational health or occupational safety; and 3) industry related terms. Using this combination of terms, references unrelated to the study (eg, those dealing with health and safety in different occupations) were more likely to be excluded from the search results, while those related to health and safety R2P in AgFF remained. Using the identified key words, medical subject headings (MeSH terms) were identified through PubMed, and those deemed appropriate by the authors were added to the search terms to be used. A complete list of search terms can be found in Table 2.

2.3 | Inclusion and exclusion criteria

To be comprehensive, a variety of literature types, including all forms of grey literature, were included in this review. Furthermore, work published any time prior to the date of the search (July 20, 2016) was eligible for inclusion. References were excluded from the study if they did not meet the NAICS definitions for at least one of the included industry sectors, as well as the definitions of occupational health and safety. Additionally, non-English language references were excluded.

During an initial literature search which included not only AgFF research, but also that of construction and mining, eligible references were required to meet the above criteria and describe the barriers and facilitators to widespread (intentional) implementation of an evidence-based solution. This search resulted in just one eligible reference, and also demonstrated the vast difference in R2P terminology used by AgFF, construction, and mining health and safety researchers. For that reason, the aims of this study were updated to their current state and the inclusion criteria were modified so that any text that referenced translational research or another of the related search terms (category 1 in Table 2) in its title or abstract was retained for analysis. For texts without abstracts, the search terms needed to be present in the title and/or introductory sections (eg, in books and longer texts) or full texts (eg, in news releases and short texts).

2.4 | Literature search process

Six databases (PubMed, Scopus, Web of Science, Medline, PsychInfo, ProQuest Dissertations) were searched by the lead author and information specialist using all possible combinations of search terms (ie, one term from each category per search). When possible, truncated forms of industry related terms (category 3 in Table 2) were used to consolidate searches. During this process, filters for "English language" and "title and abstract search, only" were used whenever available. The lists generated by each search were imported into EndNote[35] for tracking purposes. Once all of the searches were complete and duplicates were removed, titles and abstracts were reviewed by the lead author and articles were removed if they did not meet the inclusion criteria. One reference, which used the term "diffusion of innovations" in its abstract, was excluded because the authors described and applied the term as a method in planning an intervention, rather than a method for R2P. Bibliographies of the remaining texts were then scanned to identify additional references (see Figure 2 for the process flow chart).

TABLE 2 Literature review search terms

Category 1	Category 2	Category 3[a]
• Research to practice	• Occupational safety	• Agriculture
• Translational research	• Occupational health	• Farm* (Farms, farming, farmers)
• Diffusion of innovation		• Forest* (Foresters, forestry)
• Evidence-based medicine		• Logg* (Logging, loggers)
• Research design		• Fish* (Fishing, fisheries, fishermen, fishers)
• Implementation science		• Commercial fish* (commercial fishing, commercial fisheries, commercial fishermen, commercial fishers)
• Scale up		
• Research translation		

[a]Terms in Category 3 are listed as, "truncated search term* (all related search terms)." In conducted literature searches, asterisks indicate that the term is truncated, and that all complete terms should be searched.

2.5 | Analysis

Full texts were analyzed using NVIVO qualitative data analysis software.[36] Each reference was first coded to determine how authors defined and applied key R2P terms (such as those listed in column 1 of Table 2). The "definitions" were largely extracted from introductory sections of the texts and the "applications" were based on the methods, results, and discussion sections of the texts.

Within the definition and application categories, sub-categories reflective of each phase of research, including: prioritizing needs, innovation development, manufacturer collaboration, pilot-testing and evaluation, diffusion, dissemination, implementation, and impact evaluation, were developed. These sub-categories were largely based on the authors' own descriptions of the research process and the types of work in which they were they were engaged.

Secondly, the texts were analyzed to describe the current progress along the R2P continuum by using the categories and sub-categories developed in the first stage of analysis as well as by returning to the full texts. References describing the action of putting research into practice (ie, those coded under the sub-categories of diffusion, dissemination, and implementation) in either definitions or applications were further examined to determine if the discussion was related to widespread or localized efforts. Texts describing or applying dissemination efforts were evaluated to determine if policies, standards, or guidelines were discussed. During this stage, the authors also analyzed the texts for indication of barriers and facilitators to following through with the R2P process that were specific to AgFF health and safety. Using the information collected during the first two stages of analyses, the utility of the NIH T0-T4 model in AgFF health and safety was assessed, and a revised version specific to, and based on, AgFF health and safety research processes was developed.

