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Factors Influencing How Health and Safety Professionals View Their Roles and Responsibilities Under NAFTA and the USMCA

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Abstract

Beginning in 1994, the North American Free Trade Agreement was the first trade deal to include labor provisions intended to protect workers. In 2020, the United States-Mexico-Canada Agreement (USMCA) went into effect and included enhanced health and safety provisions in its labor chapter. However, there is limited information on how the professionals responsible for managing workplace health and safety view their roles and responsibilities under these free trade agreements. In order to elicit this information, a 47-question online survey modified from the International Labour Organization (ILO) was administered to 347 self-identified American health and safety professionals (stakeholders). Contingency table analyses were used to explore relationships between stakeholder demographics and variables pertaining to the roles and responsibilities of health and safety professionals. Four factors were found to influence how stakeholders view their responsibilities under North American free trade agreements. These factors included: job title, years of experience, years with employer, and type of site. Our results suggest that different outreach and messaging strategies should be employed by the Office of the U.S. Trade Representative during the dissemination of free trade agreements to ensure all stakeholders are equally aware and understand these important changes to the field.

KEY WORDS: *workplace safety, free trade agreements, professional perspectives, global public health*

1. Introduction

As globalization and the interconnection of nations continues through free trade, differences in worker health, safety regulations, labor standards, and enforcement among nations has become a crucial issue. Year after year, companies are under pressure to produce high, short-term financial gains, which often leads them to minimize expenditures directed toward the health and safety of their workers (Brown, 2005a). As a result, industrial firms often relocate their operations from developed nations to developing nations where occupational health and safety standards are lax and, therefore, compliance is less expensive (Tiemin, 2001). As health and safety professionals are charged with the day-to-day management and execution of programs to support the safety of workers, this study aims to explore what factors influence how these stakeholders view their roles and responsibilities under the North American Free Trade Agreement (NAFTA).

Historically, regulations protecting occupational and environmental health have often been omitted from international trade treaties and the global marketplace. In fact, over the years, American labor advocates have expressed concerns regarding the United States' entry into free trade agreements (FTA) with developing countries because of those countries' comparatively lower wages and labor standards (Villarreal and Cimino-Issacs, 2023). Specific to North America, it has been shown that disparities in worker protection exist among the U.S., Canada, and Mexico due to separate and unequal health and safety standards among the three countries (Brown, 2005a). However, starting on January 1, 1994, NAFTA, with its labor side agreement, became known as the first recognized attempt at protecting workers as part of an international trade treaty (Brown, 2005a; Brown, 2005b).

Negotiated under the Clinton administration, NAFTA was intended as a means to reduce barriers to trade and investment between the U.S., Mexico, and Canada (Nevaer, 2004). In response to the U.S. public's concern regarding the impact of trade liberalization on labor rights and environmental standards, two side agreements to NAFTA were signed to create an environmental protection commission and a labor commission (Martin, 1993). The labor side agreement, known as the North American Agreement on Labor Cooperation (NAALC), was intended to improve the health and safety of workers within the trade region (Brown, 2005a; Brown, 2005b). For this reason, NAFTA and its side agreements were expected to set a precedent for reducing economic and public health inequalities between developed and developing nations in future trade and investment treaties (Brown, 2005a).

Shortly after his election in 2016, President Donald Trump called for the renegotiation of NAFTA (Trump and Clinton, 2016). Beginning in May 2017, the Trump administration initiated the process of renegotiating NAFTA with its neighbors to the north and south (Villarreal, 2023). After more than a year of talks and a round of revisions, the U.S.-Mexico-Canada Agreement (USMCA) was ratified on November 30, 2018, and went into effect on July 1, 2020 (Villarreal, 2023). In comparison to NAFTA, the USMCA directly includes enforceable labor standards in its labor chapter (Torrico et al., 2021). This chapter adopted the 1998 (and amended in 2022) ILO's "Declaration on Fundamental Principles and Rights at Work," which affirms a commitment to acceptable conditions of work with respect to occupational safety and health (U.S. Trade Representative, n.d.). Under the USMCA, the International Labor Affairs Bureau of the U.S. Department of Labor works with the U.S. trade representative to review complaints under the USMCA's Labor Chapter and Rapid Response Labor Mechanism (RRLM) (Sarukhan et al., 2023).

Despite these apparent successes, critics of the USMCA indicate that it falls short in several key areas, as it is largely a continuation of NAFTA with very few improvements (Labonté et al., 2019; Labonté et al., 2020; Santos, 2019; Whiting and Beaumont-Smith, 2019). Specific to occupational health, the USMCA comes with a significant administrative compliance burden that risks wrapping new health, safety, or environmental protective measures in extensive red tape (Labonté et al., 2019). In fact, Labonté et al. (2019) argue that the USMCA appears to set trade above, if not in direct competition with, health and safety regulations. This is because not only does the USMCA indicate that new international standards should not create unnecessary barriers to trade, but it only requires the three signatory countries to simply consider all possible international standards in the creation of their own (Labonté et al., 2019). In theory, this could allow a country to accept an international standard with a lower threshold of safety in lieu of their own more protective standard, as long as they provide a reason for doing so and do not specifically gain a trade or investment advantage as a result (Labonté et al., 2019).

For health and safety professionals, globalization, FTAs, and other policy initiatives, this has the potential to impact their profession, work environments, safety practices, and the people they work to protect. In fact, the task of protecting the workforce (albeit in domestic or international work environments) requires an understanding of the changing dynamics of the global playing field. Therefore, it is increasingly important that health and safety professionals be aware of any changes to the field as a result of FTAs. By evaluating how these stakeholders view their roles and responsibilities under NAFTA and the USMCA, future FTAs can be developed in such a way that they are vehicles for the strategic diffusion of harmonized workplace health and safety policies. This study seeks to identify factors that influence how health and safety professionals view their roles and responsibilities under FTAs.

2. Methods

We administered a cross-sectional survey instrument to American health and safety professionals practicing in the North American free trade area. This survey instrument was modified from the 2017 ILO questionnaire called "Survey on How Occupational Experts Carry Out Their Roles and Responsibilities". This ILO survey was used in Turkey following the reform of their national occupational health and safety legislation where several changes were introduced, including the requirement that enterprises employ occupational safety experts who are trained through a certificate program and maintain professional independence in the execution of their duties (ILO, 2017). ILO first carried out a pilot study to develop the survey questions and to verify appropriate content validity, level of difficulty, question types, sequence of questions, and length of survey (ILO, 2017). Additionally, the internal consistency between different questions was measured, including the application of a Cronbach's alpha test (0.89) to obtain statistical results across all questions. Our research study's survey instrument was comprised of 47 questions, which included questions from the ILO survey, as well as questions developed as a result of the principal investigator's experience as a health and safety professional in the field. The survey instrument was written in English and implemented in Qualtrics.

Recruitment methods were primarily conducted through the memberships of several professional health and safety organizations, including the American Industrial Hygiene Association (AIHA), American Society of Safety Professionals (ASSP), Blacks in Safety Excellence, and Women in Safety and Health. The electronic link to the Qualtrics survey was also posted and shared on various health and safety discussion boards and social media platforms in order to solicit responses from health and safety professionals who may not be members of a professional organization due to cost or other factors. All respondents who self-identified as being a U.S. citizen and were currently working as a health and safety professional in at least one or more North American countries (Canada, U.S., or Mexico) were eligible for inclusion in the study.

Our 47-question survey instrument was comprised of close-ended questions including demographic questions, multiple choice questions, Likert-scale questions, and questions that allowed respondents to select all that apply. Demographic information included job level, years of experience, education level, professional certification, type of industry, gender, race, ethnicity, and age. Non-demographic questions were used to assess how stakeholders view their roles and responsibilities under FTAs. These questions were used to help define the factors that influence stakeholders' views of global health and safety policies, global health and safety training and certification, and their practices.

The survey was voluntary in nature, and respondents remained anonymous. After receiving approval from the University of Iowa's Institutional Review Board, the survey was made available to study participants from January 18, 2022, to March 4, 2022. After closing the survey, cross-tabulation analysis and modeling was utilized to evaluate the data. Cross-tabulations, which elucidate if a non-chance relationship exists between two variables (Huck, 2004), were run between demographic questions and questions pertaining to the roles and responsibilities of health and safety professionals. The chi-square test was used to explore the relationship between the two categorical variables in a cross-tabulation (Pallant, 2016). If the chi-square value is significant, it can be concluded that the data supports evidence of an independent relationship between the variables. All cross-tabulations were carried out in SPSS (IBM SPSS v29), and the number (frequency) of respondents who had the specific characteristics described by the cells in the table was recorded. A total of 532 cross-tabulations were performed. Additionally, expected frequencies were considered for our cross-tabulations. Expected counts are the number of cases one would expect to see in that category (cell) given the distribution of the data (Huck, 2004). A guideline suggested by Cochran (1954) indicates that cross-tabulations should have no more than 20% of cells with expected counts below five (5). Therefore, these statistical considerations were taken into account during the analysis of our results.

3. Results

3.1 Demographic Data

The Qualtrics survey received 407 responses. After removing redundant IP addresses and incomplete survey responses, the remaining sample size was 347. As shown in Fig. 1, the gender composition of those who responded to the survey was 33.7% female (n = 117) and 64.8% male (n = 225). Respondents were primarily not of Hispanic, Latino, or Spanish origin (92.2%, n = 320), and 83.6% (n = 290) identified as White. Most survey respondents were 45 years of age or older: 45-54 (27.1%, n = 94), 55-64 (29.7%, n = 103), and 65-74 (10.7%, n = 37). Survey participants also had many years of experience working in health and safety. Approximately 60% of respondents (n = 205) had at least 16 years of health and safety experience, while 14.7% (n = 51) had 11 to 15 years of health and safety experience. Roughly 15% of respondents (n = 53) had 6 to 10 years of health and safety experience, leaving about 10% with less than 5 years of experience.

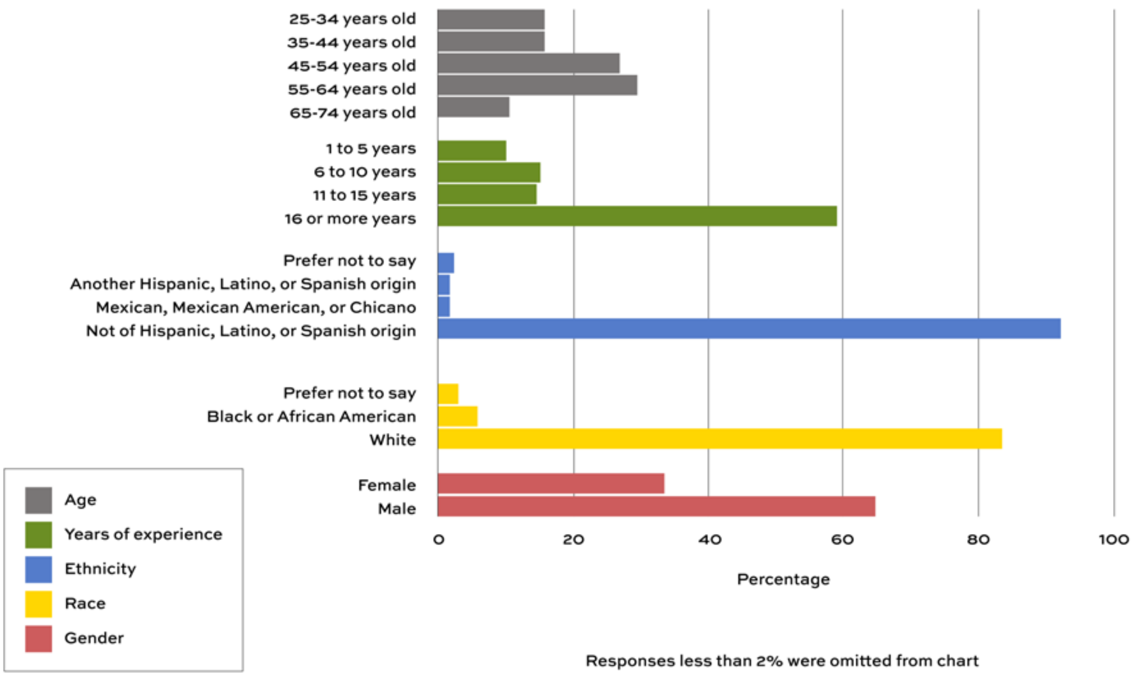

Figure 1. Age, years of experience, ethnicity, race, and gender of questionnaire respondents.

The vast majority of respondents had obtained a graduate degree (51.0%, n = 177) or a bachelor's degree (43.8%, n = 152) as their highest level of education (Fig. 2). Additionally, they reported that the education and training they initially received to be a health and safety professional consisted of the following: four-year college/university (31.4%, n = 109), on-the-job training (26.1%, n = 91), training courses/workshops (19.3%, n = 67), or certificate programs (9.3%, n = 32). Furthermore, respondents indicated that they updated their health and safety knowledge through professional organizations/networks (26.0%, n = 90), continuing education (meetings, symposia, conferences) (25.0%, n = 87), and/or by individual research (18.4%, n = 64). The Certified Safety Professional (CSP) certification was held by 31.5% of respondents (n = 109). Another 19.8% of respondents (n = 69) had other certifications not listed in the survey, while 12.2% (n = 42) had a Certified Industrial Hygienist (CIH) certification, 9.0% (n = 31) had an Associate Safety Professional (ASP) certification, and 4.0% (n = 14) had a Graduate Safety Practitioner (GSP) designation. Only 10.5% (n = 36) had no certifications.

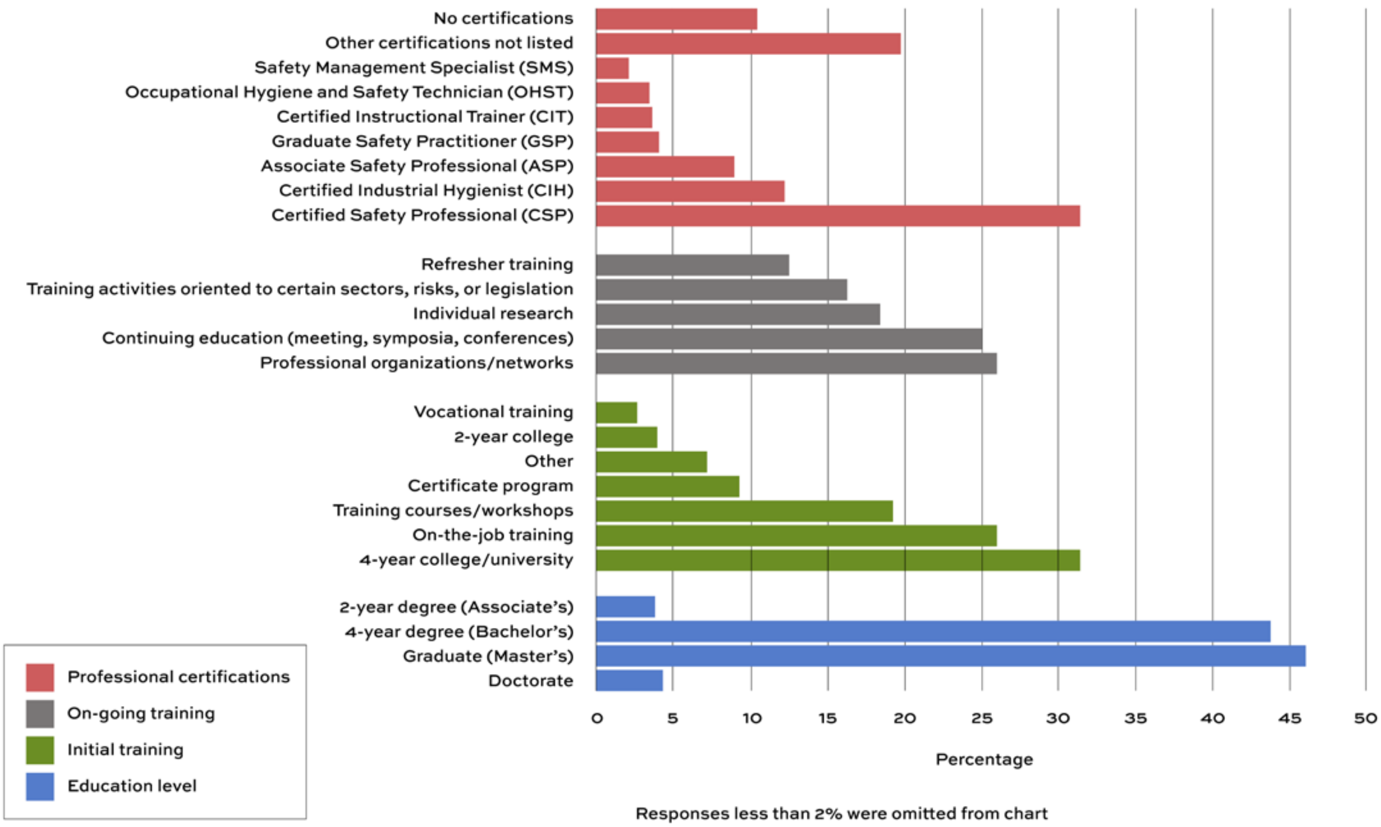

Figure 2. Professional certifications, ongoing training, initial training, and education level of questionnaire respondents.

Most respondents (91.9%, n = 319) reported having a U.S.-based employer (Fig. 3). The majority of survey participants responded that their employer maintained operations/facilities in the U.S. (99.1%, n = 344). Furthermore, 29.1% (n = 101) reported that their employer maintained facilities/operations in Canada, (25.4%, n = 88) in Mexico, and (38.3%, n = 133) in other countries. The top five industry sectors that employed survey respondents were: manufacturing (37.2%, n = 129); services (21.9%, n = 76); finance, insurance, and real estate (9.8%, n = 34); construction (8.9%, n = 31); and public administration (7.5%, n = 26). Additionally, most respondents were health and safety professionals for multiple (regional) sites (59.1%, n = 205), while 30.5% (n = 106) reported responsibility for a single site. The majority of respondents were reported to have been employed by their current employer for 1 to 5 years (37.5%, n = 130), 6 to 10 years (20.5%, n = 71), or 16 or more years (20.2%, n = 70). The most commonly reported job title among respondents was "Manager" (33.7%, n = 117), followed by "Specialist" (17.6%, n = 61), "Director" (16.1%, n = 56), and "Other" (16.1%, n = 56). Most respondents had achieved a job level of "Mid-Senior" (54.2%, n = 188). Nearly all respondents were employed full-time (98.0%, n = 340), and their job status was permanent (96.0%, n = 333).

