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Ouzounian, Alex C. ***An Analysis of Acute Injuries Experienced by Operators of Pneumatic Fastener Driving Tools at Company XYZ***

Abstract

The purpose of this study was to identify actions which would eliminate or reduce acute injuries experienced by employees that utilized pneumatic fastener driving tools (PFDTs) in assembly operations at Company XYZ. Approximately nine years of worker compensation claim data was analyzed to identify factors inherent to previous injuries at Company XYZ. In addition, two PFDT safety audits were performed in assembly areas which possessed the highest risk for PFDT acute injury based on findings from the worker compensation claim analysis. The PFDT safety audit was conducted utilizing a form created by the researcher which specified generally accepted requirements for the safe operation of PFDTs which the research identified from the literature review. By auditing PFDT conditions and observing operator behaviors when interacting with these tools, the researcher was able to make recommendations utilizing the hierarchy of controls to eliminate or reduce PFDT acute injuries at Company XYZ.

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Chapter I: Introduction

Powered by compressed air, pneumatic powered fastener driving tools (PFDTs) are used by workers across many industries for tasks that require high-volume assembly and construction. To operate these tools, a worker ensures compressed air is connected to the tool, loads the appropriate fasteners into the magazine (i.e. staples or nails), and uses a trigger to release compressed air to a piston that drives the fastener out of the tool to secure objects together (Howard, Branche, & Earnest, 2017). In addition, PFDTs today often include a safety device that must be engaged before or after the trigger is pulled by the operator to discharge a fastener. With the ability for some PFDTs to insert up to eight fasteners per second (Nagurka, Marklin, & Larson, 2017), organizations have benefited from reduced cycle times and increased production in industries such as residential construction, window and door manufacturing, and furniture manufacturing.

Though a huge step forward when compared to manually hammering fasteners, these tools still fail to safeguard operators from the unintended release of a fastener in multiple circumstances. According to the U.S. Consumer Product Safety Commission (CPSC), a total of 26,417 occupational and non-occupational pneumatic nail gun injuries were treated in hospital emergency rooms between August 1, 2000, and July 15, 2001 (United States Consumer Product Safety Commission [U.S. CPSC], 2002a). Of these 26,417 injuries, approximately 60% of these injuries were work-related (U.S. CPSC, 2002a). Additionally, a retrospective review of the Washington State Department of Labor and Industries Industrial Insurance System from 1990-1998 revealed 3,467 lost-time days due to pneumatic nail guns used by employees in the wood products manufacturing industrial classification code (Baggs, Cohen, Kalat, & Silverstein, 2001). Organizations need to address the safety concerns these tools present in the workplace.

Company XYZ is a window and door manufacturer in the Midwest region of the United States. At this site, Company XYZ employs over 1,500 employees each year to support daily operations in producing a variety of residential windows and doors. Every employee within this facility strives to safely produce industry leading quality windows and doors, on time to the customer, without unplanned costs to the business. These duties include (but are not limited to) processing lumber and extruded material, milling various window and door profiles, coating and painting parts, assembly, and distribution.

The assembly areas for Company XYZ are responsible for combining various parts using staples, nails, silicone, and glue to produce a final product. At this stage in the manufacturing process, overall equipment effectiveness and operator efficiency is critical to the business. An error by an operator would likely cause downtime to the assembly line, which could jeopardize on-time delivery to the customer and profit to the company. One perceived operator error Company XYZ has experienced is acute injuries from PFDTs.

Statement of the Problem

Employees at Company XYZ have experienced acute injuries from PFDTs in assembly operations, leading to direct and indirect unplanned costs to the business and an outcome misaligned with the organization's goal to provide a safe and secure workplace for all employees.

Purpose of the Study

The purpose of this study was to identify actions that would eliminate or reduce acute injuries experienced by employees that utilized PFDTs in assembly operations at Company XYZ. The following objectives were established to guide the purpose of this study:

1. Analyze acute PFDT-related incident history of Company XYZ to identify factors inherent to previous injuries.
2. Conduct a PFDT safety audit for assembly areas at Company XYZ that possessed the highest risk for PFDT acute injury.

Assumptions of the Study

This study was conducted under the following assumptions:

1. The injury data was correct and reflected incidents that occurred during the reviewed timeframe.
2. All acute injuries from PFDTs were reported and occurred while employees performed work for Company XYZ at their facility.
3. The observed PFDT operators accurately followed standard operating procedures during the audit of their assembly area.

Limitations of the Study

The limitations of this study are represented by the following conditions:

1. The research is limited to the evaluation of the recorded acute PFDT workers' compensation claim data and assembly operations at Company XYZ between January 1, 2010 and September 30, 2018.
2. Previous research for PFDT injuries was nearly exclusive to the construction industry.
3. Findings are specific to Company XYZ and may produce different results for other organizations and industries.

Chapter II: Literature Review

The purpose of this study was to identify actions which would eliminate or reduce acute injuries experienced by employees that utilized PFDTs in assembly operations at Company XYZ. A literature review was conducted to explore the extent to which this problem has been examined in the past. Though research regarding this problem produced discoveries almost exclusively to the construction trades, it is believed similar findings exist when PFDTs are used in a manufacturing setting. The findings within this chapter are divided into four sections. The first section provides perspective on the various trigger systems used to discharge a fastener from a PFDT. The second section outlines the extent of PFDT-related injuries and the impacts to operators and employers. The third section highlights regulatory organizations that attempt to influence employer practices to mitigate PFDT-related injuries. The last section identifies control methods requiring consideration to control the risk of acute injury for operators who utilize PFDTs.