2.6 | Ethics approval

This research was approved by the Mary Imogene Bassett Hospital (Cooperstown, NY) as part of a larger research study. No informed consent was needed due to the nature of the research.

3 | RESULTS

3.1 | R2P in the literature

Fourteen references were eligible for inclusion in the literature review (Table 3). One reference was related to health and safety research within all three industries (AgFF)[37]; two were related to fishing[20,38]; and the remaining 11 examined agricultural safety and health.[8,39–48] No references related to forestry work met the inclusion criteria.

Although each of the references included in this review discusses R2P in some form, there is little agreement among their authors about what the end goal of R2P is and how related terms are defined. In part,

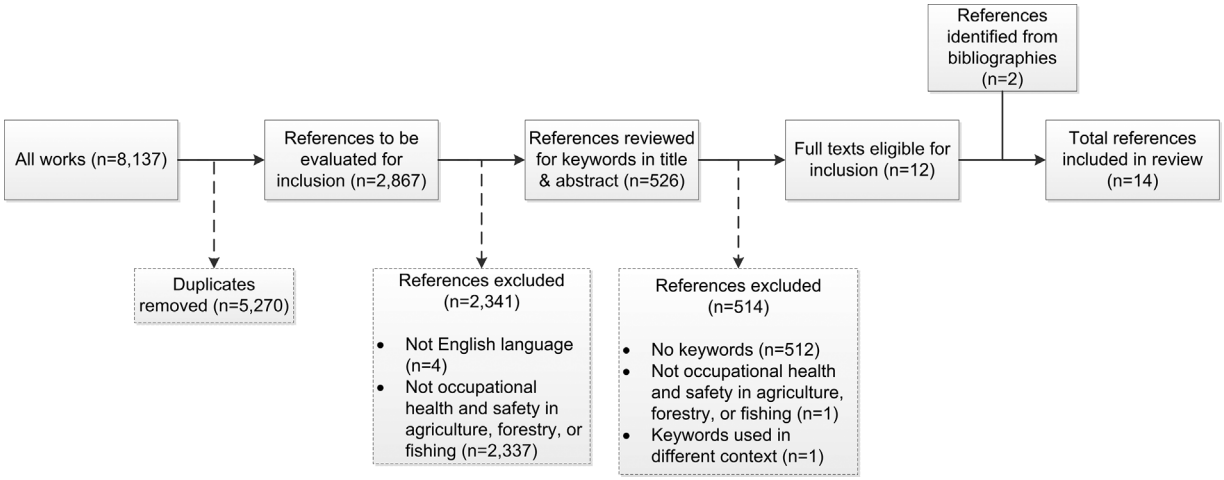

FIGURE 2 Literature review search process

TABLE 3 Summary of references with an overview of how each author defines R2P and applies it to real-world settings

			Definition		Application	
References	**Title**	**Type**	**Research activities**	**Stage[a]**	**Research activities**	**Stage[a]**
Husman (1990)	Farmers' occupational health program in Finland, 1979-1988: from research to practice	Original research	• N/A	N/A	• Innovation development • Dissemination (through policy)	T1, T3
London (1998)	Occupational epidemiology in agriculture: a case study in the southern African context	Original research	• Innovatio•Pilot testing & evaluation • Greater use of piloted solutions and evaluation of use •Implementation of findings into practice • Evaluation of impact on health outcomes	T1-T4	• N/A	N/A
Arcury (2001)	Farmworker pesticide exposure and community-based participation research: Rationale and practical applications	Original research	• Innovation development • Pilot testing (small-scale adoption of solutions by workers) & evaluation • Evaluation of impact on health outcomes	T1, T4	• N/A	N/A
O'Fallon (2001)	The commitment of the National Institute of Environmental Health Sciences to community-based participatory research for rural health	Original research	• Innovation development • Pilot testing & evaluation • Dissemination	T1, T3	• Innovation development • Dissemination	T1, T3
Western Farm Press (2006)	Reducing illnesses and injuries in the agricultural workplace	News article	• Dissemination	T3	• N/A	N/A
Schenker (2008)	Introduction to the special issue: Research to practice in the agricultural workplace	Journal introduction	• Innovation development • Pilot testing (small-scale adoption of solutions by workers) & evaluation • Evaluation of impact on health outcomes	T1, T4	• Innovation development • Pilot testing & evaluation • Diffusion •Dissemination (through policy)	T1, T3
Huy (2010)	Involving Farmers in Preventing Work-Related Injuries and Illnesses: The NIOSH Research-to- Practice Initiative	Conference presentation summary	• Prioritizing needs • Innovation development • Pilot testing (small-scale adoption of solutions by workers) & evaluation •Evaluation of impact on health outcomes	T0, T1, T4	• Dissemination	T3
Kirkhorn (2010)	Ergonomic Risks and Musculoskeletal Disorders in Production Agriculture: Recommendations for Effective Research to Practice	Conference paper	• Manufacturer collaboration • Pilot testing & evaluation • Large-scale field trials • Dissemination	T1-T3	• N/A	N/A
Levin (2012)	Helping Gulf Shrimpers Adopt Safety Measures: Importance of Partnerships and Research to Practice	Original research	• Adoption of findings into practice	T3	• Innovation development • Pilot testing & evaluation • Dissemination	T1, T3