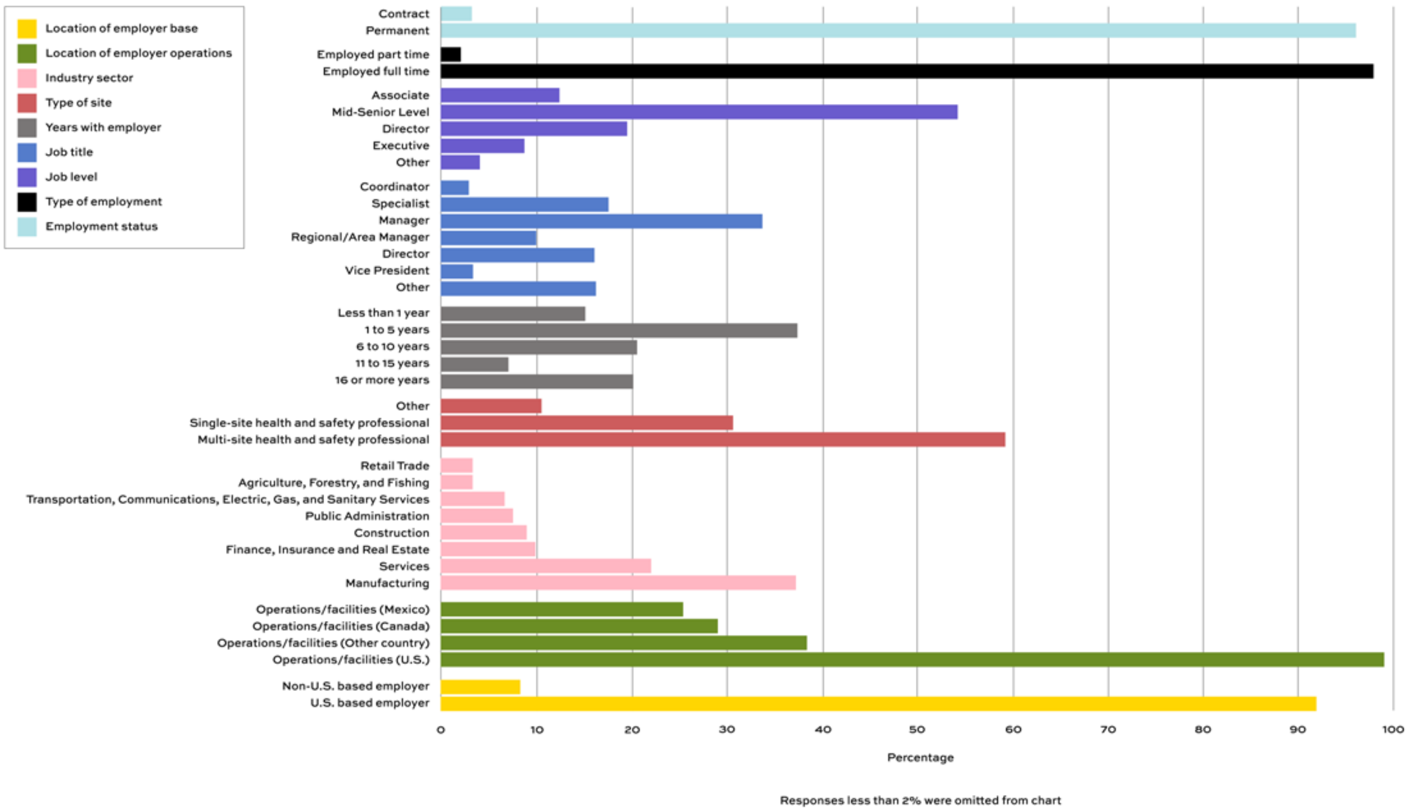

Figure 3. Type of site, location of employer operations, industry sector, location of employer base of questionnaire respondents, years with employer, job title, job level, type of employment, and employment status of questionnaire respondents.

3.2 Cross-tabulations

Cross-tabulations were performed to understand what factors influence stakeholders' views of their roles and responsibilities under FTAs. Four cross-tabulations were found to be statistically significant, contained ≤ 20% of cells with expected counts less than five, and demonstrated meaningful relationships relevant to our study. The first of these involved a question that asked respondents if they perceived that further health and safety provisions are needed as part of FTAs. This question was cross-tabulated with job titles to explore the relationship between the job titles of stakeholders and their perspectives regarding if further health and safety provisions are needed as part of FTAs. Results of this cross-tabulation are found in Table 1.

Table 1. Perception of further need for health and safety provisions in FTAs by job title: Pearson's $X^2 = 17.4$, $df = 9$, $p < 0.05$.

Job title	Further need for health and safety provisions in FTAs				
	N (%)	Agree	Neither agree nor disagree	Disagree	I don't know
Entry level (Coordinator, Specialist, Technician)	73 (21.0%)	37.0%	12.3%	0.0%	50.7%
Manager level (Manager, Area Manager)	151 (43.5%)	23.8%	19.9%	4.6%	51.7%
Executive level (Director, Vice President)	67 (19.3%)	37.3%	19.4%	6.0%	37.3%
Other	56 (16.1%)	26.8%	8.9%	1.8%	62.5%
Total	347 (100%)	29.7%	16.4%	3.5%	50.4%

It was found that 21.0% of respondents (n = 73) worked in entry-level roles, 43.5% (n = 151) worked in manager-level roles, 19.3% (n = 67) worked in executive-level roles, and 16.1% (n = 56) worked in "other" roles. Importantly, half of all respondents across all job titles (50.4%, n = 175) selected "I don't know" if further health and safety provisions are needed as part of FTAs. This was the most selected answer for all job titles except for the executive group. The executive group equally selected "agree" (37.3%, n = 25) and "I don't know" (37.3%, n = 25). It was striking that there was limited knowledge of the details of FTAs and their health and safety provisions among stakeholders of all job titles. However, these results also suggest that there is a relationship between job title and perceptions that further health and safety provisions are needed as part of FTAs. Perceptions of health and safety professionals in executive level positions differed from those in manager level and below positions as executives appear more aware of NAFTA and the USMCA given the high-level scope of their roles.

Our second cross-tabulation (Table 2) interrogated the relationship between health and safety professionals' years of experience and their perceptions regarding the usefulness of an international certificate program as part of FTAs.

Table 2. Perception of usefulness of international certification program by years of experience: Pearson's $X^2 = 10.9$, df = 4, $p < 0.05$.

Years of experience	N (%)	Usefulness of international certificate program		
		Yes	No	I don't know
≤ 5 years	38 (11.0%)	50.0%	28.9%	21.1%
6-15 years	104 (30.0%)	46.2%	34.6%	19.2%
16+ years	205 (59.1%)	31.2%	48.8%	20.0%
Total	347 (100%)	37.8%	42.4%	19.9%

Over 40% of respondents across all years of experience (n = 147) responded "no," indicating that they did not perceive an international training certificate program as part of FTAs to be useful to them in their role. However, the majority of health and safety professionals who had 5 or fewer years of experience (50.0%, n = 19) or who had 6 to 15 years of experience (46.2%, n = 48) responded "yes" that they did perceive an international training certificate program to be useful in their role. This difference in perceptions among health and safety professionals may be because health and safety professionals with low to moderate years of experience (≤ 15 years) are still learning their roles and responsibilities and may not be aware of the knowledge required, while more tenured health and safety professionals (16+ years) have not found a need for an international certificate during their career.

The third cross-tabulation (Table 3) explored the relationship between stakeholders' tenure with their employer and their perceptions regarding the usefulness of an international certificate program as part of FTAs.

Table 3. Perception of usefulness of international certification program by years with employer: Pearson's $X^2 = 15.3$, df = 4, $p < 0.05$.

Years with employer	N (%)	Usefulness of international certificate program		
		Yes	No	I don't know
≤ 5 years	182 (54.2%)	46.7%	36.3%	17.0%
6-15 years	95 (27.4%)	30.5%	44.2%	25.3%
16+ years	70 (20.2%)	24.3%	55.7%	20.0%
Total	347 (100%)	37.8%	42.4%	19.9%

Over 40% of respondents across all years with their employer (n = 147) responded "no," indicating that they did not perceive an international training certificate program as part of FTAs to be useful to them in their role. Not surprisingly, 46.7% of health and safety professionals who had ≤ 5 years with their employer (n = 85) responded "yes" that they did perceive an international training certificate program as part of FTAs would be useful to them in their role. This was expected given that years of experience were moderately correlated with years with employer ($r = 0.4$, $p < 0.001$).

Our fourth cross-tabulation (Table 4) evaluated if the type of location health and safety professionals were responsible for was a factor in how they perceived the sufficiency of governmental audits/monitoring during the implementation of health and safety legislation.

Table 4. Perception of sufficient monitoring of health and safety legislation by type of site: Pearson's $X^2 = 18.5$, df = 10, and $p < 0.05$.

Type of site	N (%)	Sufficient monitoring of health and safety legislation					
		Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree	I don't know
Single site	106 (30.5%)	8.5%	20.8%	12.3%	25.5%	14.2%	18.9%
Multi-site	205 (59.1%)	8.8%	14.1%	21.0%	24.9%	15.6%	15.6%
Other	36 (10.4%)	2.8%	8.3%	8.3%	27.8%	36.1%	16.7%
Total	347 (100%)	8.1%	15.6%	17.0%	25.1%	17.3%	16.7%

More than two-fifths of health and safety professionals (n = 148) "somewhat disagreed" or "strongly disagreed" that there is sufficient monitoring of the implementation of health and safety legislation through governmental audits/monitoring. This included respondents in single sites (39.7%, n = 42) and those working in multiple/regional sites (40.5%, n = 83). However, 63.9% of respondents working in "other" types of arrangements (n = 23) indicated that they "somewhat disagreed" or "strongly disagreed" that there is sufficient monitoring of the implementation of health and safety legislation through governmental audits/monitoring. This suggests that there is a relationship between the type of site health and safety professionals are responsible for and their perception regarding the sufficient monitoring of the implementation of health and safety legislation through governmental audits/monitoring. These perceptions may differ across worksites as their practices could be different given the scope of their roles. While the "other" category for the type of site could represent a variety of different things, it is possible that these health and safety professionals are consultants or contractors who are exposed to unique working environments.

4. Discussion

Our results suggest that "job title" is a factor that influences how stakeholders view the need for further health and safety provisions as part of FTAs. The majority of respondents across all job titles responded that they "did not know" if further health and safety provisions are needed as part of FTAs. This was the most selected answer for all job titles except the executive group. While this indicates a general lack of knowledge of NAFTA and the USMCA, these results suggest that those in executive roles are more aware of a need for further health and safety provisions in FTAs as compared to those working in manager level and below positions. This may be due to an increased exposure to health and safety policies across different industries, countries, and potentially different contexts due to the high level of their position.

The outcomes of our second and third cross-tabulations indicate that "years of experience" and "years with employer" are additional factors that influence stakeholders' views of their global health and safety training and certification under FTAs. Stakeholders who are less to moderately tenured in their careers (≤ 15 years) may perceive that an international certificate program would be useful to them in their role as they are early in their careers, eager to gain a variety of potentially relevant knowledge, and still in the process of understanding their roles and responsibilities. On the other hand, very experienced health professionals (16+ years) may feel that in their years of experience, they have not needed such a certificate program to perform their roles and responsibilities.

The results of our fourth cross-tabulation suggest that stakeholders working in different types of sites view their global health and safety practices differently under FTAs. Practices of health and safety professionals working in single sites and multiple sites may be different from those working in "other" sites. Stakeholders who more strongly disagree that there is sufficient monitoring of health and safety legislation may be less likely to implement certain programs if they believe that they will not be enforced. This is relevant to the understanding of how stakeholders view their roles and responsibilities under FTAs, as the sufficiency/insufficiency of governmental audits/monitoring affects how health and safety policies are operationalized and made compulsory within their site(s).

While the conclusions of our cross-tabulations suggest that a non-chance relationship exists between the variables, it is important to note that cross-tabulations were run between multiple demographic questions and questions pertaining to stakeholders' views of their roles and responsibilities under NAFTA and the USMCA. Thus, significant findings could be the result of chance alone. Additionally, it is important to note that our sample population represents a specific subset of stakeholders practicing in the North American free trade area. Health and safety professionals from Canada and Mexico were not recruited to participate in the study, and recruitment methods focused mainly on health and safety professionals who were part of professional organizations. Furthermore, as the professional certification of health and safety professionals is a self-regulated industry, it is likely that our sample population consists of individuals who are motivated to gain knowledge with regard to global health and safety as compared to the holistic population of health and safety professionals. Given the age and education level of most respondents, our sample population may be more experienced in health and safety than what is truly representative of the landscape of health and safety professionals currently practicing in the NAFTA area. Given this potential bias, it is particularly striking that there was little understanding of the health and safety provisions of FTAs.

5. Conclusion

Our study found that that "job title," "years of experience," "years at employer," and "type of site" are factors that influence how stakeholders view their roles and responsibilities under FTAs. Therefore, these factors should be taken into consideration by the Office of the U.S. Trade Representative during the diffusion of future FTAs to the field through governmental agencies, non-governmental agencies, and interactions with professional organizations for health and safety professionals. Special attention should be directed towards single-site health and safety professionals and those who are early in their careers to ensure this audience is reached and that they are aware of their roles and responsibilities under FTAs. Additionally, the inclusion of training as part of FTAs would allow for all stakeholders in the NAFTA area to have a consistent, standardized baseline knowledge of health and safety regardless of other factors. This could reduce the training inequality that currently exists among health and safety professionals by requiring them to complete a prescribed amount of training in order to be qualified to carry out their roles and responsibilities. Further research in this area could investigate the extent to which data can identify a need for standardized health and safety knowledge across stakeholders. Additionally, opportunities can be explored for American health and safety professionals to network with Canadian and Mexican counterparts for knowledge exchange.

As American corporations continue to venture further and further into the international marketplace, this result has far-reaching implications for the health and safety of global workers. For health and safety professionals, the task of protecting the workforce (albeit in domestic or international work environments), is a challenge as it requires an understanding of the changing dynamics of the global playing field. This study is the first to evaluate factors that influence how American health and safety professionals perceive their roles and responsibilities under FTAs. The results of this work attempt to fill a knowledge gap in the field and provide best practices for the dissemination and internalization of future FTAs among stakeholders.

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Aircrew Members’ Perceived Risk to Cancer and Other Adverse Health Conditions from Cosmic Radiation Exposure

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Abstract

Aircrew members are exposed to cosmic radiation from the sun and outer space throughout their careers. The goal of this study is to evaluate contributing factors to individual perceived risk from this cumulative exposure. A 22-question, self-administered online survey was utilized to assess flight experience, demographic information, and attitudes regarding individual risk from cosmic radiation exposure among flight crew members.

Both gender and base location were found to be statistically significant indicators of how aircrew members perceived their individual risk of exposure. Results suggest that female aircrew members are more concerned with their individual risk from cosmic radiation exposure than male crew members, especially in areas regarding reproductive health and pregnancy. Results also suggest that aircrew members perceive their individual risk from exposure to be higher when they have a greater background knowledge of cosmic radiation. A greater level of background knowledge of cosmic radiation exposure was reported in aircrew members based outside of the United States.

Additional research is needed to determine if current U.S. regulations offer adequate training and protection for aircrew members and if access to radiation information may affect other aspects of aircrew health and personal lives.

KEY WORDS: *aircrew, cancer, cosmic radiation exposure, occupational exposure, reproductive health, risk perception*

1. Introduction

Commercial airline travel continues to be one of the safest modes of transportation, although negative reports continue to rise as customers return to air travel after the pandemic (Bureau of Transportation Statistics, 2024). Public safety concerns about commercial airline travel increased in 2024 due to media coverage of a series of airplane malfunctions on the Boeing 737, 777, and 787 models (Cameron, 2024). Customer complaints about commercial air travel continue to increase year after year due to flight delays and cancellations, long lines, lack of customer service, and technology and booking malfunctions (Associate Press, 2024). As the commercial airline industry continues to increase the number and frequency of flights while finding new ways to control costs, flight attendants are experiencing an increase in workers’ compensation claims due to overexertion (strain) injuries as a result of lifting, falls, and struck-by injuries caused by in-flight turbulence and aisleway trip hazards. Injuries due to violence with irate passengers, and health and psychological distress due to shift work and/or long flights or schedules are also an increasing concern (Johnson and Gilbert, 2024). For the past several years, the Federal Aviation Administration (FAA) commissioned a committee of experts to study the mental health of pilots and air traffic controllers. The FAA committee provided a 164-page final report in April 2024 that identified 24 recommendations to improve current mental health policies (Hoffman, 2024). One powerful finding in this report is that pilots are afraid to report concerns, symptoms, or treatment for mental health issues because it could affect their employment or standing with peers (FAA, 2024). This is just one example of undisclosed or “non-spoken” safety and health concerns among pilots and flight crews.

Despite aircrew members’ classification as occupationally exposed workers, there is little regulation for monitoring cosmic radiation exposure in the United States (International Commission on Radiological Protection, 1991). Furthermore, little is known about the health effects of cumulative small doses of cosmic radiation exposure. This lack of information is particularly problematic for female aircrew members, who may be given different guidance for how to safely support a pregnancy depending on the country they live in and by what rules their employer abides. Cosmic radiation is a naturally occurring mixture of various types of ionizing radiation, including galactic cosmic radiation (GCR) measured in millisievert (mSv), which originates outside of our solar system, and solar particle events (SPE), which originate from the sun (Bartlett, 2004). The International Commission on Radiological Protection’s (ICRP) recommended guideline for annual exposure to cosmic radiation is 20,000 mSv per year (based on a five-year average of 100,000 mSv). Aircrew members who travel at higher altitudes near the earth’s poles have less protection from atmospheric shielding and are exposed to higher levels of GCR (FAA n.d.; Scheibler et al., 2022). NASA researchers have also concluded that among occupational exposures, aircrew members are the most highly exposed (Wilson et al., n.d.).

Little is known regarding the effects of cumulative long-term cosmic radiation exposure or the effects on DNA from high-energy neutron exposure (Wilson et al., n.d.). The primary health concern to aircrew members regarding the effects of GCR is an increased risk of cancer (Scheibler et al., 2022). Studies examining male and female aircrew members have found an increased likelihood of malignant melanoma, breast cancer (in females), and brain cancer in individual cancer sites but haven’t been able to provide a clear association with cosmic radiation exposure (Wilkison and Wong, 2017; Rafnsson, 2000; Zeeb et al., 2012). Non-stochastic risks in terms of radiation exposure in pregnancy include miscarriage, mental deficit, congenital malformations, and growth restrictions, in which the risk of the effect is a function of dosage (Aspholm et al., 1999; Irgens et al., 2003; McCollough et al., 2007). Many agree that there is no demonstrative data correlating specific fetal harm (birth defects, neurological effects) at dose levels less than 20 mSv, but exposures of much less could cause miscarriages in the early stages of pregnancy (Barish, 2004). Increased rates of down syndrome in infants from airline pilots and cabin attendants have been documented but have not been specifically linked to GCR exposure (Irgens et al., 2003). Increased risk of childhood cancer has not been documented at lower in-utero exposure levels, but physicians recommend a 1 mSv limit to their expecting patients (Barish, 2004).

The ICRP and the FAA currently describe aircrew members to be occupationally exposed workers (International Commission on Radiological Protection, 1991; White, 1994; Nicholas et al., 2000). ICRP guidance suggests that occupational workers, regardless of gender, should not be exposed to dosage levels exceeding 20mSv annually (Lochard et al., 2016). When a worker becomes pregnant, their fetus is considered a member of the public whose annual exposure limit is 1 mSv. The maternal abdomen provides no effective shielding to the fetus, so the equivalent dosage to the fetus is equal to their mother (Bartlett, 2004). FAA Report AM-92/2 reveals that a crewmember working 1,000 block hours (time the plane engine(s) is/are running) annually would likely receive less than half of the ICRP’s recommended limit of 20 mSv. The average airline pilot in the U.S. reports flying 75 hours a month, so a pregnant crewmember flying 70 block hours per month could reasonably exceed the recommended limit of 1 mSv during the pregnancy (Friedberg et al., 1992; Bureau of Labor Statistics, 2021). The National Commission on Radiation Protection (NCRP) guidelines describe an embryo or fetus of a pregnant worker as an individual whose dose is recommended to be monitored, and the FAA recommends that an unborn child not exceed doses of up to 0.5 mSv per month (Cool et al., 2019; Tobiska et al., 2015).

In the European Union (EU), member states are required to assess exposure, inform workers of health concerns, organize schedules to reduce doses of “highly exposed aircrew,” and apply special considerations to female aircrew members (Council of the European Union, 1996). In the United States, the FAA currently supports “as low as reasonably achievable”

(ALARA) guidance as the basis for exposure management, but there are no current regulations requiring employer training or monitoring of long-term exposures (Federal Aviation Administration, 2014; White, 1994; Copeland, 2013). Recently, the National Aeronautics and Space Administration (NASA) began re-examining past exposure thresholds created for astronauts, as former exposure restrictions put on female astronauts were seen as discriminatory (Niiler, 2021). The perception that individual workers have over their own exposure can be more detrimental than the actual risk of harm from radiation exposure. Misconceptions instill fear among employees despite having radiation training, and actual psychological stress from perceived exposures highlight the importance of gaining a better understanding of exposed worker perceptions (Ghatan et al., 2016, Collett et al., 2020). Aircrew members' perceptions, specifically, are largely under-researched due to the lack of information available regarding cumulative long-term exposures.

Historically, aviators and astronauts have been recognized as explorers—those who have a high-risk threshold due to inherently dangerous aspects of their career (Slovic, 1996). This topic is increasingly important to understand as we subject aircrew members to flights with more cumulative GCR exposure and as more women get involved in aerospace careers. This study's objective is to determine how aircrew members perceive their individual risks to cosmic radiation exposure.