Trigger Configurations of PFDTs

PFDTs are used to secure objects in many tasks for the construction trades and manufacturing environments. Though weight, size, and the type of fastener discharged from these guns may vary, the distinctive aspect of these tools is the relationship between the safety contact tip (also known as a workpiece contact or nose) and its trigger. The order of operation used to engage the workpiece contact and its trigger is collectively known as the trigger system. Through varying sequences of these devices, different types of trigger systems can be realized.

However, not all PFDTs have this relationship. For PFDTs that discharge a small nail or staple for finishing work, a workpiece contact might not be present and only require depression of the trigger (U.S. CPSC, 2002b). Though some PFDT manufactures do away with the safety contact piece altogether for these smaller guns, some opt for a dual trigger arrangement comprised of two triggers that work in conjunction with each other (ANSI SNT-101, 2015) to prevent accidental discharge should the operator engage the trigger when they did not intend to do so. Some PFDTs also allow the operator to choose between more than one trigger systems using a selector switch located on the gun (Department of Health and Human Services & Department of Labor [DHHS & DOL], 2011). This selector switch affords the operator variability based on the task at hand. If a PFDT has a selector switch or can be converted to a different type of actuation system, the PFDT must be marked to indicate the selected actuation system according to ANSI SNT-101 (2015).

Though different trigger systems exist in today's marketplace, the following trigger systems discussed in this section are regarded as the most widely used PFDTs today.

Sequential triggers. Albers et al. (2015) described PFDTs with a sequential actuation trigger (SAT) as a trigger system that discharges a fastener once the safety contact tip is first engaged and, while held depressed against the substrate, the trigger is squeezed by the operator. Furthermore, this sequence must be repeated after each fastener is ejected from the gun (Howard et al., 2017).

However, the National Institute for Occupational Safety and Health (NIOSH) and Occupational Safety and Health Administration (OSHA) further described an SAT as either a full sequential trigger or a single sequential trigger in a nail gun safety guide for construction contractors (DHHS & DOL, 2011). The full sequential trigger is the same system that Albers et al. (2015) referred to as a SAT. However, NIOSH and OSHA described a single sequential trigger as one which has the same order of operation as a full sequential trigger but only requires the operator to squeeze the trigger if the safety contact tip is depressed into the workpiece for the remaining expulsion of fasteners (DHHS & DOL, 2011).

NIOSH and OSHA claimed the full sequential trigger provided the safest operation for construction workers who used nail guns. Chalupka and Moynihan (2012) echoed the use of SATs to reduce the risk of unintentional nail discharge and double fires. Lowe, Albers, Hudock, and Krieg (2016) provided evidence supporting SATs after concluding the lack of a SAT was accountable for unintentional discharge in 53.5-70% of injuries and 70% of fatal injuries in 258 pneumatic nail gun accidents identified in the OSHA database of Fatality and Catastrophe Investigation Summaries (F&CIS) from 1985-2012.

Though SATs were widely acknowledged as the safest option by many authors, some such as Baggs et al. (2001) believed skilled operators should have access to tools with a contact actuation trigger (CAT) because repetitive activation of sequential triggered guns might cause trigger finger. Albers et al. (2015) doubted the potential association between SAT use and finger tendon cumulative trauma claiming no documentation existed. In addition, Lipscomb, Nolan, and Patterson (2015) questioned carpenters about MSDs as part of an active surveillance program related to nail gun injuries between 2010 and 2013. The authors found reports of musculoskeletal disorders to be relatively rare with no differences seen in the rate of MSDs based on trigger configuration. This, too, was at a time when Lipscomb et al. (2015) identified a considerable increase in the use of SATs since 2005.

Another criticism surrounding the use of sequential triggers was the potential for decreased production due to added time required by operators when using a SAT. Lipscomb et al. (2008) conducted an experiment to explore this apprehension using ten journeymen carpenters to evaluate productivity variability between contact actuation triggers and sequential actuation triggers and found the mean time required for the carpenters to build a yard shed using a SAT was 10.2 minutes longer compared to building the same yard shed using a CAT. However, the study failed to provide details as to how much prior experience each journeyman had with each trigger system.

Contact actuation trigger. Lipscomb, Nolan, & Patterson (2010) surveyed contractors who hired union residential carpenters and found tools with contact triggers to be more common than those with sequential triggers. Known as bump fire, this type of PFDT requires no specific sequence between the workpiece contact and trigger (ANSI SNT-101, 2015). Instead, the nail gun fires a nail when pressed against the substrate as long as the operator is holding down the trigger (Howard et al., 2017). If the trigger is kept squeezed, a nail will be discharged every time the safety contact tip is pressed into the work surface (DHHS & DOL, 2011).

However, Lipscomb, Dement, Nolan, & Patterson (2006) claimed that CAT guns were twice the risk compared to guns with a sequential trigger based on their findings from a questionnaire they distributed to apprentice carpenters over a 6-month period. Their results showed 78% of apprentice carpenters who sustained a nail gun injury did so when using a CAT gun, and over 40% of CAT injuries occurred when the apprentice was bump firing nails into material. Howard et al. (2017) also claimed the CAT design increased the risk of double firing and accidental discharge. Worst of all, these guns have proven they can kill. Lowe et al. (2016) found the leading injury mechanism among fatal and catastrophic nail gun injuries was the unintended actuation from direct contact of the victim with a contact actuation trigger PFDT.