(Continues)

TABLE 3 (Continued)

			Definition		Application	
References	**Title**	**Type**	**Research activities**	**Stage[a]**	**Research activities**	**Stage[a]**
Fiske (2013)	Farm safety research to practice: the long road from the laboratory to the farm	Editorial	• Manufacturer collaboration to develop solutions • Diffusion	T1, T3	• Diffusion	T3
Lucas (2014)	Application of a translational research model to assess the progress of occupational safety research in the international commercial fishing industry	Literature review	• Prioritizing needs • Innovation development • Pilot testing & evaluation • Widespread dissemination of findings • Evaluation of impact on health outcomes	T1-T4	• Prioritizing needs • Innovation development • Pilot testing & evaluation • Widespread dissemination (through policy) • Evaluation of impact on health outcomes	T0-T4
McCullagh (2015)	Protocol of a randomized controlled trial of hearing protection interventions for farm operators Environmental and occupational health	Original research	• Dissemination	T3	• Dissemination	T3
NIOSH (2015)	Research to Practice	Website	• Prioritize needs • Innovation development • Pilot testing (small-scale adoption of solutions by workers) & evaluation • Evaluation of impact on health outcomes	T0, T1, T4	• Prioritize needs • Pilot testing & evaluation • Large-scale pilot testing & evaluation	T0-T2
Storm (2016)	Adapting Certified Safe Farm to North Carolina Agriculture: An Implementation Study	Original research	• Widespread implementation of findings into practice	T3	• Large-scale pilot testing & evaluation	T2

[a]Stages are based on the AgFF OHS T0-T4 model.

this is likely due to the fact that R2P is conceptualized as a continuum and that there is some disagreement among AgFF OSH researchers regarding how this continuum works.[8,20,38,40–44,46,47] Take, for example, O'Fallon and Dearry's definition of R2P that involves intervention development, pilot testing/evaluation, and dissemination of findings, which implies that if you develop and share an innovation, others will adopt it.[46] This is in comparison to Huy's definition, which includes these same research components, but also emphasizes the need to ensure worker adoption to initiate a change in health and safety outcomes.[42]

3.2 | Toward widespread adoption: T3 in AgFF health and safety research

In order to make a significant impact on worker health and safety outcomes, evidence-based solutions must be successfully adopted by the workforce on a widespread basis during the T3 phase. Many authors identified in this review described their beliefs about and efforts to move research into worker practice; however, lessons learned about successful translational processes were not discussed, most likely because it was not a central component of the interventions driving research questions.

In regard to methods used to achieve T3 research aims, six of the authors did not specify which method (diffusion, dissemination, or implementation) should be used to encourage adoption of research innovations by the workforce.[37–40,42,47] The remaining authors described diffusion, dissemination, and implementation efforts as follows.