2. Material and Methods

2.1 Data Collection and Survey Instrument

This study utilized a self-administered online survey to gather participant information. Survey data was collected from a group of aircrew members over the course of two weeks utilizing an online Qualtrics survey. This survey was available to Facebook groups, including Professional Jet Pilots, Female Aviators Sticking Together, Skywest Pilots Group, Skywest Pilots Official, and an SC Aviation employee email list. After a preliminary message was sent out, a list was compiled of interested aircrew members. These volunteers were then sent an anonymous link to the online Qualtrics survey. Aircrew members were informed of the voluntary nature of their participation and the benefit to our combined knowledge from their contribution. Aircrew members were given an anonymous link via email on January 26, a reminder email on February 2, and a thank you email on February 7. A total of 210 completed surveys were collected from aircrew members. The instrument used was a 22-item, self-administered online survey that asked participants questions relevant to demographic information, flight experience, cosmic radiation background knowledge, perceived risk, and known health experiences.

2.2 Measures

2.2.1 Risk Perspective

Risk perspective was assessed with four statements and their following Likert scale responses. These four statements were: "I feel that I am more at risk from cosmic radiation exposure than the non-flying public;" "I feel I have a higher risk of getting cancer than an average person due to exposures in my job;" "I am concerned about cosmic radiation's impact on my fertility/virility;" "I am concerned about cosmic radiation's impact on my future offspring's health." Participants could choose between "strongly agree," "somewhat agree," "somewhat disagree," or "strongly disagree" for each statement.

2.2.2 Known Health Experiences

Known crew member health experiences were collected using four "yes or no" questions embodying main health concerns often attributed to radiation. Participants could answer "yes" or "no" to: "I have confirmation of someone in my field who has been diagnosed with cancer;" "I have confirmation of someone in my field who has had reproductive health problems;" "I have confirmation of someone in my field who has had difficulty having a healthy pregnancy;" "I have confirmation of someone in my field that has had health concerns due to cosmic radiation exposure."

2.2.3 Radiation Knowledge

Participant radiation knowledge was assessed using five "yes or no" questions regarding the level of background knowledge or radiation exposure training that the participants underwent. The five statements were: "I would classify myself as a radiation-exposed worker;" "My employer has a maximum allowable cosmic radiation exposure limit for employees;" "My employer has written procedures on cosmic radiation exposure avoidance;" "I have monitored my individual cosmic radiation exposures;" "I have made a change in flight routing/altitude due to radiation exposure concerns."

2.3 Statistical Analyses

Descriptive statistics and a two-tailed T-test (assumed unequal variances) were performed in Microsoft Excel version 2107, comparing crew members' gender with the groups' risk perspective mean score to determine the effect that gender has on their perception of individual risk. Additionally, each question regarding crew member background knowledge was compared to crew members' risk perspective answers to determine if access to monitoring materials correlated with participant risk perspective.

Known health experiences were assessed by asking crew members four "yes or no" questions; a "2" was entered for "yes," and a "1" was recorded as "no." The average of the calculated total responses for each question was then compared with answers gathered depending on gender and base location.

3. Results

3.1 Demographic Profile of Study Subjects

An initial pool of 232 potential crew members was created through email solicitation. A total of 210 surveys were received. An approximate participation rate was 90.5%, but a true rate could not be determined because the research survey link was shareable among crew members. Two crew members did not disclose their gender. A total of 152 crew members identified as male, and 56 identified as female.

Table 1. Survey Participants (Crew Member) Demographic Information

	MALE	FEMALE	TOTAL
TOTAL	152 (72.3%)	56 (26.7%)	208[i]
AGE			209[ii]
18-25	11 (7.2%)	5 (8.9%)	16 (7.7%)
26-40	95 (62.5%)	33 (58.9%)	129 (61.7%)
41-60	38 (25.0%)	17 (30.4%)	55 (26.3%)
61 or more	8 (5.3%)	1 (1.8%)	9 (4.3%)
BASE			208[iii]
USA	147 (96.7%)	39 (69.6%)	186 (89.4%)
International	5 (3.3%)	17 (30.4%)	22 (10.6%)

[i] Two crew member did not disclose their gender.
[ii] One crew member did not disclose their age.
[iii] Two crew members did not disclose their base location.

The reported age range among males and females was similar, with most respondents in both groups ranging from 26-40 years old (61.5%). U.S.-based participants comprised 89.4% of respondents, and 10.6% were internationally based. Two crew members didn't disclose their base location. A larger percentage of male crew members were U.S.-based than female crew (96.7% American men vs. 69.6% American women) (see Table 1). A sample disproportionate to the world demographics of female aircrew members responded to this survey. Approximately 26.7% of crew members surveyed identified as female, although the world average percentage of female commercial aircrew is closer to 7% (Women in Aviation International, 2021).

Table 2. Survey Participant (Crew Member) Flight Experience

	MALE	FEMALE	TOTAL
Flight Altitude[i]			
<10,000 Ft.	2 (1.3%)	1 (1.8%)	3 (1.4%)
19,000 Ft. – 26,000 Ft.	9 (6.0%)	4 (7.1%)	13 (6.2%)
27,000 Ft. – 41,000 Ft.	121 (80.1%)	47 (83.9%)	170 (81.3%)
>41,000 Ft.	19 (12.6%)	4 (7.1%)	23 (11.0%)
Poplar Route Use[ii]			
Most of the time	0 (0.0%)	1 (1.8%)	1 (0.5%)
Half of the time	0 (0.0%)	1 (1.8%)	1 (0.5%)
Sometimes	8 (5.3%)	8 (14.3%)	16 (7.6%)
Never	144 (94.7%)	46 (82.1%)	192 (91.4%)
Certification Year[iii]			
Mean Year	2007.4	2009	2007.9
Standard Deviation	10.4	7.8	9.8
Annual Flight Hours			
Mean	509.2	476.0	499.8
Standard Deviation	160.7	184.4	166.9
% Long Haul Trips[iv]			
Mean	17.8	37.8	22.9
Standard Deviation	22.6	30	27.6

[i] One crew member didn't disclose their average cruise altitude, and two crew members who didn't disclose their gender did disclose their average cruise altitude.
[ii] Two crew members who answered Polar Route Use did not disclose their gender.
[iii] Four crew members did not disclose their year of certification.
[iv] Twenty-five crew members did not disclose their percentage of time flying long haul trips.

The most reported cruise altitude was 27,000-41,000 ft. (81.3%), and 23 crew members reported flying even higher at 41,000 ft. or higher (11%). A majority of crew members reported that they "never" utilized polar routes (91.4%), but 18 crew members reported utilizing polar routes at least "sometimes" (8.6%). A greater percentage of female aircrew members (17.9%) indicated that they utilized polar routes at least "sometimes" when compared to the male aircrew members (8.6%) (see Table 2). The average calendar year of commercial pilot certification was reported to be about 2008 (2007.8), with an associated average of approximately 12 years of professional flight experience at the time the survey was distributed. Average reported annual flight hours were 499.8 hours (SD = 116.9). The average reported percentage of trips that were perceived as a "long haul" (more than 4 hours flight time or 2,000 nautical miles) was 22.9% (SD = 27.6%) (see Table 2).

3.2 Aircrew Radiation Perceptions, Knowledge, and Experiences

Table 3. Aircrew Radiation Perception, Knowledge, and Experiences

Risk Perception	Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree
More at Risk than Public	115 (54.8%)	84 (40.0%)	5 (2.4%)	6 (2.9%)
Cancer Risk	82 (39.1%)	103 (49.0%)	19 (9.1%)	6 (2.9%)
Fertility/Virility	20 (9.5%)	76 (36.2%)	81 (38.6%)	33 (15.7%)
Future Offspring	20 (9.5%)	70 (33.3%)	82 (39.1%)	38 (18.1%)
Radiation Knowledge		Yes		No
Radiation Worker Classification		141 (67.1%)		69 (32.9%)
Max. Amount		41 (19.5%)		169 (80.5%)
Written Procedures		44 (21%)		166 (79.1%)
Self – Monitoring		21 (10%)		189 (90%)
Flight Change		30 (14.3%)		180 (85.7%)
Known Health Experience[i]		Yes		No
Cancer		116 (55.5%)		93 (44.5%)
Reproductive Health Problems		34 (16.3%)		175 (83.7%)
Difficulty in Pregnancy		34 (16.3%)		175 (83.7%)
Health Concerns due to GCR		51 (24.4%)		158 (75.6%)

[i] One crew member did not disclose their known health experiences

Roughly 95% of crew members felt that they were more at risk from cosmic radiation than the general non-flying public. Majority of crew members (88.1%) felt they have a higher risk of getting cancer than the non-flying public. Nearly half (45.7%) of crew members indicated they were concerned about cosmic radiation's impact on their fertility or virility, and 42.9% of crew members were concerned about their future offspring's health (see Table 3).

More than half (67.1%) of crew members classified themselves as radiation-exposed workers, despite only 21.0% of crew members indicating that their employers have written radiation avoidance procedures and 19.5% of crew members indicating that their employers have a maximum allowable exposure limit. Only 10% of crew members indicated that they have monitored their individual cosmic radiation exposure, and 14.3% indicated that they had made a change in flight routing or altitude due to exposure concerns (see Table 3).

Slightly more than half of crew members (55.5%) indicated they had confirmation of someone in their field who had been diagnosed with cancer. A majority of crew members answered "no" to having confirmation of someone with reproductive health problems (83.7%), difficult pregnancies (83.7%), or general health concerns due to cosmic radiation (75.6%) (see Table 3).

3.3 Effect of Gender

Table 4. Gender and Risk Perception [a]

	MALE		FEMALE	
	Average	SD	Average	SD
More at Risk than Public*	3.41	0.71	3.63	0.59
Cancer Risk	3.20	0.75	3.38	0.68
Fertility/Virility*	2.28	0.81	2.71	0.93
Future Offspring*	2.24	0.84	2.64	0.94

[a] Two crew members did not disclose their gender.
* $p<0.05$, T-test (two-tailed, assumed unequal variances)

T-tests on gender and risk perception indicated female crew members had greater concern about risk from cosmic radiation ($p<.05$), more concern about cosmic radiation's impact on their fertility ($p<.005$), and more concern for their future offspring's health ($p<.01$) than their male counterparts indicated. The difference in concern for cancer among males and females was not significant ($p = 0.12$) (see Table 4).

Table 5. Gender and Known Health Experiences [a]

	MALE				FEMALE			
	Yes	No	Avg.	SD	Yes	No	Avg.	SD
Cancer	52.0%	48.0%	1.5	0.5	66.1%	33.9%	1.7	0.5
Reproductive Health Problems *	10.5%	89.5%	1.1	0.3	32.1%	67.9%	1.3	0.5
Pregnancy Difficulties **	10.5%	89.5%	1.1	0.3	32.1%	67.9%	1.3	0.5
Health Concerns due to GCR	22.4%	77.6%	1.2	0.4	30.4%	69.6%	1.3	0.5

[a] Two crew members did not disclose gender, and one crew member did not disclose their known health experiences.
* $p<0.05$, T-test (two-tailed, assumed unequal variances)
** $p<0.001$, T-test (two-tailed, assumed unequal variances)

Gender influenced the percentage of crew members who answered "yes" to each of the "health experience" questions. Female aircrew answered "yes" at a higher percentage than male aircrew, with the greatest difference seen in reproductive problems (32.1% vs. 10.5%) and pregnancy difficulties (32.1% vs. 10.5%). Reproductive health problems and pregnancy difficulties were both found to be highly significant among respondent groups. Known cancer diagnosis (p = 0.07) and health concerns due to GCR (p = 0.26) were not significant between male and female crew members (see Table 5).

3.4 Effect of Base Location

Table 6. Base and Risk Perception [a]

	U.S. BASED		INTERNATIONAL BASED	
	Avg.	SD	Avg.	SD
More at Risk than Public *	3.43	0.70	3.77	0.43
Cancer	3.25	0.74	3.27	0.63
Fertility/Virility *	2.35	0.85	2.82	0.85
Future Offspring *	2.30	0.88	2.77	0.81

[a] One crew member did not disclose their base location.
* p<0.05, T-test (two-tailed, assumed unequal variances)

Internationally-based crew members were significantly more likely to indicate that they were more at risk from exposure than the general public (p<.005), more concerned with radiation's impact on their fertility/virility (p<.05), and more concerned about radiation exposure's impact on their future offspring (p<.05) (see Table 6).

Table 7. Base and Radiation Knowledge [a]

	U.S. BASED		INTERNATIONAL BASED	
	Yes	No	Yes	No
Classification as Radiation Worker	64.2%	35.8%	90.9%	9.1%
Employer Maximum	15.0%	85.0%	59.1%	40.9%
Written Procedures	18.2%	81.8%	45.5%	54.6%
Self-monitoring	7.0%	93.1%	36.4%	63.6%
Flight Change	12.8%	87.2%	27.3%	72.7%

[a] One crew member did not disclose their base location.

Internationally-based crew members were more likely to indicate that they classified themselves as radiation workers, had an employer-set maximum exposure limit, had written avoidance procedures, had individually monitored their exposure, and had made a change in their flight path due to radiation concerns (see Table 7).

Table 8. Radiation Knowledge and Risk Perception

	MORE RISK THAN PUBLIC		CANCER		FERTILITY/ VIRILITY		OFFSPRING	
	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD
Classification	3.67**	0.53	3.45*	0.57	2.56*	0.83	2.53*	0.86
No Classification	3.06	0.78	2.83	0.86	2.06	0.84	1.96	0.81
Employer Maximum	3.83**	0.38	3.51*	0.55	2.76*	0.89	2.73*	0.90
No Maximum	3.38	0.71	3.18	0.76	2.31	0.84	2.25	0.86
Written Procedures	3.77**	0.42	3.43*	0.55	2.61	0.92	2.55	0.95
No Written Procedures	3.39	0.72	3.19	0.77	2.34	0.84	2.29	0.86
Self-Monitoring	3.81*	0.51	3.67**	0.58	3.10*	0.83	3.05*	0.74
No Self-Monitoring	3.43	0.69	3.20	0.74	2.32	0.83	2.26	0.87
Flight Change	3.77**	0.43	3.57	0.57	2.73*	0.94	2.87*	1.01
No Flight Change	3.42	0.71	3.19	0.75	2.34	0.84	2.26	0.83

* p<0.05, T-test (two-tailed, assumed unequal variances)
** p<0.001, T-test (two-tailed, assumed unequal variances)

Crew members who considered themselves to be radiation-exposed workers were more likely to perceive that they were more at risk from cosmic radiation exposure than the non-flying public ($p<.001$), felt they were at higher risk of getting cancer ($p<.002$), were more concerned about GCR impact on their fertility/virility ($p<.003$), and were more concerned about the health of their future offspring ($p<.004$) than those who did not consider themselves to be "radiation-exposed workers." Crew members whose employers had a maximum exposure limit felt they were more at risk from exposure ($p<.001$), had higher chances of getting cancer ($p<.002$), were more concerned about cosmic radiation's impact on their fertility/virility ($p<.005$), and were more concerned about their future offspring's health ($p<.004$) than those who did not have a maximum exposure limit at their work (see Table 8). Having written procedures regarding GCR exposure from their employer affected the way that crew members felt about their personal risk from radiation exposure and their chances of getting cancer. Crew members who had written procedures at their work felt that they were more at risk from cosmic radiation exposure ($p<.001$) and were more likely to feel they had a higher risk of getting cancer ($p<.05$). The relationship between having written procedures and an indication of fertility difficulties ($p=.076$) and offspring concerns ($p=0.11$) was insignificant.

Crew members who had monitored their individual exposures were more likely to indicate they were at greater risk from exposure than the general public ($p<.005$), more likely to get cancer ($p<.005$), more concerned with radiation's impact on their fertility/virility ($p<.001$), and more concerned about radiation exposure's impact on their future offspring ($p<.002$). Crew members who indicated they had changed their route of flight due to GCR exposure concerns were more likely to indicate that they felt more at risk than the general public ($p<.001$), more at risk for cancer ($p<.005$), fertility/virility implications ($p<.05$), and were more concerned about their future offspring's health ($p<.005$) (see Table 8).

All things considered, internationally-based crew members were more likely to indicate that they had greater knowledge or experience with cosmic radiation exposure in each survey parameter. Radiation knowledge in each question was correlated with increased perceived risk, and internationally-based crew members indicated that they felt more risk from radiation exposure than U.S.-based crew members.

Table 9. Risk Perception in Female Aircrew – Internationally-based vs. U.S.-based

	U.S.-BASED FEMALES		INTERNATIONALLY-BASED FEMALES	
	Average	SD	Average	SD
More at Risk than Public	3.54	0.64	3.82*	0.39
Cancer Risk	3.38	0.71	3.35	0.61
Fertility	2.62	0.99	2.94	0.75
Offspring	2.56	1.05	2.82	0.64

* $p < 0.05$, T-test (two-tailed, assumed unequal variances)

The group of female participants comprised a greater percentage of internationally-based women (30.4%) than the male group (3.3%) (see Table 1). Although being based outside the U.S. correlated with higher feelings on average risk from cosmic radiation exposure, regardless of base location, female crew members had similar perceived risk levels of developing cancer, their fertility concerns, and their concern for the health of their future offspring. When asked if crew members were more at risk from cosmic radiation exposure than the non-flying public, U.S.-based females were slightly less concerned, on average, than females based outside the U.S. ($p<.05$). The concern for cancer ($p = 0.87$), fertility ($p = 0.18$), and offspring ($p = 0.26$) between U.S. females and internationally-based females was insignificant (see Table 9).

4. Discussion

Although both male and female aircrew members in this study had concern for their individual exposure to cosmic radiation, females reported significantly more concern in all areas other than the risk of cancer, including overall risk, fertility, and the health of their future offspring. This gender-risk effect has been examined following industrial accidents, such as the Fukushima nuclear disaster in 2011, where there was a reluctance in males to acknowledge danger when it impeded their ability to provide for their families (Morioka, 2014). While this disaster was a source of acute radiation exposure, compelling parallels exist in the comparison of male and female parents interviewed afterward. The NCRP describes risk perception as not only the data we examine from health effects but the perceived benefits from that exposure (Slovic, 1996). When mothers were interviewed following the Fukushima disaster, physical well-being was expressed as a greater threat than in fathers, whose concern was their own economic stability (Morioka, 2014). This gender-risk effect may carry varying results in cultures where occupations (and benefits gained) are divided more evenly between genders.

How we perceive our personal risk is also determined by the culture around us and how the magnitude of those risks is presented to us (Slovic, 1996). A greater percentage of female aircrew indicated that they had more knowledge of members in their field who had either reproductive health problems ($p<.005$) or difficulty having a healthy pregnancy ($p<.005$) than their male counterparts. This may be due to the ability of women in many cultures to discuss pregnancy details more comfortably with other women than men would to discuss potential reproductive problems with other men. Regardless of where the knowledge comes from, this difference in the information received may contribute to how aircrew members perceive their own risk from exposure. In experiencing pregnancy, women have more to lose from myriad possible pregnancy complications than their male counterparts, which may inherently increase their perceived risk.

The relationship between radiation knowledge and risk perception has been studied in several practices, typically in professional medical training. Adequate training among students has been found to decrease risk perception, but perceptions have also varied among different professional vantage points (Yoshida et al., 2020, Hyde et al., 2016). Despite having received ionizing radiation training, occupational patterns have emerged suggesting that exposure risk beliefs are socially constructed (Hyde et al., 2016). Past research suggests that increased radiation education decreases subject risk perception, but only if the training given is adequate and understood properly (Yoshida et al., 2019). Conversely, aircrew members in this study who received more radiation exposure guidance felt, on average, more at risk from radiation exposure. Like results published by Pepin et al. (2023), this study suggests that radiation exposure training given to aircrew members is either inadequate in an effort to calm aircrew perceptions or that cultural beliefs have a stronger impact on aircrew perceptions than evidence-based training.

One of the key challenges in gathering a representative sample of surveys among the aircrew member population was a lack of representation of female aircrew members in the field. Despite offering this survey online, there was still a much larger respondent pool based in the U.S. than based outside of the U.S., misrepresenting the world population of aircrew. Although the participants sampled had a greater proportion of female aircrew than representative of the actual population of aircrew (roughly 7% worldwide), the data gathered was from a relatively small sample size, also leading to possible misrepresentation. Finally, this survey was self-administered, so responses could have been collected from unqualified or unrequested participants. The effect of different cultural protections in pregnancy was not examined in this study. Outside of having access to information about radiation exposure, there may be more cultural pressure in some countries to take time off during pregnancy. Family structure and societal norms may also influence risk perception, depending on the aircrew member's responsibility for their household's financial security. This information is important to understand as more women are launching aerospace careers and will require adequate information to care for themselves.