Extent of Injuries from PFDTs

PFDTs are not only utilized by workers in construction and manufacturing. These tools can be purchased by everyday consumers at local hardware stores for tasks ranging from small crafts to large construction projects. Depending on the type of fastener a consumer is looking to discharge, PFDTs can be purchased by a consumer for a price of about $80 to $350 (U.S. CPSC, 2002b). These prices arguably make PFDTs accessible to almost anyone in the United States. Thus, PFDT injuries are likely to be seen across both occupational and non-occupational groups.

This section explores the frequency of PFDT injuries, injury exposure characteristics where PFDTs exist, and the severity of PFDT injuries recognized by consumers, workers, and employers.

Frequency of PFDT injuries. From January 1996 to December 2001, approximately 67,755 non-occupational nail gun injuries were seen in hospital emergency rooms and showed an average increase of 1,356 injuries per year during this time frame (U.S. CPSC, 2002a). The rate of hospitalization for non-occupational operators was three percent above the average rate of all consumer products at that time. A specific study conducted between August 2000 and July 2001 estimated 11,000 consumer-related victims and 17,800 occupational victims had been treated in U.S. hospital emergency departments for injuries associated from nail gun use based on a statistical sample (U.S. CPSC, 2002a). Unfortunately, no improvement seemed to be recognized for the subsequent years thereafter. Between 2001-2005, an average of approximately 37,000 patients were treated annually in emergency departments with injuries related to nail guns with 14,800 from consumer use and 22,200 due to work-related incidents (excluding heavy duty staplers, rivet drivers and electric or powder actuated tools) based on the National Electronic Injury Surveillance System (NEISS) and NEISS-Work data (United States Centers for Disease Control and Prevention [U.S. CDC], 2007).

NEISS data was obtained by the Consumer Product Safety Commission (CPSC) from a national sample of 101 U.S. hospital emergency departments. NEISS-Work is an adjunct occupational injury and illness surveillance program conducted by the National Institute for Occupational Safety and Health (NIOSH) in collaboration with CPSC. NEISS-Work drew cases from 67 U.S. hospital emergency departments. Lipscomb and Schoenfisch (2015) reviewed NEISS-Work between 2006 and 2011 and found 86,600 nail gun injuries to be work-related that were treated in the ED. This was significantly lower than what was reported by the U.S. CDC between 2001 and 2005. However, Lipscomb and Schoenfisch (2015) attributed the decline of their data to the residential housing market decline that left a lot of residential construction workers unemployed as part of the Great Recession.

Injury exposure characteristics. To prevent recurrence of work-related injuries, employers and operators need to recognize various exposure characteristics of previous PFDT injuries. Eighty percent of injuries resulted in PFDT operators being injured among non-occupational and occupational groups (U.S. CPSC, 2002a). The remaining injuries occurred to bystanders or helpers (U.S. CPSC, 2002a). In the workplace, experience seemed to be a deciding factor. Apprentices in residential construction had a work-related nail gun incidence rate 3 times higher than journeyman in residential construction (Lipscomb, Dement, Nolan, Patterson, & Li, 2003). Lipscomb et al. (2006) later found in a separate study that 33% of apprentice carpenters had incurred two or more injuries from nail guns.

Risk factors for PFDT injury included unintended nail discharge from double fire due to pushing hard on the tool to compensate for recoil, unintended nail discharge from knocking the safety contact with the trigger squeezed, nail penetration through lumber work piece, nail ricochet after striking a hard surface or metal feature, missing the work piece, awkward position nailing, and bypassing safety mechanisms (DHHS & DOL, 2011). The U.S. CPSC (2002a) also listed a jammed nail gun, operator slipping, tripping on the air hose, and picking up the gun by the air hose as other reasons for accidental discharge.

Lipscomb et al. (2003) noted that placement of the hand not holding the tool was a highly prevalent characteristic for injuries across both types of CAT and SAT nail guns. Baggs et al. (2001) identified the body part most likely to be injured by pneumatic nail guns in eight Washington Industrial Classification (WIC) codes were fingers (42.7%), hand (23.3%), and the foot (5.9%) through 1990-1998. Besides the hand and finger, the thigh was the next body part most often requiring treatment among occupational and non-occupational victims of PFDT injuries (U.S. CPSC, 2002a). However, Horne and Corley (2008) documented only 38.6% of injuries were sustained to the hand and fingers after reviewing an admissions database from University Hospital, San Antonio, Texas, for nail gun related injuries to the extremities between April 2000 and July 2004.

Severity of PFDT injuries. The severity of PFDT injuries can be expressed in a variety of manners. Research showed varying types of injuries and different levels of impact among operators and employers.

Types of injuries. Seventy-two thousand work-related nail gun injuries were led by puncture wounds and foreign bodies, followed by 5,900 fractures (Lipscomb & Schoenfisch, 2015). Similarly, the U.S. CDC (2007) found 87% of nail gun injuries in 2005, for both consumers and workers, were diagnosed as either a wound with a foreign body (open wound with a nail or other object retained in the body) or puncture wound (open wound, excluding those with a foreign body). However, the U.S. CDC (2007) stated that fractured bones accounted for approximately 4% of nail gun injuries among workers, which is lower than the approximate 8% identified by Lipscomb and Schoenfisch (2015). Chalupka and Moynihan (2012) also believed objects could be embedded into the body at the time of the puncture injury leading to infection, which is why appropriate treatment is important even if a PFDT injury appears to be minor in nature.