3.2.1 | Diffusion (passive effort)

Two references discussed using diffusion to increase adoption of research findings.[8,37] Fiske and Earle-Richardson, for example suggest that once manufacturing challenges have been overcome, little should be needed to encourage worker adoption of safety products.[8] This is echoed on the NIOSH R2P website, which discusses several engineering solutions (including personal air-sampling devices, emergency stops for fishing winches, and mobile assessment systems for musculoskeletal injury prevention, among others) that have been developed, but not actively promoted.[37]

3.2.2 | Dissemination (active encouragement)

In demonstrating how R2P terminology was applied in their work, the authors of the texts included in this sub-category relied heavily on policy and non-policy based dissemination efforts. Three references cited using policy to spread innovations.[20,41,47] Although two of these texts demonstrated widespread success in policy implementation efforts, neither incorporated evidence-based solutions in these policy recommendations. Husman et al describe the implementation of an untested occupational health system for farmers, and indicate that there was no subsequent change in health and safety outcomes.[41] Similarly, Lucas et al described a government mandated program that provided safety recommendations and guidelines to trawlers. Over the course of this program, an increase in fatalities was reported.[20]

In addition to those references which described policy based attempts at dissemination, five texts described non-policy attempts at dissemination.[20,38,42,45,46] Levin et al, for example, describes the development and testing of a training course to help fishermen understand how to execute a Mayday call.[38] Once the course proved to be effective, the team swapped hands-on instruction for an instructional DVD that could be quickly disseminated and promoted to regional fishermen by local opinion leaders; however, long-term measures of effectiveness, adoption, or impact were not discussed or reported.[38]

3.2.3 | Implementation (active and planned effort)

Within this sub-category, just two references discussed implementation efforts.[37,48] Although Storm et al discussed the need for widespread adoption of innovations and described their study as, "the first large-scale implementation of Certified Safe Farm outside the mid-western United States," the authors also indicate that only 3.1% of North Carolina farms participated in the intervention.[48] Although authors provide evidence that a certain level of implementation occurred, the results do not reflect T3 phase outcomes. Examples and case studies provided on the NIOSH R2P effort website also described implementation efforts; however, they did not specify the need for or demonstrate widespread adoption.[37]

4 | DISCUSSION

4.1 | Evaluating progress toward widespread adoption of innovations

This extensive literature review identified a relatively small number of publications in which researchers have uniformly discussed the challenges of widespread adoption. Even in these examples, we find that few AgFF health and safety studies have progressed to the T3 phase of research. Based on the results of this review, only two studies have successfully achieved widespread adoption of an intervention; however, neither of these interventions had been shown to be effective or efficacious, and both failed to improve health and safety outcomes.[20,41] While others have attempted various methods of increasing worker adoption to improve health and safety outcomes, no studies reported having successfully accomplished this mission on a large scale, at least using the criteria outlined in this review. This indicates that either these efforts were not published, were not captured using the literature review search terms, or that successful navigation of the T3 phase is a primary challenge for occupational health and safety researchers. This suggests that researchers need to focus increased efforts on evaluating solutions to ensure that they are effective and efficacious, prior to translating solutions to worker adoption, and finally, to increase the consistency in how T0-T4 phases are described and discussed in the published literature. With these adjustments it will be possible to increase researchers understanding

regarding what works or does not work in moving research to the end goal-population level improvements.

4.2 | Utility of the NIH T0-T4 model

Although AgFF health and safety interventions could, in theory, follow a similar developmental trajectory as is demonstrated by the NIH T0-T4 model (Table 1), there are several barriers which impede the application of the NIH T0-T4 model in AgFF health and safety settings.

In AgFF health and safety and public health settings, cultural and environmental factors related to the target population must be taken into account in early stages of research.[49,50] Several of the references included in this review have acknowledged this.[38,40,42–44,46,47] However, thus far, these components have not been reflected in the NIH T0-T4 model. Unlike clinical settings where the end-users of an intervention are medical professionals, and the benefits are clearly salient to patients, their families, and clinicians, interventions targeting AgFF injury prevention may provide less immediate benefits to the end-user. For example, although the US logging workforce face the highest risk of occupational fatal injury (132.7 per 100 000 full-time workers, compared to the US all worker fatality rate of 3.4 per 100 000), only 67 total fatalities occurred in this industry in 2015.[1]