5. Conclusions and Recommendations

This study provides a compelling example of an occupation with varying degrees of exposure risk perception. The results corroborate that female aircrew members are more concerned about individual health effects from cosmic radiation exposure than their male counterparts. Furthermore, when cosmic radiation exposure is perceived as a tangible risk, crew members feel more concerned about their individual risk of exposure. This relationship contradicts current research, displaying the need for better understanding of radiation exposure among the aviation industry. The total and long-term effects of this increased risk perception among female aircrew members is unknown. Further research is needed to determine the impact of these beliefs among female aircrew members, the causes of these beliefs, and the possible effects of monitoring exposures in the U.S.

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Mattress Manufacturing: Bowtie Dermal Risk Assessment Model

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Abstract

Several sources indicate that dermal exposure to harmful substances in an occupational setting is a significant problem both globally and in the U.S. The authors examined the latest detailed data available from the Bureau of Labor Statistics (BLS). Polyurethane mattress manufacturing requires the use of toxic substances like toluene diisocyanate (TDI). This presents challenges from an occupational health perspective. Dermal exposure to toxic chemicals is sometimes difficult to assess due to a lack of exposure limits. The purpose of this study is to estimate the risk of TDI, Tetrahydrofuran (THF), and boric acid exposures to the mattress manufacturing operators. Field sampling methods were considered, and a new bowtie dermal risk assessment model was developed.

KEY WORDS: *dermal exposure, risk assessment, bowtie dermal risk assessment model, field sampling*

1. Introduction

Polyurethane foam was created in 1937 by Otto Bayer, based on a reaction between a polyester diol and a diisocyanate. During World War II, polyurethane was used for the insulation of refrigerators and aircrafts. This polymer was cheaper and easier to shape, and it had great potential to be used in many practical applications (Gama et al., 2018). Mattress polyurethane is formed by mixing a polyol with Toluene diisocyanate (TDI) in the presence of suitable catalysts and additives.

The purpose of this research project is to evaluate TDI exposures utilizing field methods and colorimetric wipe samplers (direct-read wipes for surface chemical detection). The project was initiated due to skin and respiratory irritation complaints from mattress manufacturing workers in Columbia, South America. The authors wanted to answer the following research questions: Are colorimetric methods suitable for TDI risk assessment during mattress manufacturing? Is the bowtie dermal risk assessment model applicable to such a process?

The scope of the study was to estimate the risk of TDI, tetrahydrofuran (THF), and boric acid exposure to the mattress manufacturing operators. At the time of the sampling, there were no American Industrial Hygiene Association (AIHA) accredited laboratories in South America. TDI samples are usually collected on glass fiber filters (GFFs) or impingers (or a combination of the two) based on methods developed by the Occupational Safety and Health Administration (OSHA) and the National Institute for Occupational Safety and Health (NIOSH). However, due to restrictions in sampler storage and transportation before and after sampling, in addition to the limited ability to ship the collected samples in cold conditions within 24 hours, the authors had to consider field sampling methods. Therefore, TDI colorimetric tubes and direct-read wipes for surface TDI contamination were acquired. For this project, the authors concentrated on surface sampling and detector tubes to estimate the risk of dermal exposure.

Dermal exposure to harmful substances in an occupational setting is a significant problem globally. According to OSHA (2017), the number of cases and the rate of skin disease in the U.S. exceeds recordable respiratory illnesses. According to the latest detailed data available from the Bureau of Labor Statistics (BLS) in 2017, 24,800 recordable skin diseases or disorders were reported at a rate of 2.2 diseases or disorders per 10,000 employees, compared to 14,900 respiratory illnesses with a rate of 1.3 illnesses per 10,000 employees.

Nonfatal occupational illnesses by major industry sector and category of illness, 2017

Industry sector	Total Cases		Skin diseases or disorders		Respiratory conditions		Poisonings		Hearing loss		All other illnesses	
	Number of cases (000s)	Incidence rate [1]	Number of cases (000s)	Incidence rate [1]	Number of cases (000s)	Incidence rate [1]	Number of cases (000s)	Incidence rate [1]	Number of cases (000s)	Incidence rate [1]	Number of cases (000s)	Incidence rate [1]
All industries including private, state and local government [2]	169.9	15	24.8	2.2	14.9	1.3	2.3	0.2	15.9	1.4	112	9.9
Private industry [2]	126.4	12.8	18.5	1.9	10.4	1.1	1.7	0.2	14	1.4	81.8	8.3
Goods-producing [2]	41.6	20.3	5.3	2.6	1.7	0.8	0.4	0.2	10.9	5.3	23.2	11.3
Natural resources and mining [2,3]	3.4	20.7	0.7	4.3	0.3	1.8	0.2	1.1	0.3	1.8	1.9	11.7
Construction	3.8	6	1	1.6	0.3	0.4	0.1	0.2	0.1	0.2	2.3	3.6
Manufacturing	34.3	27.6	3.6	2.9	1.1	0.9	0.2	0.1	10.5	8.4	18.9	15.2
Service-providing	84.4	10.8	13.2	1.7	8.7	1.1	1.2	0.2	3.1	0.4	58.6	7.5
Trade, transportation, and utilities [4]	21	9.2	2.6	1.2	2	0.9	0.4	0.2	2.1	0.9	13.8	6
Information	1.7	6.7	0.2	0.7	0.1	0.4	0.1	0.2	0.1	0.4	1.3	5.1
Finance, insurance, and real estate	4.1	5.4	0.5	0.7	0.8	1	(-5-)	(-5-)	-	-	2.4	3.2
Professional and business services	9.3	5.9	1.7	1.1	1.1	0.7	0.3	0.2	0.3	0.2	6	3.8
Educational and health services	36.1	22.1	5.3	3.2	3.5	2.1	0.3	0.2	0.1	0.1	27	16.5
Leisure, entertainment, and hospitality	10.3	10.2	2.4	2.4	1.2	1.2	0.2	0.2	0.1	0.1	6.4	6.3
Other services (except public administration)	2.3	7.3	0.5	1.5	0.1	0.4	-	-	-	-	1.7	5.4
State and local government [2]	43.5	30	6.3	4.3	4.5	3.1	0.6	0.4	1.9	1.3	30.2	20.9
State government [2]	11.1	27.7	1.3	3.2	1	2.5	0.1	0.3	0.6	1.5	8	20.1
Local government [2]	32.5	30.9	5	4.8	3.5	3.3	0.5	0.4	1.3	1.2	22.2	21.1

[1] The incidence rates represent the number of illnesses per 10,000 full-time equivalent workers and were calculated as: (N/EH) x 20,000,000, where
N = number of illnesses EH = total hours worked by all employees during the calendar year 20,000,000 = base for 10,000 equivalent full-time workers (working 40 hours per week, 50 weeks per year)
[2] Excludes farms with fewer than 11 employees.
[3] Data for Mining (Sector 21 in the North American Industry Classification System -- United States, 2012) include establishments not governed by the Mine Safety and Health Administration rules and reporting, such as those in Oil and Gas Extraction and related support activities. Data for mining operators in coal, metal, and nonmetal mining are provided to BLS by the Mine Safety and Health Administration, U.S. Department of Labor. Independent mining contractors are excluded from the coal, metal, and nonmetal mining industries. These data do not reflect the changes the Occupational Safety and Health Administration made to its recordkeeping requirements effective January 2002; therefore, estimates for these industries are not comparable to estimates in other industries.
[4] Data for employers in railroad transportation are provided to BLS by the Federal Railroad Administration, U.S. Department of Transportation.
[5] Data too small to be displayed.

NOTE: Because of rounding, components may not add to totals. Dash indicates data do not meet publication guidelines. SOURCE: U.S. Bureau of Labor Statistics, U.S. Department of Labor

In 2015, 28,300 recordable skin diseases or disorders were reported by the BLS at a rate of 2.6 diseases or disorders per 10,000 employees, compared to 17,200 respiratory illnesses with a rate of 1.5 illnesses per 10,000 employees.

Nonfatal occupational illnesses by major industry sector and category of illness, 2015

Industry sector	Total Cases		Skin diseases or disorders		Respiratory conditions		Poisonings		Hearing loss		All other illnesses	
	Number of cases (000s)	Incidence rate [1]	Number of cases (000s)	Incidence rate [1]	Number of cases (000s)	Incidence rate [1]	Number of cases (000s)	Incidence rate [1]	Number of cases (000s)	Incidence rate [1]	Number of cases (000s)	Incidence rate [1]
All industries including state and local government [2]	187.9	16.9	28.3	2.6	17.2	1.5	2.5	0.2	19.5	1.8	120.4	10.9
Private industry [2]	140.5	14.6	21.9	2.3	12.1	1.3	1.7	0.2	16.8	1.8	88.0	9.2
Goods-producing [2]	49.7	24.6	6.6	3.3	2.7	1.3	0.5	0.2	13.8	6.9	26.0	12.9
Natural resources and mining [2,3]	3.8	20.0	1.0	5.3	0.6	3.0	0.2	0.9	0.3	1.6	1.7	9.1
Construction	5.1	8.6	1.4	2.3	0.5	0.8	0.1	0.2	0.1	0.1	3.1	5.2
Manufacturing	40.8	32.9	4.2	3.4	1.7	1.3	0.2	0.2	13.5	10.9	21.2	17.1
Service-providing	90.9	12.0	15.4	2.0	9.3	1.2	1.2	0.2	3.0	0.4	61.9	8.2
Trade, transportation, and utilities [4]	23.7	10.6	3.0	1.3	1.6	0.7	0.3	0.1	2.4	1.1	16.3	7.3
Information	1.9	7.8	0.2	0.8	0.1	0.3	-	-	0.2	0.7	1.5	6.0
Finance, insurance, and real estate	3.6	4.9	0.3	0.5	0.3	0.4	-	-	-	-	2.9	4.0
Professional and business services	11.8	7.8	3.1	2.1	1.3	0.8	0.2	0.2	0.1	0.1	7.0	4.6
Educational and health services	37.3	23.6	5.8	3.7	4.7	3.0	0.2	0.1	0.1	0.1	26.4	16.7
Leisure, entertainment, and hospitality	10.4	10.8	2.4	2.4	1.2	1.2	0.3	0.3	0.1	0.1	6.5	6.8
Other services (except public administration)	2.2	7.0	0.5	1.6	0.2	0.7	-	-	(5)	0.1	1.2	4.0
State and local government [2]	47.4	32.0	6.4	4.3	5.1	3.4	0.8	0.5	2.7	1.8	32.4	21.9
State government [2]	12.5	31.4	1.6	4.1	1.4	3.5	0.1	0.4	0.7	1.7	8.7	21.7
Local government [2]	34.8	32.2	4.8	4.4	3.7	3.4	0.6	0.6	2.0	1.8	23.7	22.0

[1] The incidence rates represent the number of illnesses per 10,000 full-time equivalent workers and were calculated as: (N/EH) x 20,000,000, where
N = number of illnesses EH = total hours worked by all employees during the calendar year 20,000,000 = base for 10,000 equivalent full-time workers (working 40 hours per week, 50 weeks per year)
[2] Excludes farms with fewer than 11 employees.
[3] Data for Mining (Sector 21 in the North American Industry Classification System -- United States, 2012) include establishments not governed by the Mine Safety and Health Administration rules and reporting, such as those in Oil and Gas Extraction and related support activities. Data for mining operators in coal, metal, and nonmetal mining are provided to BLS by the Mine Safety and Health Administration, U.S. Department of Labor. Independent mining contractors are excluded from the coal, metal, and nonmetal mining industries. These data do not reflect the changes the Occupational Safety and Health Administration made to its recordkeeping requirements effective January 2002; therefore, estimates for these industries are not comparable to estimates in other industries.
[4] Data for employers in railroad transportation are provided to BLS by the Federal Railroad Administration, U.S. Department of Transportation.
[5] Data too small to be displayed.

NOTE: Because of rounding, components may not add to totals. Dash indicates data do not meet publication guidelines. SOURCE: U.S. Bureau of Labor Statistics, U.S. Department of Labor

In 2013, 33,600 recordable skin diseases or disorders were reported by the BLS at a rate of 3.2 diseases or disorders per 10,000 employees, compared to 19,600 respiratory illnesses with a rate of 1.8 illnesses per 10,000 employees.

Nonfatal occupational illnesses by major industry sector and category of illness, 2013

Industry sector	Total Cases		Skin diseases or disorders		Respiratory conditions		Poisonings		Hearing loss		All other illnesses	
	Number of cases (thousands)	Incidence rate [1]	Number of cases (thousands)	Incidence rate [1]	Number of cases (thousands)	Incidence rate [1]	Number of cases (thousands)	Incidence rate [1]	Number of cases (thousands)	Incidence rate [1]	Number of cases (thousands)	Incidence rate [1]
All industries including private, state and local government [2]	199.4	18.8	33.6	3.2	19.6	1.8	3.2	0.3	21.2	2.0	121.9	11.5
Private industry [2]	152.3	16.6	26.0	2.8	13.0	1.4	1.6	.2	18.1	2.0	93.5	10.2
Goods-producing [2]	52.5	27.6	6.7	3.5	2.7	1.4	.5	.3	14.0	7.4	28.6	15.0
Natural resources and mining [2,3]	4.5	24.9	.9	5.1	.8	4.4	.1	.6	.3	1.4	2.5	13.5
Construction	5.2	9.8	1.1	2.0	.4	.7	.2	.3	.3	.6	3.3	6.2
Manufacturing	42.7	35.9	4.7	4.0	1.5	1.3	.2	.2	13.4	11.3	22.8	19.2
Service-providing	99.9	13.7	19.3	2.7	10.3	1.4	1.1	.2	4.1	.6	65.0	8.9
Trade, transportation, and utilities [4]	25.5	11.8	3.3	1.5	2.2	1.0	.6	.3	-	-	16.2	7.5
Information	2.7	11.0	.3	1.1	-	-	-	-	.2	.9	2.0	8.0
Financial activities	4.9	6.9	.6	.9	.5	.7	-	-	-	-	3.8	5.3
Professional and business services	11.8	8.3	-	-	1.3	.9	.1	([5])	.3	.2	6.4	4.5
Educational and health services	41.7	27.4	7.5	4.9	4.9	3.2	.3	.2	.1	.1	28.8	19.0
Leisure and hospitality	10.1	11.2	3.1	3.4	.9	1.0	.2	.2	.1	.1	5.8	6.4
Other services (except public administration)	3.1	10.4	.8	2.7	.3	1.0	-	-	.1	.2	2.0	6.5
State and local government [2]	47.1	32.7	7.5	5.2	6.6	4.6	1.5	1.1	3.1	2.1	28.4	19.7
State government [2]	14.3	35.3	1.7	4.3	1.7	4.2	.4	1.0	.9	2.1	9.6	23.7
Local government [2]	32.8	31.7	5.8	5.6	4.9	4.7	1.1	1.1	2.2	2.1	18.8	18.1

[1] The incidence rates represent the number of illnesses per 10,000 full-time equivalent workers and were calculated as: (N/EH) x 20,000,000, where
N = number of illnesses EH = total hours worked by all employees during the calendar year 20,000,000 = base for 10,000 equivalent full-time workers (working 40 hours per week, 50 weeks per year)
[2] Excludes farms with fewer than 11 employees.
[3] Data for Mining (Sector 21 in the North American Industry Classification System -- United States, 2007) include establishments not governed by the Mine Safety and Health Administration rules and reporting, such as those in Oil and Gas Extraction and related support activities. Data for mining operators in coal, metal, and nonmetal mining are provided to BLS by the Mine Safety and Health Administration, U.S. Department of Labor. Independent mining contractors are excluded from the coal, metal, and nonmetal mining industries. These data do not reflect the changes the Occupational Safety and Health Administration made to its recordkeeping requirements effective January 2002; therefore, estimates for these industries are not comparable to estimates in other industries.
[4] Data for employers in railroad transportation are provided to BLS by the Federal Railroad Administration, U.S. Department of Transportation.
[5] Data too small to be displayed.

NOTE: Because of rounding, components may not add to totals. Dash indicates data do not meet publication guidelines. SOURCE: U.S. Bureau of Labor Statistics, U.S. Department of Labor

The authors summarized the number and ratios of recordable skin diseases or disorders against respiratory illnesses in the U.S. The results are presented in Figs. 1 and 2.

Figure 1. Number of Recordable Skin Diseases or Disorders vs. Respiratory Illnesses in the US.

	2013	2015	2017
Recordable skin diseases or disorders	33,600	28,300	24,800
Respiratory illnesses	19,600	17,200	14,900
Ratio	1.71	1.65	1.66

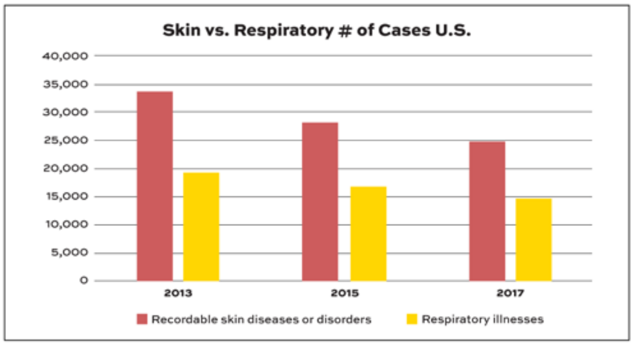
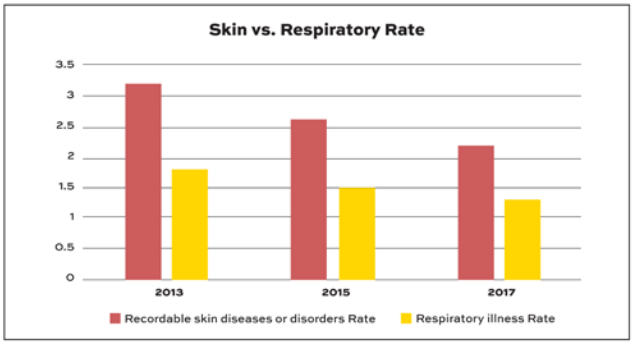


Figure 2. Rate of Recordable Skin Diseases or Disorders vs. Respiratory Illnesses in the US.

	2013	2015	2017
Recordable skin diseases or disorders Rate	3.2	2.6	2.2
Respiratory illnesses Rate	1.8	1.5	1.3
Skin vs. Respirtatory Ratio	1.78	1.73	1.69



The trend, presented in Fig. 2, is obvious. There are approximately 1.7 recordable skin diseases or disorders for every respiratory illness. A significant number of chemicals are readily absorbed through the skin. These chemicals can cause undesirable health effects and/or contribute to the dose absorbed by inhalation of the chemical from the air (OSHA, 2017).

In many cases, absorption of chemicals through the skin can occur without being observed by the affected employee. As indicated in the latest BLS trends, the skin has a more significant route of exposure than the respiratory system. This especially applies to non-volatile chemicals. Such chemicals can remain on an employee's clothes or work surfaces for long periods of time. It is virtually impossible to determine the number of occupational illnesses caused by skin absorption of chemicals. However, it can be estimated that the risk of skin diseases or disorders represent a significant health risk for employees and organizations.

2. Methods

2.1 Dermal Risk Assessment

There are a number of dermal risk assessment models available. However, one of the most user-friendly models is the Dermal Risk Assessment Model (DRAM)™ (AIHA, 2022). This tool provides a systematic screening evaluation of the relative risks of dermal exposure to material and may be especially useful for the purposes of prioritizing additional analysis for specific materials or scenarios. It runs only in Microsoft Excel (with macro-enabled mode) but requires no other software. What is unique about this tool is the fact that it includes a deterministic (single value inputs) option and a Monte Carlo simulation (distributions of input values) option.

The tool uses information about the nature of the dermal toxicity and categorical choices for exposure factors such as dermal contact area, contact frequency, dermal retention time, dermal concentration/loading, and dermal penetration potential. The factors are used in an algorithm to estimate the risk and plot it on the risk grid. The authors and developers of the tool are Jennifer Sahmel, Daniel Drolet, and Susan Arnold.