Other nail gun injuries among workers or consumers according to the U.S. CDC (2007) included eye injuries from foreign bodies and corneal abrasions, noise-induced hearing difficulty, and musculoskeletal injuries (sprains, strains, tendonitis, and nerve damage from tool use). Musculoskeletal disorders (MSDs) have often been a cause for concern among many operators and employers who use sequential triggers. Lipscomb et al. (2015) noticed a considerable increase in the use of sequential triggers since 2005. Therefore, the authors asked carpenters about their experience in sustaining MSDs based on trigger configuration but reported relatively rare MSD occurrences. However, since sequential triggers are relatively new in their acceptance among industry, and the fact that MSD injuries can take many years before revealing symptoms, it may be too early to accurately state the impacts of their use on the musculoskeletal system.

The impact on PFDT operators. Ninety-four percent of consumers and workers were treated and released from the emergency departments in 2005 and did not require hospitalization (U.S. CDC, 2007). Similarly, Lipscomb and Schoenfisch (2015) found approximately 78,900 work-related nail gun injuries were treated in the emergency department and then released, but 7,200 were treated and then admitted or transferred to the hospital. Horne and Corley (2008) reviewed an admissions database from University Hospital, San Antonio, Texas, for nail gun related injuries and found 9% of patients presented later than the day of the injury. Of the only 27.3% of patients who returned for a follow-up appointment after their initial admittance to the emergency room, 33% continued to have some pain at an average follow-up time of 12.3 days

(Horne & Corley, 2008). The authors also found a low frequency of infection and rapid return of function to the extremities and concluded that patients can be managed with simple extraction and minimal debridement with a short course of oral antibiotics except for grossly contaminated wounds, neurovascular compromise, and clear penetration of a joint.

The impact on employers. Employers must consider medical costs, lost time costs, and potential fines levied against them for noncompliance of federal and/or state laws. Of the 80 injuries from nail guns in an active surveillance study performed by Lipscomb et al. (2003), approximately half of puncture wounds resulted in lost time beyond the date of injury. Hospitalization rates were around 3 percent and 4 percent for non-occupational and occupational victims while the average rate for all consumer products is 4 percent (U.S. CPSC, 2002a). From 1990-1998, Baggs et al. (2001) conducted a retrospective review of the Washington State Department of Labor and Industries Industrial Insurance System to extract data related to the claim initiation forms generated by pneumatic nail gun injuries. A total of $6,232,392 and 42,841 lost-time days were incurred over this time between 8 WIC codes and an “Other” code. The Washington Industrial Classification (WIC) code with the highest cost and number of lost-time days was Wood Frame Building Construction (0510) at $3,853,378 and 26,270 lost-time days. Wood Products Manufacturing (2903) amounted to $251,255 over this same period and was the second highest among number of lost-time days with 3,467 (8.1%). Wood Products Manufacturing (2903) had a rate of 42.9/10,000 FTEs injuries per year over this span compared to the highest rate, Wood Frame Building Construction (0510), at 205.8/10,000 FTEs injuries per year.

Lowe et al. (2016) analyzed cases in the OSHA Integrated Management Information System Fatal and Catastrophe Investigation Summaries (F&CIS) database throughout a 27-year period from 1985-2012 involving PNGs. Two hundred fifty-eight cases were deemed to be traumatic injuries in which the injury victim was struck by a discharged nail from a pneumatic nail gun after the authors performed their query using the word “nail.” A total of 325 citations and 299 initial penalties were issued to the construction industry (SIC 15, 17) and 122 citations and 109 initial penalties issued to non-construction industries. The inflation-adjusted mean monetary penalty (in 2013 USD) was $1,056 for the construction industry and $1,312 for non-construction industries. Unfortunately, this monetary penalty by the government is not a deterrent to many employers. Instead, the burden for employers is likely medical and lost time costs that impact the business directly and indirectly. However, government agencies are often seen by employers as the foundational resource to prevent outcomes that compromise the safety and health of employees.

Regulatory Considerations

Legal and consensus standards have been established to protect the safety and health of workers in the United States. These standards require and encourage employers to enact control methods once a hazard assessment has been completed. The governing body overseeing legal standards pertaining to the safety and health of workers in the United States is the Occupational Safety and Health Administration (OSHA). OSHA is a federal agency of the United States Department of Labor. The OSHA Act of 1970 excludes Federal OSHA’s jurisdiction over employees of the State and local government. However, States can assume responsibility for occupational safety and health programs under the State's own plan, but it must be approved by the U.S. Department of Labor. State plans must be at least as effective as Federal OSHA, if not more stringent, and include protection of public employees. To make the distinction between the two agencies in conversation and in writing, the state name is often inserted in full or abbreviated prior to the word “OSHA” (i.e. Minnesota OSHA or MNOSHA) when referring to a state-run program and Federal OSHA when “OSHA” is characterized by itself.

Additionally, the American National Standards Institute (ANSI), a private entity that oversees voluntary consensus standards in the United States, is often regarded by industry as a best practice resource for implementing safe control measures. At times, ANSI standards have been incorporated by reference in OSHA standards and been considered when issuing a citation to employers. For this reason, a general search was conducted to identify standards relating to PFDTs.