Although many of these fatalities, as well as the many non-fatal injuries that occur in the logging industry, can be prevented by adopting evidence-based solutions, this outcome may take longer and require more of a commitment than clinical solutions. In a world where small business owners face myriad competing demands, safety and health initiatives often take a backseat to those that have a direct impact on work productivity and financial viability.[10–14] In addition, the NIH T0-T4 model provides guidance for those interventions that are supported by the rigid structure and processes of the healthcare system, a scenario which is rarely reflected in the AgFF health and safety field.[51] Although regulations and legislation could be used to implement evidence-based solutions, they are often counterproductive in AgFF health and safety settings for three main reasons: 1) business owners and workers tend to oppose such actions and have been shown to stop such action from being taken[52–54]; 2) such regulations, when implemented, are only applicable to those under OSHA jurisdiction which excludes more than 60% of the AgFF health and safety workforce[55]; and 3) enforcement of such regulations can be challenging due to the number of worksites compared to the availability of regulatory staff.[56]

The need to address relatively rare events such as occupational fatalities in a population that is resistant to change, especially when mandated by regulation, creates a challenge for AgFF health and safety researchers working through the translational research process. Within the NIH T0-T4 model, there is little room to explore the target population's culture and environment beyond small, localized pilot tests, a task that is vital to successfully implementing AgFF health and safety and other public health research.[49] As is evidenced by the references included in this review, AgFF health and safety has not consistently progressed beyond these small pilot tests,[37,48] with the exception of studies that have relied upon dissemination or diffusion and have not been able to demonstrate widespread adoption or improved outcomes.[8,20,37,38,41,42,45–47]

Combined with limited R2P resources and infrastructure (such as common language, discussion forums, and training),[57] these barriers have resulted in limited success in widely implementing AgFF health and safety evidence-based solutions. Many of these obstacles can be tied to limited applicability of the NIH T0-T4 model in AgFF health and safety settings, and the inconsistencies presented when researchers develop their own interpretations of this model to adjust for the realities of health and safety research.

4.3 | Adapting the NIH T0-T4 model for AgFF health and safety efforts

To address the NIH T0-T4 utility issues identified through this review, the authors propose a modified AgFF health and safety T0-T4 model (Figure 3), which is tailored to the AgFF health and safety sectors and could potentially be applied to other areas of public health. In moving through the AgFF health and safety T0-T4 model, there are several key differences from the original, NIH T0-T4 model.

First, while clinical studies often undergo a lengthy period of pre-clinical research in laboratory settings, this phase is not well represented in the NIH T0-T4 model, falling somewhere between the T0 and T1 phases. Although Khoury suggests that such research be a part of the T1 phase,[17] clinical applications often suggest that T1 is dedicated to testing solutions that have already passed through the pre-clinical stages, which are not a part of T1 research.[18,19] While basic research is important to both clinical and AgFF health and safety research, its ambiguity within the NIH T0-T4 model can be particularly challenging for AgFF health and safety researchers. Without fully exploring cultural contexts at various phases in the T0-T4 process, it can be difficult to ensure successful implementation and sustainability. For this reason, initial formative research (related to understanding the health and safety issue and target population, as well as development of an appropriate solution) was added to the T1 phase of the AgFF health and safety T0-T4 model, and additional research on the barriers and facilitators to expansion was added in later phases. Examples of this stage in practice can be found in several of the references included in this review.[20,38,41,46,47]

While both the NIH and the AgFF health and safety T0-T4 models provide space for larger pilot tests in T2, the AgFF health and safety T0-T4 model places more of an emphasis on the steps required to scale up, which can pose different challenges than those experienced in clinical research settings where guidelines and policy development are heavily relied upon. This is exemplified by both Storm et al's efforts to expand the Certified Safe Farm Program[48] and several examples highlighted on the NIOSH R2P website.[37] The AgFF health and safety T2 level therefore includes specific efforts, such as collaboration with manufacturers (when necessary), to ensure that research products are appealing, user-friendly, and cost-effective for the larger target population. Unfortunately, most manufacturing companies are far removed from the target populations that they serve, and therefore have a limited knowledge of the contextual factors related to product