One of the limitations of the model is that it only allows for single compound/substance dermal risk assessment. The tool does not address the risk summation or additive/synergistic effects of multiple substance exposures. To address the limitations, the authors developed the Bowtie DRAM. This model is based on the well-established simplified model for assessing and managing workplace risk factors, as shown in Fig. 3.

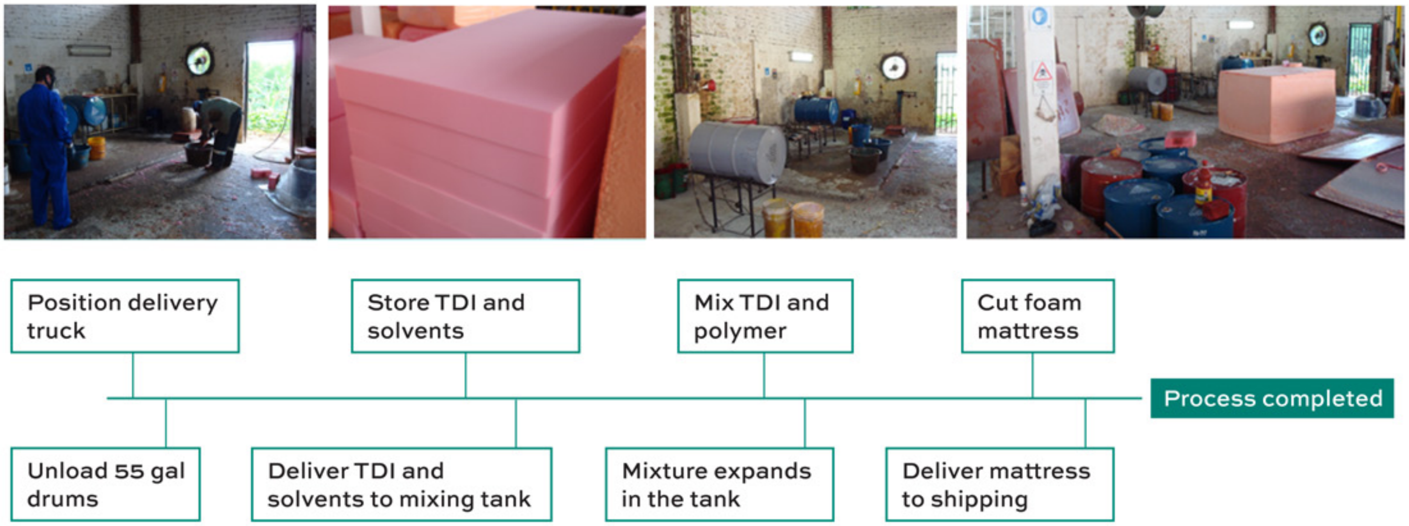
Figure 3. Simplified Model for Assessing and Managing Workplace Risk Factors

To further develop the DRAM, the authors selected a real-case scenario to present a practical application of the newly developed method.

2.2 Practical Application of the Bowtie Dermal Risk Assessment Tool

A small company that produces foam mattresses imports a variety of chemicals used in the production process. Three chemicals were selected to demonstrate the applicability of the Bowtie Risk Assessment methodology. For instance, polymeric polyols are generally used to produce other polymers. They react with isocyanates to make polyurethanes used in mattress manufacturing. Furthermore, tetrahydrofuran and boric acid are also added to the mix. The process is shown in Fig. 4.

Figure 4. Mattress production – Process Flow



The production process requires the mixing of chemicals and polymeric polyols, as shown in Exhibit 1.

Exhibit 1. Mixing of Chemicals

3. Results

The mixing operator used nitrile gloves and work clothing for skin protection and a full-face respirator for respiratory protection. An industrial hygienist collected air samples from nine locations. Corresponding surface wipe samples were also collected from the same locations. The results from screening for airborne concentrations and surface contamination of TDI are presented in Table 1.

Table 1. Toluene Diisocyanate 0.02 Detector Tubes and TDI Wipe Samples Comparison

Area	Sample #	Wipe Sample	Detector Tubes
Middle of chemical mixing table	1	TDI Present	TDI >0.02 ppm
End of chemical mixing table	2	TDI Present	TDI >0.02 ppm
Handle of TDI drum	3	TDI Present 	TDI >0.02 ppm 
Chemical weight scale	4	TDI Present 	TDI >0.02 ppm 
Machine panel	5	TDI Present 	TDI >0.02 ppm 
Stool next to machine panel	6	TDI Trace 	ND 
Side of foam molding tank	7	TDI Present	TDI >0.02 ppm
Edge of SW exit door	8	ND	ND
Edge of molding tank	9	TDI Present	TDI >0.02 ppm

Toluene diisocyanate 0.02 detector tubes are specialized and sophisticated tubes that require 25 strokes. The standard deviation is ± 30 %. Before the measurement, the lower reagent ampoule was broken and the liquid was transferred to the indication layer, resulting in the color changing to yellow. Next, the upper reagent ampoule was broken, and the liquid was transferred to the indication layer so that it returned to a white color. After performing 25 pump strokes, the sampling professional had to wait for 15 minutes before evaluating the indication. After that, the discoloration was compared to the color comparison tube, as shown in Table 1.

Direct-read wipes for surface TDI detection provided on-the-spot detection of trace chemicals on surfaces. The highly sensitive wipes offer low minimum detectable limits with few, if any, known interferences. On-the-spot testing is faster and less expensive than sending samples to a lab. Although the screening methods used in this case are no replacement for the evaluation of airborne concentrations for compliance purposes, the results provided valuable information on TDI concentrations in air at specific times and locations. Moreover, surface sampling demonstrated the advantages of using the direct-reading technique to evaluate on-the-spot presence of TDI, thus preventing cross-contamination and improving procedures for the removal of the chemical from affected areas. The design enables the safety professional involved in sampling to clearly see color changes regardless of surface dirt.

For this case study, the researchers focused preliminary on the dermal exposure. The readers are encouraged to identify other occupational risks, but the authors wanted to point out the applicability of the Bowtie DRAM. The following chemicals were addressed in the study: toluene diisocyanate (TDI), tetrahydrofuran (THF), and boric acid.

Composite surface samples were collected at key locations along work areas to evaluate the risk of exposure to employees who may be required to work in specific locations for long periods and potentially come into contact with exposed surfaces. In addition, area sampling was used to identify any potential "hot spots" and areas that may require special control measures. Not surprisingly, the surfaces close to the mixing area showed the highest concentration of TDI, as shown in Exhibit 2.

Exhibit 2. TDI Sample Close to the Mixing Area

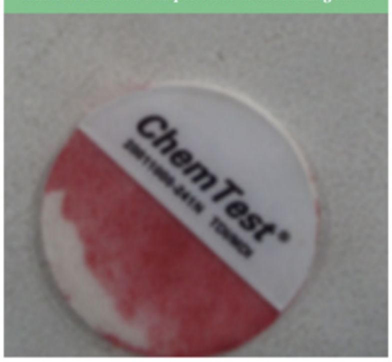


Exhibit 3. TDI Sample from the Hands and Lower Arms of the Operators

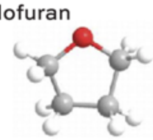
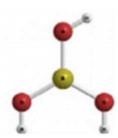
Composite dermal surface samples were collected from the hands and lower arms of the operators, as shown in Exhibit 3.

Bello et al. (2007) concluded that "Integrated animal and human research is needed to better understand the role of skin exposure in human isocyanate asthma and to improve diagnosis and prevention. In spite of substantial research needs, sufficient evidence already exists to justify greater emphasis on the potential risks of isocyanate skin exposure." Again, in this case study, the authors addressed only the skin exposure risks.

The second substance of concern was THF. Contact with THF can severely irritate and burn the skin and eyes possibly causing eye damage. Repeated contact with the skin can cause dryness, cracking, and a rash (New Jersey Department of Health and Senior Services, 2004). The third substance, boric acid, can cause irritation, redness, and pain.

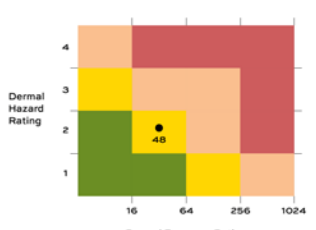
The authors proposed a new best practice model to assess the dermal exposure risks. This new model addresses the multiple chemical risks associated with the current state of mattress production. This model can be easily applied to other scenarios where multiple chemical exposures exist. The approach starts with risk identification. Using a modified OSHA Job Hazard Analysis form is shown in Fig. 5.

Figure 5. Modified OSHA Job Hazard Analysis

Task/Step/Process/ Operation	Risk Source	Current Controls	Worst Credible Consequences	Worst Case Scenario
Mixing chemicals TDI 	Chemicals/ Substances (TDI)	Hazard Communication Training and PPE	Tissue damage	Disability - eye damage/ blindness or skin burn
Mixing chemicals (tetrahydofuran (THF)) 	Chemicals/ Substances (THF)	Hazard Communication Training and PPE	Tissue damage	Contact can severely irritate and burn the skin and eyes with possible eye damage. Repeated skin contact can cause dryness, cracking and a rash.
Boric Acid 	Chemicals/ Substances (BA)	Hazard Communication Training and PPE	Irritation, redness, and pain	Erythema

Next, the latest DRAM™ was used to assess the risk involved. All three substances produced similar dermal risk assessment results under the conditions, as shown in Fig. 6.

Figure 6. Example of DRAM Practical Application for the Substances of Concern


ESSI Exposure Science and Sustainability Institute
AIHA
Deterministic Simulation

Assessment Summary Form

DRAM
Dermal Risk Assessment Model

STEP 1 **Dermal Hazard Rating** Rate with relative toxicity → Rate with GHS Code → 2

- ○ 1 - Reversible or very low skin or systemic toxicity
- ◉ 2 - Moderate but reversible skin or system toxicity
- ○ 3 - Irreversible/chronic skin or systemic toxicity or sensitization
- ○ 4 - Life threatening skin or systemic toxicity or sensitization or corrosivity

STEP 2 **Dermal Exposure Rating**

2.1 Dermal Contact Area — 3
- ○ Unexpected/unlikely
- ◉ Contact possible to hands and forearms
- ○ Very small area of skin contact
- ○ Contact possible to significant area of skin

2.2 Dermal Concentration or Loading — 2
- ○ Negligible concentration of agent likely to contact or load onto the skin
- ○ Moderate concentration of agent likely to contact or load onto the skin
- ◉ Low concentration of agent likely to contact or load onto the skin
- ○ High concentration of agent likely to contact or load onto the skin

2.2 Dermal Contact Frequency — 2
- ○ Minimal contact with skin; one or two incidental contacts; contact during less than 5% of task
- ○ Up to 50 incidental contacts with skin; contact during less than 50% of task
- ◉ Up to 10 incidental contacts with skin; contact during less than 10% of task
- ○ Routine incidental contact with skin throughout shift; contact during 50-100% of task

2.4 Dermal Retention Time — 2
- ○ Amount transferred unlikely to remain on skin for any period of time (i.e., high volatility, dry and powdery)
- ◉ Amount transferred may remain on skin for some time (i.e., some volatility or adherence to skin)
- ○ Amount transferred is likely to remain on skin for a significant period of time (i.e., low volatility, high MW, sticky or consolidated on skin even if not visible)
- ○ Amount transferred very likely to remain on skin (i.e., substance not volatile, MW > 100, substance very likely to stick to skin)

2.5 Dermal Penetration Potential — 2
- ○ Not likely (large, insoluble particles)
- ◉ Low potential (small insoluble particle > 1 micron in size, or both poor lipid solubility and poor water solubility)
- ○ Possible or slow (very small insoluble particles < 1 micron, or some lipid solubility and some water solubility, or marginal skin health)
- ○ Probable or likely (good lipid solubility and good water solubility, or poor skin health)

STEP 3 **Results**

Exposure Rating = CA * C * CF * RT * PP = 48

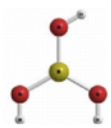
Category "Yellow"
Medium Risk

Version: 1.00, February 2022

This file was created by Jennifer Sahmel, Susan F. Arnold, Daniel Drolet and Thomas W. Armstrong

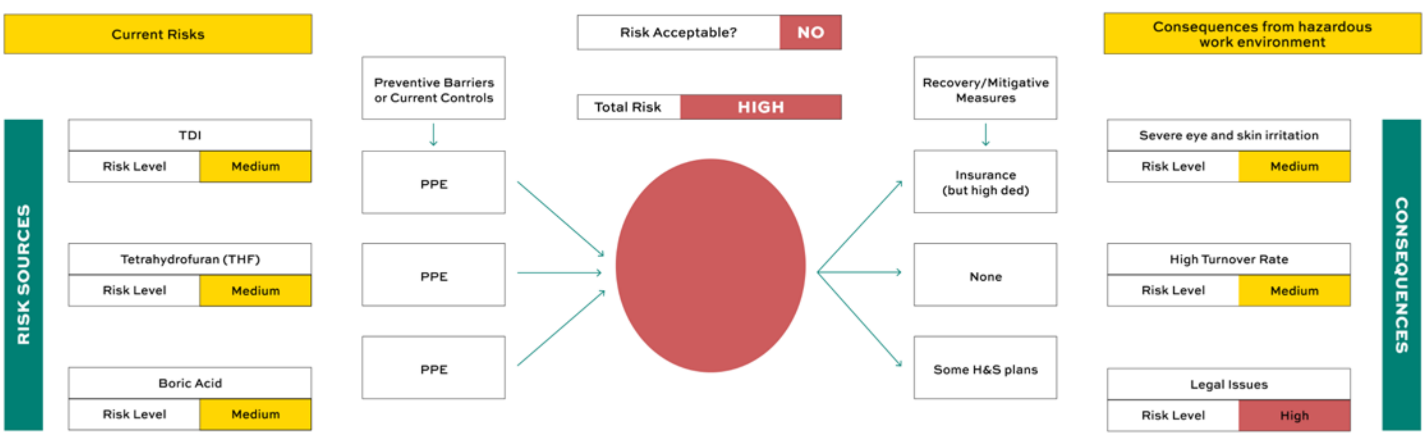
All three substances were estimated to fall in the "Medium Risk" category. The results were transferred to the qualitative job risk assessment form, as shown in Fig. 7.

Figure 7. Qualitative Job Risk Assessment

Task/Step/Process/ Operation	Risk Source	Current Controls	Worst Credible Consequences	Worst Case Scenario	Dermal Risk Level	Acceptable Risk?
Mixing chemicals TDI 	Chemicals/ Substances (TDI)	Hazard Communication Training and PPE	Tissue damage	Disability - eye damage/ blindness or skin burn	Medium	No
Mixing chemicals (tetrahydofuran (THF)) 	Chemicals/ Substances (THF)	Hazard Communication Training and PPE	Tissue damage	Contact can severely irritate and burn the skin and eyes with possible eye damage. Repeated skin contact can cause dryness, cracking and a rash.	Medium	No
Boric Acid 	Chemicals/ Substances (BA)	Hazard Communication Training and PPE	Irritation, redness, and pain	Erythema	Medium	No

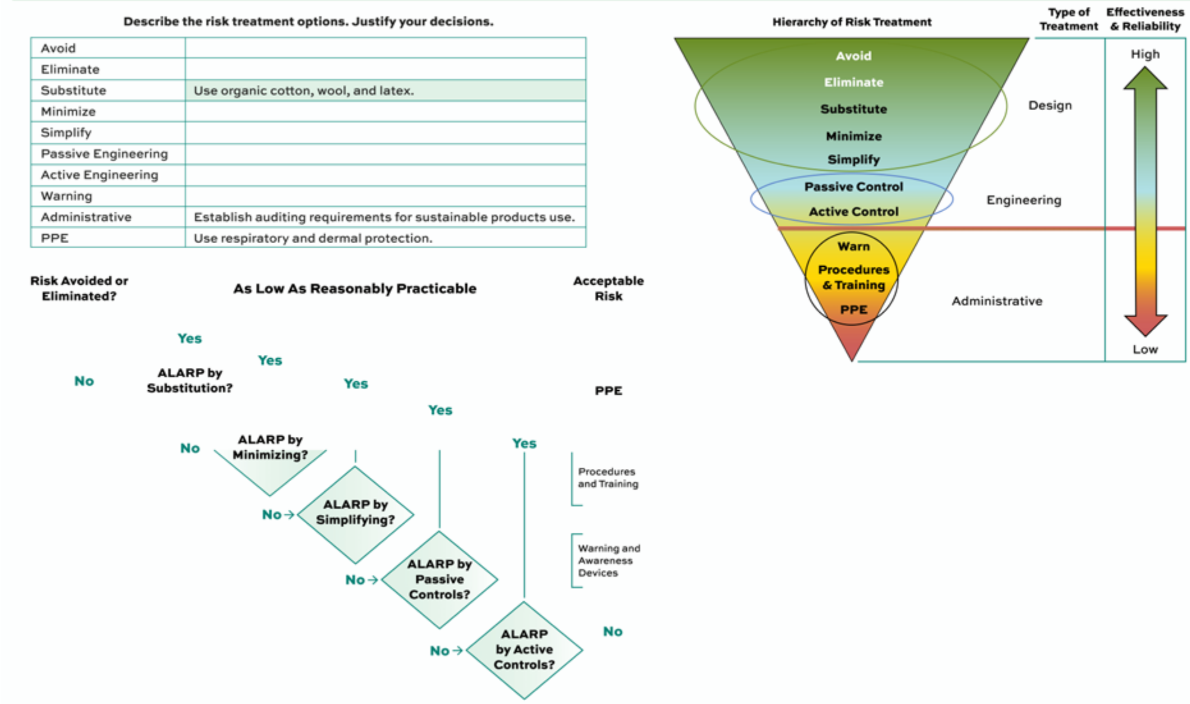
The readers will notice that most of the risk assessment methods are linear. In a way, most of the current methods don't address the risk summation or additive/synergistic effects of multiple chemical exposures. Therefore, the Bowtie DRAM was developed. The risk levels are derived from the DRAM tool. The estimated risk levels hyperlinked to the Bowtie DRAM are shown in Fig. 8.

Figure 8. Bowtie Dermal Risk Assessment Model



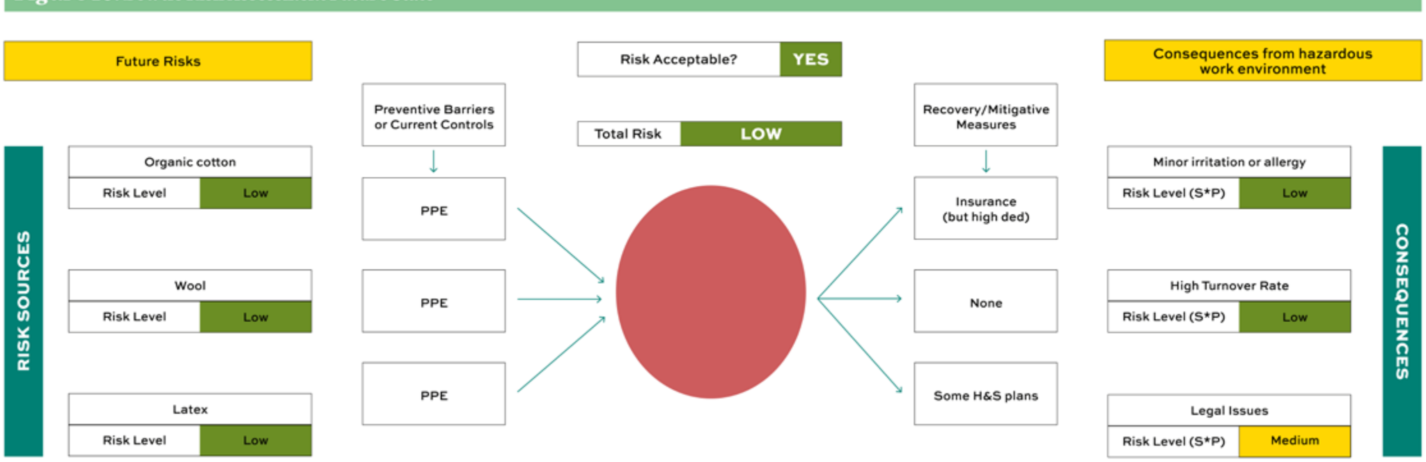
The readers will notice that all three substances are estimated as "Medium Risk," but the total risk is estimated as "High" risk category. That is due to the possibility of TFH skin contact causing skin cracking and a rash. In such cases, TDI and boric acid can cause severe skin diseases, disorders, or even enter the bloodstream. Obviously, such dermal risk will not be considered an acceptable level of risk. Therefore, the risk has to be reduced using the Hierarchy of Risk Treatment (HoRT), as shown in Fig. 9.