OSHA. Through the Section 5(a)(1) general duty clause, the Occupational Safety and Health Act requires employers to provide a workplace free of recognized hazards that may cause death or serious physical harm to employees (OSHA, n.d.). This clause also requires businesses to follow applicable standards set forth by OSHA, such as those pertaining to PFDTs.

The only Federal OSHA regulation relating to PFDTs can be found in Section 29 of the Code of Federal Regulations 1926, Construction Industry Standard 302 for hand and power tools. Regulation 29 CFR 1926.302(b)(3) requires pneumatically driven nailers, staplers and other similar tools to have a safety device on the muzzle to prevent the tool from discharging fasteners unless the muzzle is in contact with the work surface (OSHA, n.d.). However, this only applies to automatic fastener feed PFDTs that operate at more than 100 pounds per square inch (p.s.i.) (OSHA, n.d.). Though this standard does not apply to General Industry under Federal OSHA, Minnesota OSHA (MNOSHA) adopted this rule but expanded the application to General Industry requirements under administrative rule 5205.0850 Pneumatic Power Tools (Minnesota Administrative Rules, 2008).

Though California OSHA (CalOSHA) expanded the application of the Federal OSHA standard to General Industry as well, CalOSHA set forth a more stringent set of safety orders for the Construction Industry. Like Federal OSHA, the California Code of Regulations (2007) requires all pneumatically-driven nailers and staplers in construction to have a safety device on the muzzle to prevent the tool from operating unless the muzzle is depressed against the work surface. Again, similar to Federal OSHA, CalOSHA safety orders did not apply to light-duty nailers and staplers (tools designed to meet both of these requirements: only drive fasteners of 1-inch nominal length or shorter; are fasteners made from made from wire with a cross sectional area less than 18-gage per the American Steel Wire Gage) (California Code of Regulations, 2007). However, the safety orders required PFDTs to be disconnected from the air supply when performing maintenance, repair, or clearing a jam (California Code of Regulations, 2007).

Additionally, training for pneumatically-driven nailers or staplers was required to be conducted prior to initial operator assignment by a qualified person (California Code of Regulations, 2007). Training had to include at least the employer's code of safe practices for these tools, the hazards related to each mode of actuation, and hands-on training to verify the operator comprehends how to safely operate these tools (California Code of Regulations, 2007). If the operator had been observed using the tools in an unsafe manner, or the operator had been involved in an accident, CalOSHA required the employer to provide retraining (California Code of Regulations, 2007). Through these laws, it was apparent CalOSHA had set the bar for Federal OSHA and other state-run programs with regard to employer responsibilities for PFDT safety. Unfortunately, General Industry remains an opportunity for the promulgation of more in-depth PFDT safety regulations by Federal OSHA and most state-run programs when compared to the current regulations pertaining to the Construction Industry.

ANSI SNT-101-2015. The American National Standards Institute (ANSI) approves standards, which have been created by member organizations it accredits, based on the set of Essential Requirements it sets forth ("Introduction to ANSI," n.d.). The International Staple, Nail, and Tool Association (ISANTA) is a member organization of ANSI. ISANTA was founded by a small group of manufacturers in 1966 to establish a common set of standards and practices for the newly promoted pneumatically driven power fastener system at the time and was responsible for creating ANSI SNT-101-2015 Safety Requirements for Portable Compressed-Air-Actuated Fastener Driving Tools ("About," n.d.). ANSI SNT-101 (2015) established requirements for the design, construction, use, repair and maintenance of PFDTs to protect users and bystanders from injury.

The standard emphasizes the employer and PFDT operator responsibility for the safe operation of these tools by ensuring operating/safety instructions are made available to operators from the manufacturer, identifying the appropriate tool actuation system based on the work for which the tool will be used, training operators in the safe use of these devices, allowing only persons who have understood the operating/safety instructions to operate the tool, and approving tool use only when the operator and other workers in the work area are wearing eye protection that shields the front and side of the eyes (ANSI SNT-101, 2015). Though this standard provided guidance to protect workers and consumers from PFDT injury, some questioned the influence of its existence.

In 2010, Lipscomb et al. found more than 60% of residential contractors surveyed were unaware of the 2003 ANSI standard for pneumatic nailers. Due to this fact, the authors questioned the impact the 2003 ANSI standard promulgated by ISANTA had in shaping the landscape for improved safety among workers who used nail guns. Though the employees may have been unaware, it is conceivable that they may have been exposed to its contents and just not known the employer was referencing it. Howard et al. (2017) also took issue with the revised standard in 2015, for they claimed it failed to embrace key evidence-based findings that supported the use of sequential triggers to prevent nail gun injuries. In the case of revising the 2002 standard to what is now the 2015 ANSI standard, Howard et al. (2017) claimed the ISANTA consensus body lacked balance of all interests that were essential to an effective worker and consumer safety standard; the researchers also suggested that ISANTA made a mistake using the canvass method (accredited organization commonly writes the initial draft and then uses, more often than not, electronic mail ballot to determine consensus among members) versus a committee method (face-to-face meetings where dialogue between members can occur) due to the belief that the lack of interaction among canvass members made balance, dominance, and conflict of interest less apparent to contributors (Howard et al., 2017). Though admissible critiques for ISANTA to consider, ANSI SNT-101-2015 still provides more guidance for the recognition and control of PFDT-related hazards than current Federal and State OSHA programs.