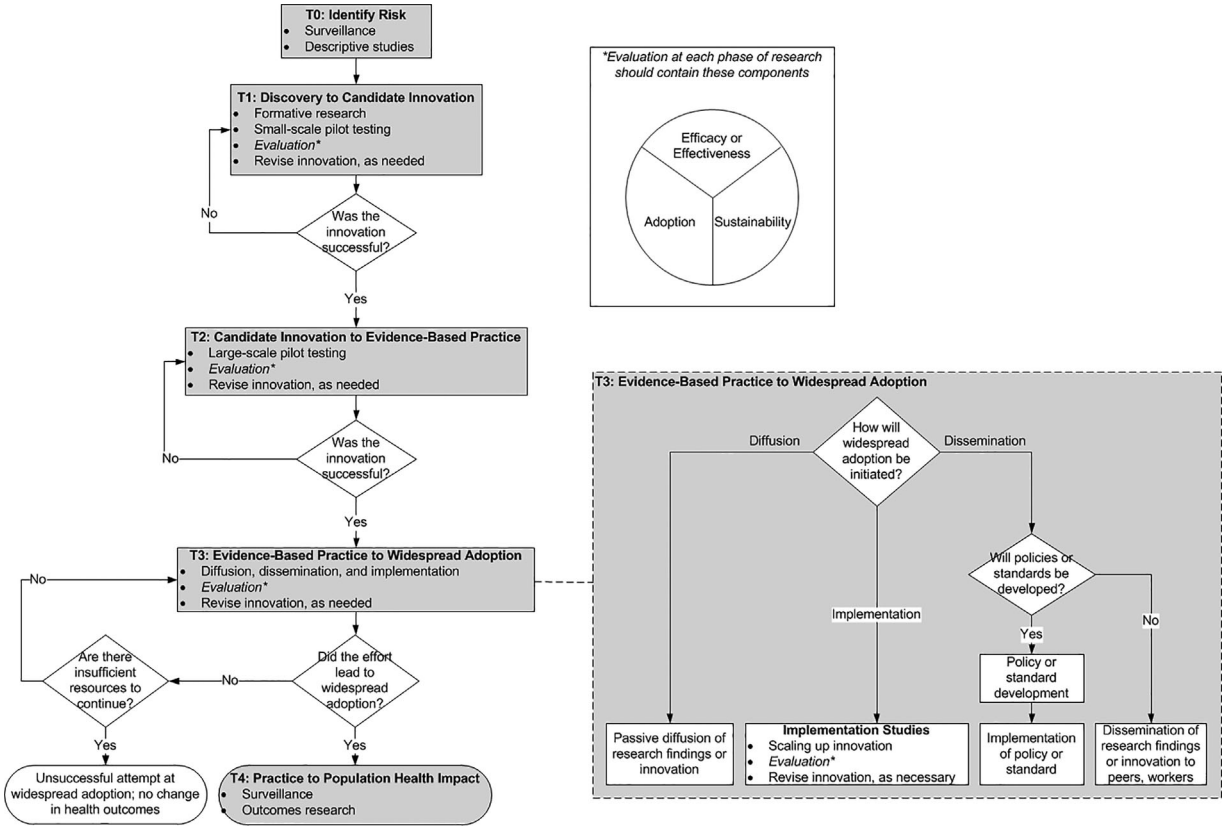

FIGURE 3 The proposed AgFF-specific T0-T4 model of research translation

adoption. In these instances, researchers must be prepared to work with manufacturers, as suggested by two authors included in this review.[8,43] Social marketing efforts, which would be developed in T1 as part of an intervention strategy, have shown to be useful in this respect, as they allow researchers to solicit necessary feedback from target populations and relay it to manufacturers so that innovations can be tailored to address the target populations' needs and barriers.[58,59] In addition to providing opportunities to partner with manufacturers, the AgFF health and safety T2 phase includes research to identify barriers and facilitators to promoting, scaling-up, and sustaining the particular innovation.

Within both the T1 and T2 phases of the AgFF health and safety T0-T4 model, every effort should be made to ensure that innovations entering the T3 phase are thoroughly evaluated and found to be suitable for widespread adoption. The Society for Prevention Research suggests rigorous criteria for defining interventions as efficacious, effective, and ready for scaling up.[60] These guidelines are intended for preventive interventions that target health problems in clinical and community contexts and the criteria are extensive and well specified. Although considerable effort would be required to adapt these criteria to AgFF health and safety interventions, the three stages of efficacy, effectiveness, and scaling-up may be more intuitive for AgFF health and safety researchers and end-users and thereby provide complementary guidance for moving through the AgFF health and safety T0-T4 model.