Figure 9. HoRT Practical Application



If the toxic chemicals used in the manufacturing process are substituted with less toxic substances, risk re-assessment shall be performed, as shown in Fig. 10. In this case, it can be suggested to substitute TDI, THF, and boric acid, currently used with organic cotton, wool, and organic latex.

Figure 10. Bowtie Risk Assessment Future State



4. Conclusion

Substitution with less toxic substances is not always possible. In addition, the Occupational and Environmental Health and Safety (OEHS) professionals have to consider new risks introduced to the process. For instance, eco-friendly mattresses may have to be reinforced with carbon nanotubes. This introduces new risks that will have to be re-assessed.

This research project clearly demonstrates that field sampling methods can be used to quickly estimate the risk of toxic substances exposures. However, due to the sample size and the uniqueness of the case study, the presented methodology can be applied in a different manufacturing environment to further validate the Bowtie DRAM. This methodology saves time and shipping, and sometimes, it is the only available option. In addition, the newly developed Bowtie DRAM allows for risk summation estimation.

4.1 Benefits

- OESH Risk Reduction
- Reduced turnover rate
- Fewer legal issues
- Improved company reputation

The Bowtie Dermal Risk Assessment Model is a useful tool for risk summation estimation. It can be used as a supplement to the DRAM tools. HoRT ranks the effectiveness of various risk reduction interventions in order, starting with avoidance, elimination, substitution, minimization, simplification, engineering, warning, and then administrative and personal protection controls.

It is likely that combinations of different DRAM tools will be needed to properly communicate the dermal exposure risks.

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Table SNR07, Illness Cases by Category of Illness - Rates, Counts, and Percent - Industry Division – 2015, *U.S. Bureau of Labor Statistics*, 2015.

Table SNR07, Nonfatal Occupational Illnesses by Major Industry Sector and Category of Illness, *U.S. Bureau of Labor Statistics*, from https://www.bls.gov/.../nonfatal...illnesses-tables/.../supplemental-table-7-20... www.bls.gov › iif › supplemental-table-7-2017-national, 2017.

Table SNR07, Nonfatal Occupational Illnesses by Major Industry Sector and Category of Illness,*U.S. Bureau of Labor Statistics*, from https://www.bls.gov/.../nonfatal...illnesses-tables/.../supplemental-table-7-20... www.bls.gov › iif › supplemental-table-7-2017-national, 2017.

U.S. Department of Labor, Dermal Exposure – Overview, Occupational Safety and Health Administration, from https://www.osha.gov/dermal-exposure#:~:text=In%202018*%2C%2025%2C000%20recordable%20skin,1.7%20illnesses%20per%2010%2C000%20employees, 2018.

Does Osha's Injury Tracking Application Data Provide Reliable Representation of U.S. Company Injury And Illness Metrics?

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Mike Wolff | Graduate Student, University of Wisconsin-Whitewater

Abstract

The Occupational Safety and Health Administration (OSHA) requires employers to investigate and document injury and illness cases in recordkeeping forms and recommends annual calculation of incidence rates as a measure of their safety program performance. Recent research literature calls into question the reliability and validity of OSHA recordkeeping data and its subsequent incidence rates (Hallowell, 2023).

The objectives of this study are to investigate the consistency and reliability of OSHA's Injury Tracking Application (ITA) datasets and their relationship to the U.S. Bureau of Labor Statistics (BLS) incidence rates (Survey of Occupational Injury and Illness [SOII] reports, n.d.). Descriptive statistics tables and annual incidence rate charts for OSHA ITA datasets collected in 2016-2022 raised concerns about entry errors. Therefore, a three-step corrective/reductive analysis was employed to reduce those errors. The average number of entries removed per year was 12.9% (ranging from 10.6% to 14.3%). The corrective steps greatly improved the consistency and reliability of the dataset and reduced variable standard deviations. The most impacted/reduced variables were total employees (76.5%), total hours worked (46.7%), hours worked per employee (95.2%), and percent of zero injury reports (6.3%). The number of cases and days reported only reduced by an average of < 2.5%. These results are very different than the commonly proposed "under-reporting" issues for OSHA recordkeeping and BLS SOII reports. This study found that over-reporting of hours worked, or number of employees, caused most of the inconsistencies in incidence rate representation.

Implications from this study indicate that the OSHA ITA system needs better management to improve employer self-reported 300A data. The validity and reliability of BLS SOII rates are also questioned and demand further investigation.

KEY WORDS: *OSHA injury tracking application, OSHA recordkeeping data, safety metrics, lagging indicators, incidence rates*

1. Introduction

Environmental health and safety (EHS) professionals are required by the Occupational Safety and Health Administration (OSHA) to investigate, document, track, and possibly report safety and health incidents that occur as part of assigned work. OSHA injury and illness recordkeeping data has long been the primary source for safety performance measurements for an organization's safety program. Many organizations focus on injury and illness incidence rates and set annual safety program performance goals of zero lost time cases or a maximum incidence rate. The two primary injury and illness rate calculations used by EHS professionals and OSHA are the total recordable incident rate (TRIR) and days away, restricted, and transfer (DART) incidence rate.

The emphasis on OSHA recordable measures has greatly influenced the EHS profession for decades. Unfortunately, organizations focus too much on these rates and comparisons to similar industry averages. This results in efforts to look better than they should, typically resulting in under-reporting recordable injuries. Achieving below-average injury rates can lead to winning bids on projects and prestigious safety awards. Prospective suppliers and business partners may request a company's TRIR or DART to evaluate their safety program as part of their business decision. This creates additional motivation for companies to under-report or reclassify incident cases to achieve lower injury and illness rates (Avetta, n.d.).

Many EHS professionals are evaluated by their employers based on the performance of the safety program they manage. It has long been assumed that OSHA recordkeeping measures are a direct result of a safety manager's efforts and influence on the organization. Due to these pressures to lower TRIR and DART data, many EHS professionals may not be accurately reporting TRIR and DART rates or unjustly reclassifying injury and illness cases as non-recordable. By hiding true injury and illness data or not completing effective incident investigations, risks or causes of injuries are not being prevented, and organizations will be at greater risk of major incidents or disasters. Further, the employer may not be aware of reportable events that occurred because some workers do not report incidents due to concerns of losing their job or other opportunities such as a raise or promotion.

The TRIR metric, typically referred to as the "Recordable Rate," is calculated by:

$$\textbf{TRIR} = \frac{\text{(Number of OSHA recordable cases, Columns H+I+J of 300 log) x 200,000}}{\text{(Total number of hours worked)}}$$

The DART rate, which represents a higher severity injury metric, is determined by:

$$\textbf{DART} = \frac{\text{(Number of Lost-time cases, Columns H+I of 300 log) x 200,000}}{\text{(Total number of hours worked)}}$$

According to BLS (2019), the TRIR and DART rate provides direct insight into a company's past safety performance. The term "OSHA recordable" is basically what OSHA defines as an injury or illness that meets published criteria as it causes harm beyond first aid treatment (29 CFR 1904.7). Injury and illness incidents are investigated and, if deemed recordable, are entered into the OSHA recordkeeping forms 301, 300, and eventually 300A. Employers with fewer than 11 employees and certain low-risk industries are partially exempt from OSHA's recordkeeping requirements (OSHA c.; OSHA d.). The list of partially exempt industries is based on the 2007 NAICS codes.

Since 2016, most employers required to keep OSHA forms must upload their 300A form data to the OSHA ITA. OSHA provides annual 300A data from the ITA site as downloadable files (CSV or MS Excel). This information is meant to help EHS professionals, researchers, academics, and OSHA evaluate the safety of a workplace, understand industry hazards, and implement worker protections to reduce and eliminate hazards—preventing future workplace injuries and illnesses (OSHA a.) The creation of the ITA, along with the BLS SOII report, creates an opportunity to compare what should be duplicate datasets (OSHA b.).

Businesses measure safety to make crucial, data-driven decisions to improve plant and construction safety management. The traditional approaches to measuring safety have been TRIR, DART, and fatality rates, which are driven by OSHA guidelines and industry experts. Researchers have started questioning the validity of OSHA data and numbers when comparing their organizations to OSHA TRIR and DART data (Hallowell, 2023). Therefore, many organizations' safety professionals are urging others to look into true and accurate means of measuring safety performance, such as leading indicators (Oguz Erkal et al., 2023). The old adages "Garbage in, garbage out" and "The truth will set you free" come to mind when gathering and analyzing OSHA average numbers. But even BLS and OSHA admit to underreporting injury data as an issue. An evaluation of recordkeeping performance during OSHA's national emphasis postulated that an up to 66% error rate in injury reporting is possible (Fagan and Hodgson, 2017). Based on these findings, the use of TRIR and DART can determine if there is additional evidence of underreporting and a possible correlation. Many safety professionals struggle to show how OSHA recordkeeping requirements lead to employers hiding or underreporting injuries (Wuellner and Bonauto, 2014). Completeness of data, along with accuracy and validity, are of crucial importance when dealing with national data. Studies have shown that incomplete data and an unclear data management process will result in poor decisions made by organizations (Kilkenny and Robinson, 2018).

Research literature increasingly demonstrates that safety program performance is not purely determined by severe injuries or recordable injury cases (Lander et al., 2011). Many studies have identified several employer misconceptions and non-compliant practices related to the OSHA record-keeping requirements (Fagan and Hodgson, 2017). The focus should be on what matters— preventive measures for safety. According to research studies, companies would rather under-report injuries to OSHA and avoid inspections (Manjourides and Dennerlein, 2019). Previous research has shown that up to 70% of the OSHA log can be under-reported (Rosenman et al., 2006). Many studies have identified several employer misconceptions and non-compliant practices related to the OSHA record-keeping requirements (Fagan and Hodgson, 2017).

This study's objectives are to determine:

1. If the OSHA ITA annual data contains minimal self-reported errors.
2. If the OSHA ITA annual data is comparable to BLS SOII data.

2. Methods

This study is historical research or historiography, which attempts to systematically recapture the complex nuances, the people, meanings, events, and even ideas of the past that have influenced and shaped the present (Berg and Lure, 2012). The analytical methods used for this study are primarily quantitative, with some qualitative assessment of annual trends. The public data files are available through the OSHA ITA and the BLS SOII reports. OSHA ITA data from 2016-2022 was downloaded to Microsoft Excel spreadsheets for storage and analysis. Data mined from BLS SOII reports were added to the results spreadsheets created by the OSHA ITA analyses.

2.1 Study Design

This study design is ex post facto and relies on historical public records created and managed through federal government-funded agencies. The public records were collected by self-reporting of OSHA recordkeeping data by two separate (but similar) systems (Brent and Leedy, 1990). An Institutional Review Board (IRB) approval was not required because no human subjects were involved, and the downloaded data is considered a secondary analysis. All data used in this study is publicly available through the U.S. Department of Labor website.

The study population is organizations mandated to report (or upload) their annual 300A data to OSHA as part of the ITA program. Organizations excluded from this study include those exempt from OSHA recordkeeping requirements, locations outside of the U.S., and non-participants in the OSHA ITA program. A primary example of excluded populations are organizations with 10 or fewer employees and special industries under 29 CFR 1904.2. It should be noted that all organizations must report to OSHA any workplace incident that results in an employee's fatality, in-patient hospitalization, amputation, or loss of an eye, but that is a separate report system from the OSHA ITA.

2.2 Variables and Measures

The two primary study variables are TRIR and DART, which were calculated from the OSHA ITA databases (Brent and Leedy, 1990). In 2024, OSHA overhauled the format of its website to make ITA data access easier for the public and include other OSHA 301 and 300 form data (OSHA b.)

It is important to note that within the new OSHA ITA data page, OSHA refers to potential quality issues within their datasets. In addition, the data should not be used as a sole source of measuring safety program performance. OSHA's statement on data quality is:

> *"While OSHA takes multiple steps to ensure the data collected are accurate, problems and errors invariably exist for some establishments." "Efforts are made during the collection cycle to correct submission errors; however, some remain unresolved." "OSHA does not validate the employee or injury and illness counts reported by establishments."*
> *"Concluding that establishments are the "most dangerous" or the "least dangerous" solely based on whether they have the highest or lowest rates from these data would be inappropriate." (Occupational Safety and Health Administration, n.d.).*

The variable classifications were derived from the ITA Summary Data Dictionary. From the original OSHA ITA data, spreadsheet "heading row" variables were downloaded into Microsoft Excel spreadsheets. Those key variables include total number of entries, total number of employees, total hours worked, maximum of reported total hours, percent of zero injuries reported, total number of fatalities, total days away from work (DAFW), total days of job transfer for restriction (DJTR) cases, total other cases, total injuries, and a simple calculation of TRIR, DART, and fatality rates.

During data analyses, additional variables and criteria were defined and included to seek to understand errors in the data. These variables include hours worked per full-time equivalency (FTE) employees and TRIR and DART calculations based on individual entries vs. overall determinations.

The BLS SOII reports were manually reviewed, and data was captured to be compared to OSHA ITA data. Variable categories collected from BLS include TRIR, DART, and fatality counts and rates from 2016 to 2022.

2.3 Data Collection

Data was downloaded directly from the OSHA website into MS Excel files. BLS SOII data was entered manually into MS Excel files. Possible confounding variables such as "COVID-19-year 2020" were analyzed and accounted for. Although errors and discrepancies were identified during the analysis, these were not deemed confounding variables due to it being the focus of the study.

2.4 Data Analysis

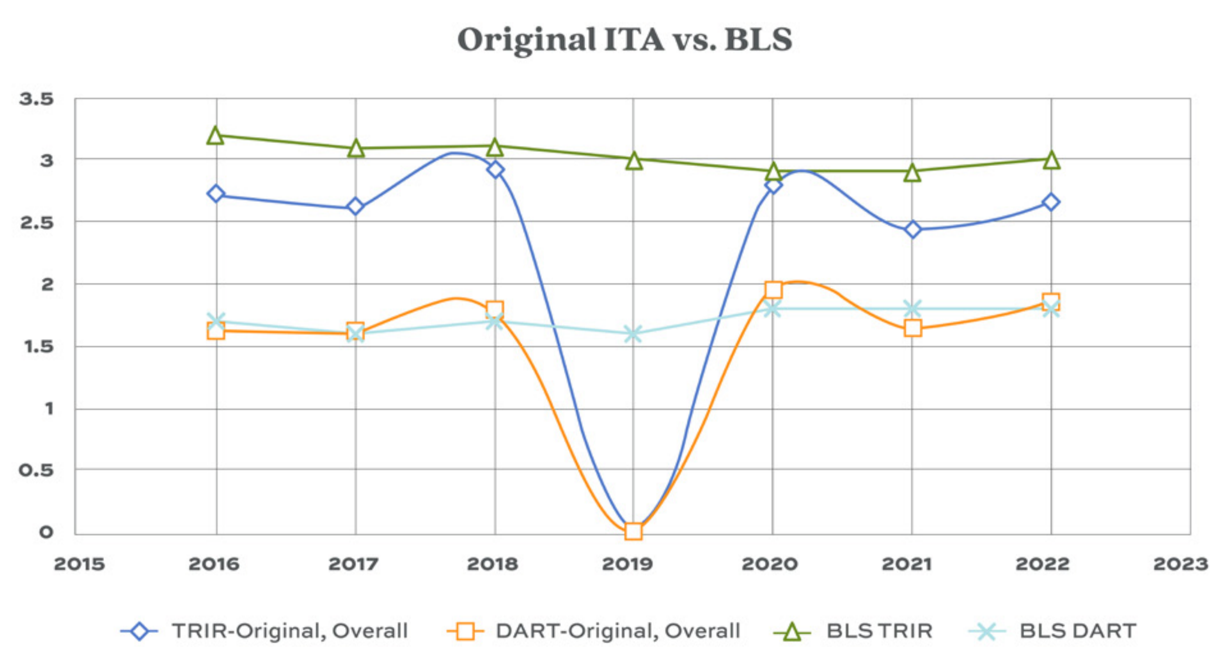
The ITA CSV file for each year was converted into an MS Excel worksheet. Each year's data was analyzed in its own MS Excel document, and each step of the analysis was performed in its own tab. The overall TRIR and DART were calculated using the total sum of injury and illness cases with the overall total hours worked. Initial attempts to calculate the hours worked per employee (dividing hours worked by the number of employees for each individual entry) indicated an issue/error due to reporting either zero hours worked or zero employees. This also prevents the calculation of individual TRIR and DART averages and medians. Table 1 indicates anomalies observed during this initial assessment. Thus, all the datasets were re-analyzed to make corrections to these errors.

Table 1. Summary of Original OSHA ITA Descriptive Statistics, 2016-2022

Descriptive Statistics, Original Download	2016	2017	2018	2019	2020	2021	2022
Total number of entries	214,978	259,758	289,534	290,475	293,391	307,902	346,799
Total number of employees	1.07E+08	1.32E+08	1.28E+08	68,831,041	7.28E+08	2.89E+09	2.47E+08
Total hours worked	7.75E+10	9.24E+10	9.37E+10	1.7E+13	1.02E+11	1.2E+11	1.29E+11
Percent zero injuries report	34.36%	33.95%	34.04%	33.25%	38.47%	38.20%	38.28%
Total fatality number	608	736	785	793	1,501	1,139	946
Total DAFW cases	311,838	380,628	424,194	431,540	645,345	609,019	773,361
Total DJTR cases	316,647	366,768	414,715	419,902	343,584	383,767	423,076
Total other cases	428,045	469,072	527,911	521,279	433,160	471,207	519,797
Total DAFW days	11,427,294	15,466,481	15,422,619	15,749,414	20,872,446	18,713,314	21,844,550
Total DITR days	15,405,035	21,806,093	24,114,990	24,893,467	20,743,857	24,076,479	1.01E+08
Total injuries	997,644	1,139,528	1,285,043	1,292,564	1,070,712	1,207,949	1,333,930
Total illnesses	58,886	76,940	81,777	80,157	351,377	256,044	382,304
Overall TRIR	2.73	2.63	2.92	0.02	2.79	2.44	2.66
Overall DART	1.62	1.62	1.79	0.01	1.94	1.65	1.85
Overall fatality rate	1.57	1.59	1.68	0.01	2.94	1.9	1.47
BLS TRIR	3.2	3.1	3.1	3.0	2.9	2.9	3.0
BLS DART	1.7	1.6	1.7	1.6	1.8	1.8	1.8
BLS fatality rate	3.6	3.5	3.5	3.5	3.4	3.6	3.7

While visually reviewing Table 1, an obvious error is found under the 2019 column. The total hours worked in 2019 were 1,000 times greater than the previous year, and overall TRIR and DART for 2019 were 0.02 and 0.01 DART, respectively. It is unreasonable to think that this is achievable for an industry average when compared to 2016, 2017, 2018, and 2020. In addition, the OSHA ITA database shows over a trillion hours worked per employee for a single entry in 2019. This is an obvious error. At the very beginning of the study, it was determined by researchers to pursue a deeper analysis of the "hours worked" entries and how it may affect the calculation and presentations of TRIR and DART.

Figure 1. Original OSHA ITA TRIR and DART rates vs. BLS rates



Subsequently, a graph (Fig. 1) of TRIRs and DARTs for this data vs. BLS was created, further demonstrating that the original OSHA ITA dataset(s) may have inconsistencies and errors in its entries. To investigate these concerns, the following corrections were applied to all OSHA ITA spreadsheets:

1. Remove entries with either zero employees or zero hours worked.
2. Remove unreasonably low entries: <11 employees, <1,000 total hours worked per year, and <100 hours worked per employee per year.
3. Remove unreasonably high entries: >3,250 hours worked per employee per year, and >500 TRIR.

Corrective Step 1 — Sorting by "DIV/0!" results under column header "HR/FTE".