Control Methods

Engineering, administrative, and personal protective equipment (PPE) are three commonly recognized categories used to control hazards in the workplace. When viewed separately, engineering controls are considered the most effective option for hazard mitigation, and PPE is considered the least effective solution. Though this section reviews these control methods separately, the examined studies of research often recommended a combination of these three control methods be adopted to mitigate PFDT acute injuries.

Engineering controls. Other than complete elimination of a hazard or substituting different chemicals to less hazardous material, implementing engineering controls is the best way to control existing hazards in the workplace because they remove the hazard at the source (National Institute for Occupational Safety and Health [NIOSH], n.d.). According to Chalupka and Moynihan (2012), understanding the gun's trigger mechanism is the first step in PFDT safety. Currently, trigger systems fall into two categories: sequential triggers or contact actuation triggers. To recount, sequential trigger systems discharge a fastener once the safety contact tip is first engaged and, while held depressed against the intended material, the trigger is required to be squeezed to release each fastener from the PFDT (Albers et al., 2015). Also known as bump fire guns, contact actuation triggers fire a fastener each time the safety contact tip is pressed against the substrate as long as the operator is holding down the trigger (Howard et al., 2017). As reviewed in the aforementioned sections of this literature review, a majority of authors accepted sequential trigger systems to be the safest solution for PFDT operators. However, opposition still claimed sequential trigger PFDTs are not practical in high volume work due to decreased production compared to that of a contact actuation trigger.

To solve this dilemma, Nagurka et al. (2017) introduced a patented prototype trigger system for a pneumatic nail gun: the "Smart Trigger." The smart trigger system uses an optical light sensor to determine whether the material surface is an intended object for fastening (i.e. nail or staple) based on an image of the intended material that is calibrated into the device before the operator uses the gun (Nagurka et al., 2017). If there is no match to the calibrated image, the system prevents fasteners from discharging. The authors conducted a limited field test both indoors and outdoors to obtain data accuracy, sensitivity and specificity for one construction material, one piece of clothing (jeans) and one skin color (Nagurka et al., 2017). The system's initial accuracy was 97.3% in the field test, and Nagurka et al. (2017) concluded that the smart trigger system afforded the production rate of a CAT gun, while providing the same (if not greater) protection compared to a single or full-sequential actuation gun.

Administrative controls. In addition to engineering controls, employers have the ability to enforce procedures for how work is performed safely at their facility. These safe operating procedures are known as administrative controls. Once engineering control methods have been evaluated, administrative controls are the next consideration for controlling hazards in the workplace (NIOSH, n.d.). Administrative controls may be required by law, required by the employer through experience, or a best practice within the industry. A few best practices are spelled out by ANSI SNT-101 (2015). While handling PFDTs, ANSI SNT-101 (2015) recommends the user always assume the tool contains fasteners, never point toward the operator's body or anyone even if it does not contain fasteners, and not grab the tool by the hose. Similarly, disconnecting the PFDT from the power source when not in use is critical when the operator performs maintenance or repairs, clears a jam, or removes fasteners from the magazine (ANSI SNT-101, 2015).

Prior to use, the PFDT should be inspected by the operator by checking for misalignment or binding of parts, identifying the actuation system, and ensuring the compressed air power source is regulated equal to or lower than the manufacturer's specified maximum air pressure (ANSI SNT-101, 2015). If a PFDT requires maintenance, the employer and operator must ensure only qualified personnel repair the tool, the manufacturer's maintenance instructions are available, and tools that require repair are tagged, removed from service, and segregated to be sure they are not put back into service until they are properly repaired (ANSI SNT-101, 2015). Chalupka and Moynihan (2012) further recommended providing safety training for PFDT operators so that they can recognize trigger system differences, safely fire while holding the substrate, recognize ricochet-prone scenarios, and understand safe work procedures while working on ladders or stairs. Reporting and reviewing injuries and close calls from PFDTs must be encouraged during training as well (Chalupka and Moynihan, 2012). Providing employees with training regarding these safe work practices may provide additional measures to prevent PFDT acute injuries. However, not all training is created equal.

Lipscomb et al. (2010) surveyed contractors who hired union residential carpenters and found some contractors surveyed set in place policies for when contact actuation triggers were allowed on the jobsite. Examples included painting the contact actuation trigger guns to differentiate them from those with sequential triggers, performing training through toolbox safety meetings and hands-on help, and requiring new apprentices to use tools with sequential triggers only (Lipscomb et al., 2010). Among apprentice carpenters in 2007, Lipscomb, Nolan, Patterson, and Dement (2008) noted convincing evidence that demonstrated reduced injury rates from nail guns through the implementation of school training and hands-on mentoring for apprentices. Specifically, their data presented a decrease of approximately 40% when apprentices received only school training compared to no school or hands-on training, and an approximate 45% decrease when apprentices only received hands-on training (Lipscomb et al., 2008). However, when apprentices experienced both school and hands-on training, researchers observed a decrease of 65% compared to no school or hands-on training (Lipscomb et al., 2008).