Once the T2 phase is completed, the AgFF health and safety T3 phase moves into efforts to diffuse, disseminate, and implement innovations widely, with a special emphasis on ensuring that target

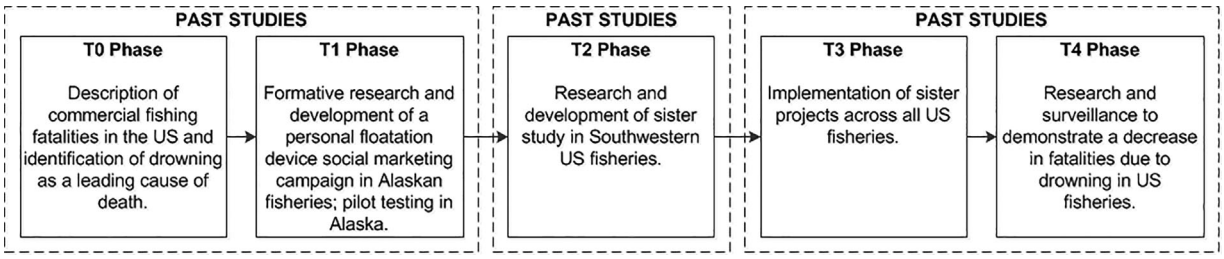

FIGURE 4 An example of the how the proposed AgFF T0-T4 model a series of studies to increase personal floatation device use among commercial fishermen[59,63–66]

populations are actively participating in and using safety and health innovations. Both diffusion and dissemination are referenced in the included literature; however, none of the examples fulfill the requirement of ensuring worker adoption of evidence-based solutions. Using this model, diffusion, dissemination, and implementation are combined in the T3 phase to provide complementary pathways for reaching target populations. Although diffusion and dissemination can be used on their own, it is possible for both strategies to be utilized as part of a larger implementation strategy or intervention. While disseminating information to other research organizations is included in this model, this should not be considered an endpoint or as fulfillment of R2P goals, as it often is in AgFF health and safety research.[61]

In the T4 phase of the AgFF health and safety T0-T4 model, work is done to measure the change in health outcomes (such as Lucas et al describe[20]), as well as to monitor sustainability, cost, and unanticipated outcomes. Throughout the T0-T4 continuum it is vital that the appropriate partnerships are identified, built, and maintained to ensure that research solutions and end outcomes are appropriate to the target population. Such partnerships will also create feedback loops which can be helpful in assessing implementation progress and troubleshooting problems.

To demonstrate the application of this model, a current effort to increase the use of personal floatation devices among fishermen is shown in Figure 4. In this example, the variet of research that has been done in support of this effort are shown in terms of the T0-T4 stages In addition to providing a more useable foundation for individual research teams moving through the translational research cycle, this model also provides a clear method for evaluating and tracking AgFF health and safety research and programs overall to ensure that research is actually having an impact on the health and welfare of target populations.

5 | CONCLUSIONS

Although the results of this review may be somewhat surprising to readers who feel that R2P goals are being met within AgFF health and safety research, they shed light on an important topic, and provide a realistic assessment of the translational trajectory of AgFF health and safety research efforts. This review demonstrates that there are few published examples of successful T3 research initiatives within the AgFF health and safety sector, and that confusion and inconsistency are fairly common when it comes to applying the NIH T0-T4 model of research translation. To ensure that the research community is making an impact on health and safety outcomes in the AgFF sector, an effective model, such as the one proposed in this manuscript, to monitor progress on this front could be developed, and used, to remove institutionalized barriers to progress.

Moving forward, it will be necessary for funders to support and require evidence of substantial progress toward the T4 phase, and for researchers to refocus their intervention development, and consider at the beginning of the intervention development phase (T1) how their research can be integrated into workplace practices, as is described by the AgFF health and safety T0-T4 model proposed in this manuscript. This is especially true in regard to widespread implementation efforts. Such efforts are likely to require more time, coordination of resources and collaborators, funding, and other resources than have previously been anticipated or made available.

Additionally, efforts to understand what works and what does not work (and why) in the T3 phase, especially, must be made. Together, the AgFF health and safety research community will need to work to identify ways to make the process of widespread worker adoption attainable if the group hopes to meet its long-term goal of significantly reducing work-related injuries and fatalities among farmers, foresters, and fishermen. Consistency in how translational terms are used will greatly enhance this conversation.

AUTHORS' CONTRIBUTIONS

The research for this manuscript was conducted by P. Tinc, with support from all other authors. The manuscript was prepared and edited by all authors.

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The authors have no conflicts of interest to report.

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None.

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