Employers reporting 0 employees and/or 0 hours worked caused the calculation of individual entry HR/FTE to result in an error, which MS Excel expresses as "DIV/0!". This basically means the equation in that cell had a zero in the denominator. For the OSHA ITA data, if an organization self-enters "zero hours worked" or "zero employees," they shouldn't be uploading data to the system (or OSHA's ITA should catch the error and seek resolution). Table 2 displays the updated results after the removal of obvious data entry errors that consisted of zero employees with zero hours worked.

Table 2. Summary of Corrected OSHA ITA Descriptive Statistics, after Removal of Zero Employees or Zero Hours Worked Entries

Descriptive Statistics, Removed Division by Zero	2016	2017	2018	2019	2020	2021	2022
Original total number of entries	214,978	259,758	289,534	290,475	293,391	307,902	346,799
Total number of entries	213,448	259,278	288,845	289,856	292,242	306,649	345,431
# removed	1,530	480	689	619	1,149	1,253	1,368
Total number of employees	1.067E+08	1.324E+08	1.281E+08	6.883E+07	7.282E+08	2.893E+09	2.467E+08
Total hours worked	7.746E+10	9.239E+10	9.369E+ 10	1.704E+13	1.020E+11	1.200E+ 11	1.291E+11
Percent zero injuries reported	33.90%	33.83%	33.89%	33.18%	38.24%	37.95%	38.06%
Total fatality number	608	736	785	792	1,501	1,139	944
Total DAFW cases	311,808	380,574	424,161	431,117	645293	608,988	773,245
Total DJTR cases	316,605	366,707	414,677	419,338	343,579	383,755	423,028
Total other cases	427,983	468,943	527,836	520,269	433,144	471,113	519,631
Total DAFW days	11,424,217	15,357,902	15,421,670	15,740,101	20,870,125	18,711,896	21,839,235
Total DJTR days	15,403,798	21,766,723	24,113,261	24,866,700	20,742,658	24,075,814	100,688,462
Total injuries	997,539	1,139,284	1,284,922	1,290,613	1,070,642	1,207,885	1,333,620
Total illnesses	58,857	76,940	81,752	80111	351,374	255,971	382,284
TRIR	2.73	2.63	2.92	0.02	2.79	2.44	2.66
DART	1.62	1.62	1.79	0.01	1.94	1.65	1.85
Fatality rate	1.57	1.59	1.68	0.01	2.94	1.90	1.46
BLS TRIR	3.2	3.1	3.1	3.0	2.9	2.9	3.0
BLS DART	1.7	1.6	1.7	1.6	1.8	1.8	1.8
BLS fatality rate	3.6	3.5	3.6	3.7	3.4	3.6	3.7
Average hours per FTE by entry	2,450.8	2,755.5	2,471	8,302,985.7	2,681.2	3,094.7	4,277.8
Average hours per FTE median	1,837.5	1,825.4	1,830	1,811	1,800.9	1,804.4	1,806.5
Average hours per FTE S.D.	20,091	59,057	74,619.1	4.466E+09	99,269.8	128,349.7	476.1
Max average hours per FTE	2.946E+06	1.931E+07	2.365E+07	2.405E+12	3.346E+07	4.316E+07	1.527E+08
TRIR average by entry	15.32	20.00	15.68	15.22	13.02	22.07	25.07
TRIR median	2.75	2.90	2.90	2.88	2.33	2.41	2.36
TRIR S.D.	1,652.16	4,007.16	1,720.69	2,035.43	908.02	5,602.70	3,216.86
TRIR percent zero	33.93%	33.88%	33.90%	33.21%	38.27%	37.99%	38.09%
DART average by entry	8.88	9.43	7.95	6.69	9.02	15.75	12.13
DART median	0.86	0.95	0.99	1.08	0.63	0.66	0.58
DART S.D.	1,001.06	1,051.94	819.61	481.95	555.13	3,879.53	1,298.78
DART percent zero	45.51%	45.51%	45.15%	44.28%	47.81%	47.69%	48.01%

Corrective Step 2 — Sorting "Number of Employees" column by low to high, then sorting "Hours Worked" by low to high, and sorting "HRS/FTE" by low to high.

The next step consisted of three sorting tasks and the removal of unrealistic "low categories." This began with removing entries with fewer than 11 employees. After removing all entries with fewer than 11 employees reported, it was determined that 1,000 hours per year, or an equivalent of 100 hours per employee, was the absolute minimum that could be accepted and should include most (if not all) consulting projects or emergency response projects which take over

Table 3. Summary of Corrected OSHA ITA Descriptive Statistics, after Removal of <11 Employees, <1,000 Hours Worked, <100 Hours Worked per FTE Entries

Descriptive Statistics, Removed Low Entries	2016	2017	2018	2019	2020	2021	2022
Original total number of entries	214,978	259,758	289,534	290,475	293,391	307,902	346,799
Remaining number of entries	188,837	229,512	256,218	262,497	256,713	272,544	301,198
Total # entries removed	26,141	30,246	33,316	27,978	36,678	35,358	45,601
Total number of employees	3.076E +07	3.455E +07	3.818E+07	3.950E+07	3.703E +07	3.908+07	4.347E+07
Total hours worked	7.718E+ 10	9.200E+ 10	9.334E+ 10	2.072E+11	1.016E+11	1.149E+11	1.276E+ 11
Percent zero injuries reported	27.36%	27.62%	27.76%	28.20%	31.87%	32.18%	31.34%
Total fatality number	601	717	771	779	1,468	1,112	923
Total DAFW cases	308,760	376,081	419,244	427,301	638,688	603,986	766,795
Total DJTR cases	314,135	363,814	411,857	416,934	340,910	381,674	420,731
Total other cases	423,933	463,478	522,851	516,568	429,308	467,083	514,409
Total DAFW days	11,321,098	15,195,429	15,267,372	15,612,746	20,689,090	18,562,284	21,665,090
Total DJTR days	15,297,935	21,633,181	23,987,351	24,741,471	20,609,995	23,969,616	100,576,228
Total injuries	988,718	1,127,195	1,273,090	1,281,286	1,060,263	1,198,452	1,322,509
Total illnesses	58,110	76,178	80,862	79,517	348,643	254,291	379,426
TRIR	2.71	2.62	2.90	1.31	2.77	2.53	2.67
DART	1.61	1.61	1.78	0.81	1.93	1.72	1.86
Fatality rate	1.56	1.56	1.65	0.75	2.89	1.93	1.45
BLS TRIR	3.2	3.1	3.1	3.0	2.9	2.9	3.0
BLS DART	1.7	1.6	1.7	1.6	1.8	1.8	1.8
BLS fatality rate	3.6	3.5	3.6	3.7	3.4	3.6	3.7
Average hours per FTE by entry	2,445.6	2,713.4	2,488.9	7,153.5	2,735.5	2,977.4	3,496.6
Average hours per FTE median	1,826.3	1,832.4	1,821.3	1,811.0	1,795.4	1,794.0	1,808.5
Average hours per FTE S.D.	20,455.8	60,574.0	79,149.6	552,651.9	105,629.9	107,485.3	294,863.8
TRIR average by entry	4.92	5.19	5.11	4.96	5.29	5.20	5.56
TRIR median	3.25	3.4	3.39	3.26	2.93	2.96	2.97
TRIR S.D.	9.16	10.92	11.12	8.15	9.96	12.13	12.58
TRIR percent zero	27.39%	27.68%	27.77%	28.24%	31.90%	32.22%	31.38%
DART average by entry	2.96	3.21	3.18	3.12	3.69	3.54	3.90
DART median	1.39	1.49	1.52	1.48	1.32	1.30	1.32
DART S.D.	6.33	6.29	5.73	6.11	8.30	8.73	10.16
DART percent zero	39.78%	40.13%	39.76%	39.91%	42.21%	42.57%	42.05%

Corrective Step 3 — Sorting "HRS/FTE" column by high to low, then sorting "TRIR" by high to low.

The third (and final) correction consisted of two sorting tasks and the removal of unrealistically "high categories." The first step was performed on "Hours Worked per Employee (HRS/FTE)" sorting from "High to Low" and removing any entry with more than 3,250 hours. This limit was determined based on 62.5 hours per week for an entire year. The researchers believed this to be reasonable considering some projects or industries require over 150% of the typical 40-hour work week. The final task in this correction was sorting the TRIR from "High to Low." The researchers decided to be very conservative and accept a TRIR of 500 or less (or 500 recordable cases per 100 FTE).

Table 4. **Summary of Corrected OSHA ITA Descriptive Statistics, after Removal of >3,250 Hours Worked per FTA and >500 TRIR Entries**

Descriptive Statistics, Removed High Entries	2016	2017	2018	2019	2020	2021	2022
Original total number of entries	214,978	259,758	289,534	290,475	293,391	307,902	346,799
Total number of entries	186,001	226,621	253,007	259,595	253,498	268,111	297,350
Total # entries removed	28,977	33,137	36,527	30,880	39,893	39,791	49,449
Total number of employees	3.038E+07	3.416E+07	3.779E+07	3.908E+07	3.668E+07	3.862E+07	4.301E+07
Total hours worked	5.233E+10	5.908E+10	6.544E+ 10	6.676E+10	6.178E+ 10	6.527E+10	7.267E+10
Percent zero injuries reported	27.40%	27.64%	27.78%	28.22%	31.90%	32.09%	31.37%
Total fatality number	586	691	751	755	1,450	1,087	895
Total DAFW cases	303,486	370,065	412,671	421,968	629,996	594,241	754,853
Total DJTR cases	309,293	357,604	406,428	412,841	337,083	376,631	415,427
Total Other cases	416,571	456,479	515,238	509,893	423,526	460,287	505,228
Total DAFW days	11,139,657	14,980,303	15,026,658	15,417,230	20,447,046	18,281,880	21,348,726
Total DJTR days	15,104,503	21,383,694	23,769,456	24,529,821	20,442,395	23,740,796	100,137,873
Total injuries	972,177	1,109,096	1,254,900	1,266,224	1,046,790	1,181,467	1,301,209
Total illnesses	57,173	75,052	79,437	78,478	343,815	249,692	374,299
TRIR	3.93	4.01	4.08	4.03	4.50	4.39	4.61
DART	2.34	2.46	2.50	2.50	3.13	2.97	3.22
Fatality rate	2.24	2.34	2.30	2.26	4.69	3.33	2.46
BLS TRIR	3.2	3.1	3.1	3.0	2.9	2.9	3.0
BLS DART	1.7	1.6	1.7	1.6	1.8	1.8	1.8
BLS fatality rate	3.6	3.5	3.6	3.7	3.4	3.6	3.7
Average hours per FTE by entry	1,742.7	1,739.7	1,730.6	1,722.9	1,699.8	1,683.6	1,720.9
Average hours per FTE median	1,815.3	1,824.2	1,813.1	1,811	1,788.4	1,782.6	1,800.8
Average hours per FTE S.D.	492.9	493.6	502.1	497.2	492.0	537.0	477.5
TRIR average by entry	4.93	5.19	5.12	4.98	5.31	5.22	5.56
TRIR median	3.30	3.44	3.43	3.29	2.97	3.03	3.02
TRIR S.D.	7.65	7.94	7.74	7.46	9.43	9.33	10.27
TRIR percent zero	27.43%	27.70%	27.79%	28.25%	31.94%	32.12%	31.40%
DART average by entry	2.97	3.21	3.19	3.14	3.70	3.56	3.89
DART median	1.42	1.52	1.55	1.51	1.35	1.35	1.35
DART S.D.	5.20	5.75	5.37	5.4	7.76	7.51	8.54
DART percent zero	39.82%	40.17%	39.80%	39.91%	42.24%	42.48%	42.09%.

3. Results

The study objectives (and hypotheses) focused on the consistency and reasonability of OSHA's ITA annual datasets, both on its own and as a comparison to BLS reports. Significant and noteworthy discrepancies were noted in the original OSHA ITA downloaded data (Table 1, Methods Section), especially in 2019 with the summed total hours worked and calculated overall TRIR and DART. Additionally, it was impossible to calculate individual entry hours worked per employee, TRIR, and DART due to "DIV/0!" errors in MS Excel. This investigation determined that some employers upload zero hours worked for the year and/or zero employees for the year, which led to the first corrective step of eliminating those entries. These discrepancies continued to be observed in the updated descriptive statistics table (Table 2, Methods Section). Two additional corrective steps were applied to render a final table of descriptive statistics (Table 4, Methods Section) that displayed some consistency from year to year with less variance over time.

3.1 How Did the Corrections Affect the Overall Datasets and Descriptive Statistics?

Table 5 displays the number of entries removed in each of the three corrective/reductive steps that were performed on each year's OSHA ITA data download. Table 6 displays the percentage of entries removed in each step.

Table 5. Number of Entries Removed for Each Correction

Count of Entries Removed	Average	2016	2017	2018	2019	2020	2021	2022
For DIV/O!	1,013	1,530	480	689	619	1,149	1,253	1,368
For < 11ee, < 1000Hr, < 100Hr/FTE	32,604	24,611	29,766	32,627	27,359	35,529	34,105	44,233
For >3250Hr/F TE, > 500TRIR	3,334	2,836	2,891	3,211	2,902	3,215	4,433	3,848
Total Entries Removed	36,951	28,977	33,137	36,527	30,880	39,893	39,791	49,449

Table 6. Percent of Entries Removed for Each Correction

Percent of Entries Removed	Average	2016	2017	2018	2019	2020	2021	2022
For DIV/O!	0.36%	0.71%	0.18%	0.24%	0.21%	0.39%	0.41%	0.39%
For < 11ee, < 1000Hr, < 100Hr/FTE	11.36%	11.45%	11.46%	11.27%	9.42%	12.11%	11.08%	12.75%
For > 3250Hr/FTE, >500TRIR	1.17%	1.32%	1.11%	1.11%	1.00%	1.10%	1.44%	1.11%
Total Entries Removed	12.89%	13.48%	12.76%	12.62%	10.63%	13.60%	12.92%	14.26%

Based on Tables 5 and 6, the largest correction occurred after removing entries that reported fewer than 11 employees, fewer than 1,000 total hours worked in a year, and fewer than 100 hours worked per employee. On average, this corrective step accounted for 11.4% of entries removed from the analysis. Overall, an average of 12.9% of entries were removed from the originally downloaded OSHA ITA data.

Tables 7 and 8 display the final corrected variables. The average amount of employees worked removed per year was 580,000,000, and the total hours worked was 2,500,000,000,000 (2019 alone accounted for 17,000,000,000,000 total hours removed). The average total hours removed per year, without including 2019, was 39,700,000,000 (almost 40 billion hours worked per year). An average of 27,930 injury cases and 4,220 illness cases were removed annually, along with 407,803 days away from work and 418,769 days in restriction or job transfer.

Table 7. Numerical Reductions in Descriptive Statistics from Original Download to Final Correction

Amount Removed after Corrections	Average	2016	2017	2018	2019	2020	2021	2022
Total number of entries	36,951	28,977	33,137	36,527	30,880	39,893	39,791	49,449
Total number of employees	5.8E+08	7.7E+07	9.8E+07	9E+07	3E+07	6.9E+08	2.9E+09	2E+08
Total hours worked	2.5E+12	2.5E+10	3.3E+ 10	2.8E+ 10	1.7E+13	4E+10	5.5E+ 10	5.6E+10
Percent zero injuries reported	6.31%	6.96%	6.31%	6.26%	5.03%	6.57%	6.11%	6.91%
Total DAFW cases	12,664	8,352	10,563	11,523	9,572	15,349	14,778	18,508
Total DTJR cases	7,593	7,354	9,164	8,287	7,061	6,501	7,136	7,649
Total Other cases	11,893	11,474	12,593	12,673	11,386	9,634	10,920	14,569
Total DAFW days	407,803	287,637	48,6178	395,961	332,184	425,400	431,434	495,824
Total DTJR days	418,769	300,532	422,399	345,534	363,646	301,462	335,683	862,127
Total injuries	27,930	25,467	30,432	30,143	26,340	23,922	26,482	32,721
Total illnesses	4,220	1,713	1,888	2,340	1,679	7,562	6,352	8,005

Table 8. Percent Descriptive Statistics Changes from Original Download to Final Correction

Percent Reduction after Corrections	Average	2016	2017	2018	2019	2020	2021	2022
Total number of entries	12.89%	13.48%	12.76%	12.62%	10.63%	13.60%	12.92%	14.26%
Total number of employees	76.52%	71.60%	74.12%	70.47%	43.23%	94.96%	98.66%	82.57%
Total hours worked	46.72%	32.48%	36.06%	30.16%	99.61%	39.42%	45.61%	43.70%
Percent zero injuries reported	17.64%	20.26%	18.59%	18.39%	15.13%	17.08%	15.99%	18.05%
Total DAFW cases	2.51%	2.68%	2.78%	2.72%	2.22%	2.38%	2.43%	2.39%
Total DJTR cases	2.01%	2.32%	2.50%	2.00%	1.68%	1.89%	1.86%	1.81%
Total Other cases	2.47%	2.68%	2.68%	2.40%	2.18%	2.22%	2.32%	2.80%
Total DAFW days	2.42%	2.52%	3.14%	2.57%	2.11%	2.04%	2.31%	2.27%
Total DJTR days	1.50%	1.95%	1.94%	1.43%	1.46%	1.45%	1.39%	0.85%
Total injuries	2.36%	2.55%	2.67%	2.35%	2.04%	2.23%	2.19%	2.45%
Total illnesses	2.44%	2.91%	2.45%	2.86%	2.09%	2.15%	2.48%	2.09%

Based on Tables 7 and 8, the largest correction occurred to the total number of employees reported for that year (average of 76.5% reduction) followed by the total reported number of hours worked (average of 46.7% reduction). It is also interesting that the number of "zero injuries" reported were reduced by an average of 17.6% (from an originally reported average of 35.8% to 29.5%). These results indicate that erroneous reporting of the number of employees and hours worked are the most egregious concerns since they represent most of the error reduction during the corrective removal of entries. It's also interesting to note that the self-reported injury and illness cases were only reduced by an average of 2.4%. This finding also provides an opposing argument to the "under-reporting" of injury cases addressed in the introduction. Focused attention to proper reporting of the number of employees and actual hours worked has a potentially greater impact on the calculation of injury and illness incidence rates and, therefore, the validity of the representation of safety program performance.

3.2 How Did the Corrections Affect Hours Worked and Incidence Rate Calculations?

The calculated "hours worked per employee" was determined to be the most drastically skewed (or erroneous) descriptive statistic. Most notable is the discrepancy in 2019. After the third corrective step, the annual hours worked per employee averaged between a low of 1,600s and a high of 1,800s, which is within expectation for full-time workers.