Personal protective equipment. Incorporating both classroom and hands-on training for the safe operation of PFDTs as part of the organization's comprehensive injury prevention program is an important control method to be considered alongside engineering and personal protective equipment (PPE). Personal Protective Equipment (PPE) is worn on the body to protect a person from injury or illness. NIOSH (n.d.) considers PPE to be the least effective control measure due to expensive sustainability costs and requires the most effort by affected workers to implement when compared to all other controls. However, some body parts such as the eyes are often considered a vital component of the human body that can't be expensed. ANSI SNT-101 (2015) approves PFDT use only when the operator and other workers in the work area are wearing eye protection that shields the front and side of the eyes. Though not a common area of the body to be injured when using PFDTs, the U.S. CDC (2007) noted nail gun injuries to the eyes do occur to workers and consumers. However, more than half of victims of non-occupational and occupational incidents from pneumatic nail guns claimed they did not remember seeing warnings to wear eye protection (U.S. CPSC, 2002a). The DHHS and DOL (2011) guide also recommended employers provide additional PPE such as safety toed shoes and hard hats along with ANSI Z87.1 safety glasses or goggles in the construction environment to prevent against acute injuries. However, numerous aforementioned studies have shown more than 50% of injuries to occur to the fingers, hands, wrist, and arm. Research about these high injury-prone areas of the body did not yield any designated PPE to protect against the accidental discharge of a fastener.

Chapter III: Methodology

The purpose of this study was to identify actions which would eliminate or reduce acute injuries experienced by employees that utilized PFDTs in assembly operations at Company XYZ. The following objectives were established to guide the purpose of this study:

1. Analyze acute PFDT-related incident history of Company XYZ to identify factors inherent to previous injuries.
2. Conduct a PFDT safety audit for assembly areas at Company XYZ that possessed the highest risk for PFDT acute injury.

This chapter covers data selection and a description of the subjects, instrumentation used to complete the study, the procedures developed to analyze PFDT acute injuries at Company XYZ, and limitations of the study.

Subject Selection and Description

Company XYZ employs over 1,500 employees each year to support daily manufacturing operations. The first objective of this study was addressed using worker compensation claim data between the years of 2010 and 2018. When a work-related incident occurs at Company XYZ, front line supervisors are expected to complete an injury/ illness report in the Health Services Department. Upon completion, Health Services notifies the Safety Department to perform a formal investigation which would include the frontline supervisor, injured employee, and site-safety representative. Health Services also initiates the beginning of a workers' compensation claim if the employee needs to seek medical treatment beyond first-aid. Due to procedural and documentation changes to the process for work-related incidents between the years of 2010 and 2018, this study used worker compensation claim data from Company XYZ's insurance claim handler between the dates of January 1, 2010 and September 31, 2018.

The second objective of this study was to conduct a PFDT safety audit for two assembly areas at Company XYZ that presented the greatest risk for PFDT acute injury based on previous worker compensation claims. The PFDT safety audit was conducted through observation at a distance to ensure PFDT operators did not deviate from their typical habits when using the PFDT. Observations were performed at times that were convenient for the investigator.

Instrumentation

The instrumentation had two purposes for the data collection process. First, a spreadsheet with previous PFDT compensable claims was obtained from an electronic database. Second, the PFDT Safety Audit form (Appendix) was assembled by the investigator based on previous research outlined in Chapter II to identify at-risk conditions and behaviors which historically accompanied PFDT acute injuries in previous studies.

Data Collection Procedures

The data for objective one was retrieved using an electronic database which amassed past worker compensation claims for Company XYZ starting January 1, 2010 and ending September 31, 2018. PFDT acute injuries were delineated by performing a search for the words "nail," "staple," and "gun" in addition to reviewing the brief description of how the injury occurred. Additional information generated by the electronic database included the date of injury, body part injured, nature of injury, and assembly area location.

To achieve objective two, a PFDT Safety Audit form (Appendix) was used during an informal observation of two assembly work areas which possessed the highest risk for PFDT acute injuries at Company XYZ. The PFDT safety audit was completed using pen and paper, but the data was then transferred to a spreadsheet. The researcher was the only one to observe, collect, and review the condition of the PFDTs and employee's performance with the PFDTs.

Answers to questions one through three of the PFDT Safety Audit form (Appendix) were collected during employee break periods or prior to start/end of shift to avoid interruption to operations and interaction among operators. Answers to questions four through fourteen were answered following collection of findings for questions one through three once employees returned to the work area. All observations and data collected occurred during normal operations.

Data Analysis

After collection of the workers' compensation claim data for PFDT acute injuries, the data was analyzed by sorting cases by nature of injury, body part injured, frequency of injuries by month, frequency of injuries by year, cause for injury, and assembly area location (Table 1-Table 6). The organized data provided factors inherent to PFDT acute injuries as well as assembly areas with the greatest risk for such injuries.

For objective two, the researcher analyzed findings from benchmark requirements (Appendix) at two different assembly areas to identify at-risk conditions and behaviors which may compromise the safety of the PFDT operator and nearby co-workers. Examining at-risk behaviors and conditions allowed the researcher to further determine appropriate recommendations to eliminate or reduce PFDT acute injuries at Company XYZ.

Limitations

Identified probable limitations of the study included:

1. The research is limited to the evaluation of the recorded acute PFDT workers' compensation claim data and assembly operations at Company XYZ between January 1, 2010 and September 30, 2018.
2. Injury data excluded close call and first-aid PFDT acute incidents.

3. Trigger systems were not characterized in the workers' compensation claim data obtained.
4. Operators performing job functions identified as high risk may proceed with operating procedures differently than those observed during the PFDT safety audit.
5. The reluctance of disclosing assembly area information specific to Company XYZ.
6. Findings are specific to Company XYZ and may produce different discoveries for other organizations and industries.