Table 9. Changes in Calculated Hours Worked per Employee, Both Overall and Individual Entry Average and Median, through Each Step of Correction

Hours Worked per EE, by Correction Step	2016	2017	2018	2019	2020	2021	2022
Average hours worked per EE, original, overall	724	700	732	2.5E+05	140	42	523
Average hours worked per EE, rem DIVO, overall	726	698	731	2.5E+05	140	41	523
Average hours worked per EE, rem DIVO, by entry	2,451	2,756	2,471	8.3E+06	2,681	3,095	4,278
Median hours worked per EE, rem DIVO, by entry	1,838	1,825	1,830	1,811	1,801	1,804	1,807
Average hours worked per EE, rem low, overall	2,509	2,663	2,445	5,246	2,744	2,941	2,935
Average hours worked per EE, rem low, by entry	2,446	2,713	2,489	7,154	2,736	2,977	3,497
Median hours worked per EE, rem low, by entry	1,826	1,832	1,821	1,811	1,795	1,794	1,809
Average hours worked per EE, rem high, overall	1,722	1,730	1,731	1,708	1,684	1,690	1,689
Average hours worked per EE, rem high, by entry	1,743	1,740	1,731	1,723	1,700	1,684	1,721
Median hours worked per EE, rem high, by entry	1,815	1,824	1,813	1,811	1,788	1,783	1,801

Figure 2. Overall Average Hours Worked per Employee After Each Corrective Step

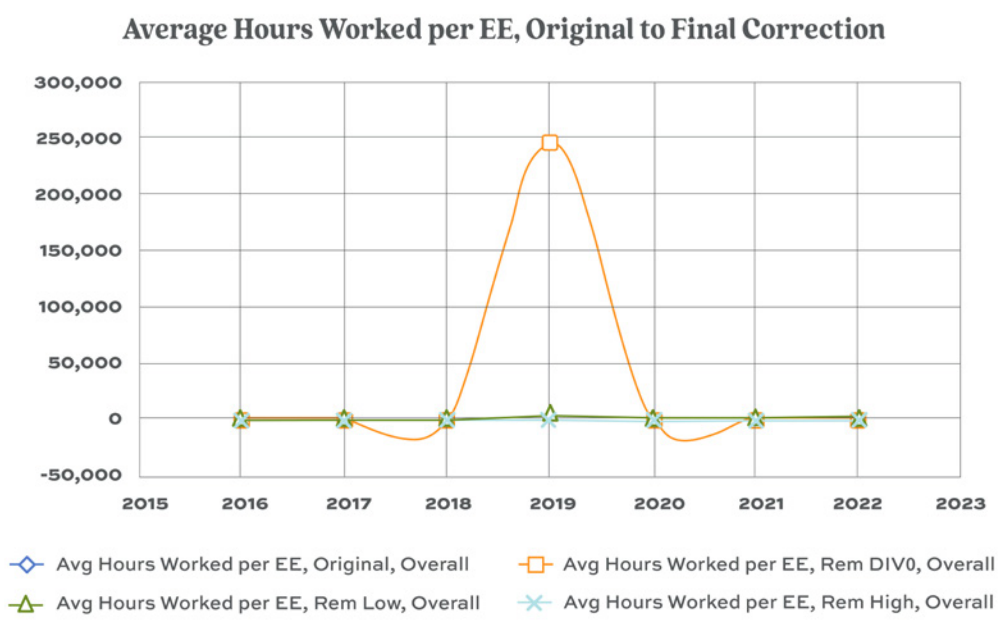


Figure 3. **Comparison of Overall vs. Individual Calculation of Hours Worked per Employee, Only After the Final Two Corrective Steps**

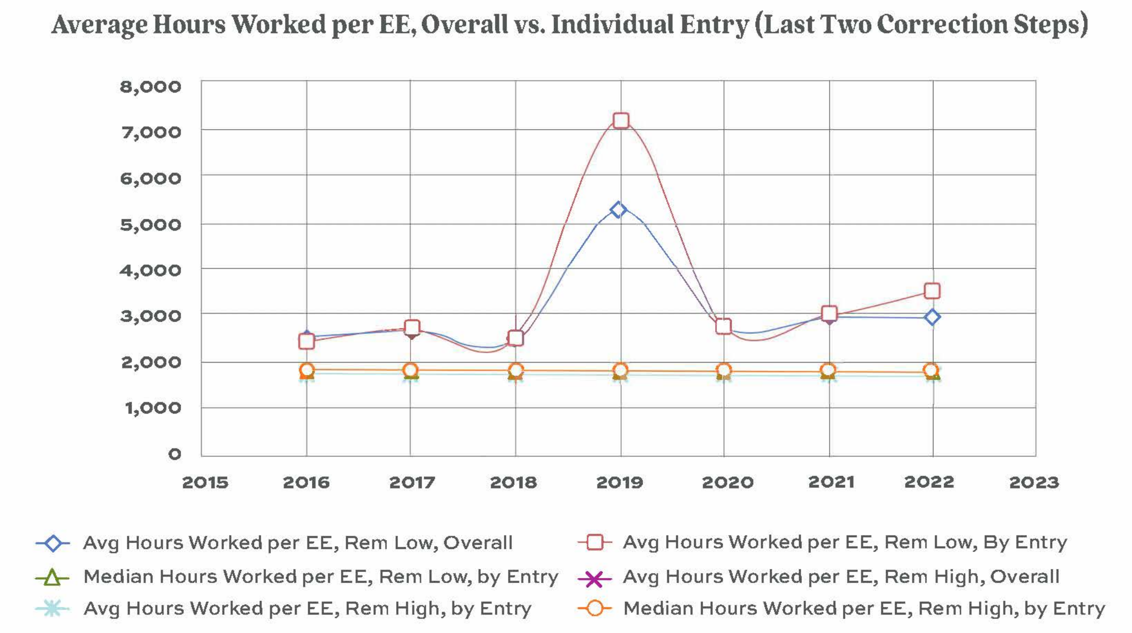


Figure 2 displays the effect of over-reporting hours worked per employee for 2019 and how that error was corrected through the three steps described in the Methods Section. Figure 3 demonstrates the consistency (and reliability) of hours worked per employee from the second to the third (and final) step. Since the incidence rate calculations rely heavily on reliable hours worked, this demonstrates the serious inconsistencies and errors in the original OSHA ITA data. Through three corrective steps, the researchers were able to achieve reliability in hours worked per employee and, therefore, presumed validity of incidence rates.

Table 10. **Final Calculated Hours Worked per Employee, TRIR, and DART after Corrections**

Final Corrected Rates and Stats	2016	2017	2018	2019	2020	2021	2022
Average hrs per FTE by entry	1,742.7	1,739.7	1,730.6	1,722.9	1,699.8	1,683.6	1,720.9
Average hrs per FTE median	1,815.3	1,824.2	1,813.1	1,811	1,788.4	1,782.6	1,800.8
Average hrs per FTE S.D.	492.9	493.6	502.1	497.2	492	537	477.5
TRIR average by entry	4.93	5.19	5.12	4.98	5.31	5.22	5.56
TRIR median	3.3	3.44	3.43	3.29	2.97	3.03	3.02
TRIR S.D.	7.65	7.94	7.74	7.46	9.43	9.33	10.27
TRIR percent zero	27.43%	27.70%	27.79%	28.25%	31.94%	32.12%	31.40%
DART average by entry	2.97	3.21	3.19	3.14	3.7	3.56	3.89
DART median	1.42	1.52	1.55	1.51	1.35	1.35	1.35
DART S.D.	5.2	5.75	5.37	5.4	7.76	7.51	8.54
DART percent zero	39.82%	40.17%	39.80%	39.91%	42.24%	42.48%	42.09%

Table 10 illustrates greater details with the calculation and presentation of hours worked per employee, TRIR, and DART after the corrective steps. The difference between "average" and "median" for all three variables may indicate a need for additional correction or the possibility that these population statistics do not meet the assumption of normality. Even though more consistency is seen from year to year, Table 10 demonstrates an effect in 2020 (the year of COVID-19) in which hours worked per employee decreased, and TRIR and DART percent zero increased. Additionally, in 2020, TRIR and DART averages and standard deviations increased while medians decreased. From a calculation perspective, increasing the number of zero entries into a sample will inevitably decrease the median. On the other hand, a decrease in hours worked per employee will increase the TRIR and DART results. Table 10 confirms the effect of "reporting no injuries" and "over-reporting of hours worked" on the reliability of incidence rate calculations.

Table 11. TRIR and DART at Each Step of Correction, Overall vs. Individual Entry, and BLS

Annual Incidence Rates	2016	2017	2018	2019	2020	2021	2022
TRIR-original, overall	2.73	2.63	2.92	0.02	2.79	2.44	2.66
DART-original, overall	1.62	1.62	1.79	0.01	1.94	1.65	1.85
TRIR-rem Div/O, overall	2.73	2.63	2.92	0.02	2.79	2.44	2.66
DART-rem DivO, overall	1.62	1.62	1.79	0.01	1.94	1.65	1.85
TRIR-rem Div/O, avg by entry	15.32	20.00	15.68	15.22	13.02	22.07	25.07
TRIR-rem Div/O, median by entry	2.75	2.90	2.90	2.88	2.33	2.41	2.36
DART-rem Div/O, avg by entry	8.88	9.43	7.95	6.69	9.02	15.75	12.13
DART-rem Div/O, median by entry	0.86	0.95	0.99	1.08	0.63	0.66	0.58
TRIR-rem low, overall	2.71	2.62	2.90	1.31	2.77	2.53	2.67
DART-rem low, overall	1.61	1.61	1.78	0.81	1.93	1.72	1.86
TRIR-rem low, avg by entry	4.92	5.19	5.11	4.96	5.29	5.20	5.56
TRIR-rem low, median by entry	3.25	3.4	3.39	3.26	2.93	2.96	2.97
DART-rem low, avg by entry	2.96	3.21	3.18	3.12	3.69	3.54	3.90
DART-rem low, median by entry	1.39	1.49	1.52	1.48	1.32	1.30	1.32
TRIR-rem high, overall	3.93	4.01	4.08	4.03	4.50	4.39	4.61
DART-rem high, overall	2.34	2.46	2.50	2.50	3.13	2.97	3.22
TRIR-rem high, avg by entry	4.93	5.19	5.12	4.98	5.31	5.22	5.56
TRIR-rem high, median by entry	3.30	3.44	3.43	3.29	2.97	3.03	3.02
DART-rem high, avg by entry	2.97	3.21	3.19	3.14	3.70	3.56	3.89
DART-rem high, median by entry	1.42	1.52	1.55	1.51	1.35	1.35	1.35
BLS TRIR	3.2	3.1	3.1	3.0	2.9	2.9	3.0
BLS DART	1.7	1.6	1.7	1.6	1.8	1.8	1.8

Table 11 provides a comparison of TRIR and DART calculations (overall vs. by individual entry) and the magnitude of change after each step of correction. This provides the opportunity to visually assess how they calculate the TRIR and DART rates and compare them against BLS SOII data for 2016-2022.

Figure 4. Overall (Calculated) TRIR and DART After Each Step of Correction, 2016-2022

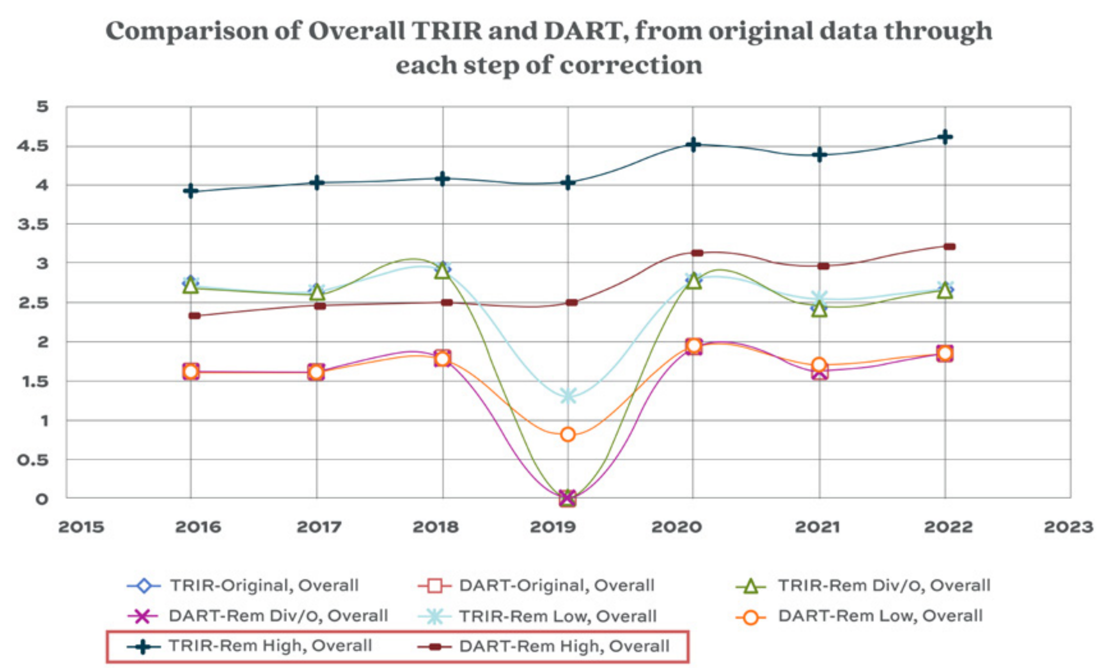


Figure 4 confirms that TRIR and DART calculations after the three corrective steps are the best representation of the data because of their consistency over time.

Figure 5. Comparison of TRIR and DART Calculation by Overall vs. Individual Entry

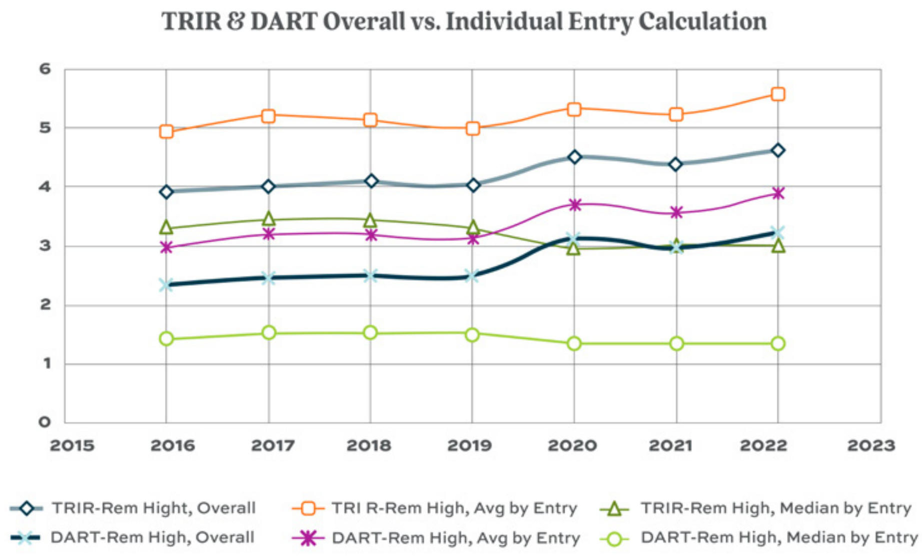
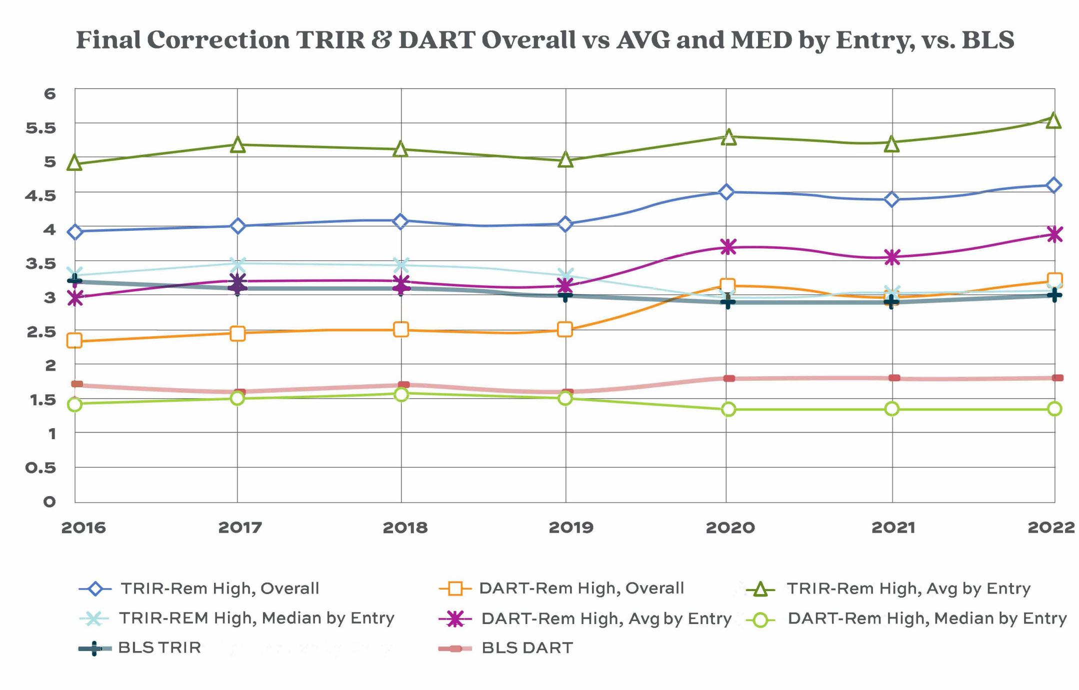


Figure 5 demonstrates that calculating incidence rates using overall total reported injury and illness cases and total hours worked falls between rates calculated by average and median (and standard deviation) from each individual entry (or employer submission). Note that Fig. 5 used the dataset after all three corrective steps. The general trend from year to year appears to be similar between the average calculation by individual entry and the overall calculation, whereas the median calculation by individual entry trends differently. It's also interesting to note that both TRIR and DART rate calculations tend to vary in similar fashion.

Figure 6. Final Corrected TRIR and DART, OSHA ITA Overall and Individually Calculated vs. BLS



In Fig. 6, the corrected TRIR median (calculated by individual entry) and corrected DART median (calculated by individual entry) are the only OSHA ITA rates that are "close" to the BLS comparison rates, but they are not perfectly representative. After 2019, the OSHA ITA median DART is lower than BLS, and prior to 2020, the OSHA ITA median TRIR was higher than BLS.

In Fig. 6, the TRIRs calculated both overall and by individual entries increase over time and are substantially greater in magnitude than the BLS TRIR. Similarly, the DART calculations, both overall and by individual entries, are increasing over time and are substantially greater in magnitude than the BLS DART. Additionally, after 2019, these DART calculations are greater than the BLS TRIR.

4. Discussion and Conclusions

The objectives of this research study were to investigate:

1. If the OSHA ITA annual data contains minimal self-reported errors.
2. If the OSHA ITA annual data is comparable to BLS SOII data.

Based on the ad hoc discovery, corrective actions, and visual determinations using results tables and figures, the OSHA ITA annual data lacks validity and representation due to errors in entries and inconsistencies over time, as well as very limited comparability with BLS annual TRIR and DART data. Although not justified by statistical analysis (significance testing), comparative analysis using tables and figures over time clearly demonstrated these determinations. Possibly more interesting is the realization of erroneous reporting of hours worked, and in the case of OSHA ITA, the reporting of employees. If the hours worked per employee variable had not been calculated on an individual entry basis, the severity and complexity of OSHA ITA data errors may not have been so vividly clear. Most "data quality" research literature focuses entirely on the impact of under-reporting of injury and illness cases as a cause for invalid or unreliable incidence rates. This study found a greater impact of both under- and over-reporting of hours worked and/or number of employees, which directly contributes to the validity and reliability of incidence rate calculations.

Poor quality data entry will lead to unreliable data output. The information gathered by OSHA needs to be highly accurate and analyzed for that accuracy. Datasets within the ITA database must be checked for validity, completeness, and accuracy (Kilkenny and Robinson, 2018). New approaches to safety measurements are needed. In addition to statistical invalidity, the use of TRIR also does not describe why the performance—good or bad—was achieved and what can be done to improve. The results and findings of this study should leave organizations wondering whether they should continue using TRIR and DART as performance measures for their safety program. Meanwhile, the academic and professional community should consider alternative measures of safety performance that assess the actual safety system at a high frequency. Increasing the number of reliable measurements could drastically improve the stability, precision, and predictive nature of safety metrics. To be comparative, however, these metrics must be standardized and consistently reported (Oguz Erkal et al., 2023). In nearly every practical circumstance, it is statistically invalid to use TRIR to compare companies, business units, projects, or teams (Hollowell et al., 2021).

OSHA recordkeeping has been the influence of safety programs for years now. This research study seriously questions whether incidence rates are the best way to measure a safety program. The study demonstrates three different TRIR and DART calculations are possible from the same data, and that, over time, they do not behave in similar ways. Are organizations under-reporting and hiding injuries to lower TRIR? Or are they over-reporting hours worked to effectively lower their TRIR and DART rates? There is a definite lack of accuracy and reliability within the OSHA ITA records and additional questions about the quality of BLS data. The errors found during this analysis point to inaccuracies within the OSHA ITA database and representation of TRIR and DART reporting from OSHA. It has become a staple to compare organizations against one another. Using this measurement system creates confusion, misrepresentation, and an overall injustice to organizations and does not improve safety performance. Safety performance should be measured by leading indicators, employee involvement, and reporting the effectiveness of corrective actions.

OSHA ITA and its incidence rate calculations are a flawed and inaccurate measurement system as proven by this study. Future research needs to focus on quantitative analyses of dataset normality, effects of inaccurate/skewed data based on reporting company size, and possibly differences between state-run and federal OSHA agencies.

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