Chapter IV: Results

The purpose of this study was to identify actions which would eliminate or reduce acute injuries experienced by employees that utilized PFDTs in assembly operations at Company XYZ. The following objectives were established to guide the purpose of this study:

1. Analyze acute PFDT-related incident history of Company XYZ to identify factors inherent to previous injuries.
2. Conduct a PFDT safety audit for assembly areas at Company XYZ that possessed the highest risk for PFDT acute injury.

Presentation of Collected Data

The findings presented in this section align with the objectives of the study. The first objective required a review of Company XYZ's workers' compensation claim data from January 1, 2010 – September 30, 2018. Six tables were developed to present the acute PFDT injury history at Company XYZ by nature, body part, frequency, cause, and location. Objective two required a PFDT safety audit to be performed in two assembly areas at Company XYZ which experienced the highest number of acute PFDT injuries. A summary of the PFDT safety audits is provided for Assembly Area A4 and A20.

Objective 1: Analysis of Acute PFDT Injuries at Company XYZ

A review of Company XYZ's workers' compensation claim data identified the nature of injuries for acute PFDT injuries between January 1, 2010 and September 30, 2018. The highest percentage of injuries resulted in a puncture to the body (69%) while a foreign body was significantly lower at 9.5% as shown in Table 1. A puncture is defined as an open wound excluding those with a foreign body whereas a foreign body is defined as an open wound with any part of the fastener or other object retained in the body. A majority of the bruise/ contusion and cut injuries occurred from retractable overhead PFDTs.

Table 1

Nature of Acute PFDT Injuries (n=42)

Nature of Injury	Frequency	Percentage
Bruise/Contusion	3	7.1
Cuts	5	11.9
Puncture	29	69
Foreign Body	4	9.5
Unknown	1	2.4

Table 2 identified over 70% of the acute PFDT injuries were incurred to parts of the hands, thumbs, or fingers. The highest proportion of injuries were to the fingers (35.7%), followed by the thumb (19%), and then the hand (16.7%). Extremities that were not directly involved with manipulation of the workpiece, handling fasteners, or handling the PFDT resulted in the lowest percentage of injuries.

Table 2

Acute PFDT Injuries by Body Part (n=42)

Body Part	Frequency	Percentage
Head	5	11.9
Eye	1	2.4
Lower Arm	1	2.4
Wrist	1	2.4
Hand	7	16.7
Finger	15	35.7
Thumb	8	19
Abdomen	2	4.8
Lower Leg	1	2.4
Foot	1	2.4

Table 3 shows a breakdown of acute PFDT injuries by month and demonstrated that the months of July (14.3%) and August (16.7%) accounted for the highest frequency of injuries. The amount of injuries from July through December accounted for 69% of injuries.

Table 3

Frequency of Acute PFDT Injuries (n=42)

Month	Frequency	Percentage
January	4	9.5
February	1	2.4
March	2	4.8
April	1	2.4
May	1	2.4
June	4	9.5
July	6	14.3
August	7	16.7
September	3	7.1
October	4	9.5
November	4	9.5
December	5	11.9

Table 4 arranged the number of acute PFDT injuries by year representing a total of 42 cases between 2010 and 2018. The largest quantity of injuries occurred in 2015, which amounted to 21.4% of all cases.

Table 4

Acute PFDT Injuries by Year (n=42)

Year	Frequency	Percentage
2010	2	4.8
2011	1	2.3
2012	7	16.7
2013	4	9.5
2014	3	7.1
2015	9	21.4
2016	7	16.7
2017	4	9.5
2018 (Jan 1 - Sept 30)	5	11.9

The highest cause for acute PFDT injury was fastener ricochet at 16.7% in Table 5. Though fastener ricochet was the highest cause for injury, all remaining reasons for injury followed closely behind. A cause for five acute PFDT injuries could not be disseminated from the workers' compensation report.

Table 5

Cause for Acute PFDT Injury (n=42)

Cause for Injury	Frequency	Percentage
Maintenance (i.e. jam, cleaning, inspecting)	6	14.3
Fastener Ricochet	7	16.7
Fastener Penetration through Work Piece	4	9.5
Struck by Falling/Swinging PFDT	5	11.9
Gun Slipped on Work Surface when Fastening	4	9.5
Mishandling or Missing Intended Work Piece	6	14.3
Loading Fasteners	5	11.9
Unknown	5	11.9

Table 6 identified acute PFDT injuries by assembly area. The data revealed that Assembly Area A4 had incurred more than twice the number of acute PFDT injuries when compared to the assembly area with the next highest frequency of injuries. Assembly Area A20 was the second leading location for injuries (5).

Table 6

Acute PFDT Injuries by Assembly Area (n=42)

Assembly Area	Frequency	Percentage
A1	1	2.3
A2	3	7.1
A3	3	7.1
A4	11	26.2
A5	1	2.3
A6	1	2.3
A7	2	4.8
A8	1	2.3
A9	2	4.8
A10	1	2.3
A11	1	2.3
A12	2	4.8
A13	1	2.3
A14	1	2.3
A15	1	2.3
A16	1	2.3
A17	1	2.3
A18	1	2.3
A19	1	2.3
A20	5	11.9
A21	1	2.3

Objective 2: PFDT Safety Audit for High Risk Assembly Areas at Company XYZ

A PFDT safety audit for assembly areas which experienced the highest frequency of PFDT acute injuries was conducted to observe at-risks conditions and behaviors which may be present in the work environment. The data in Table 6 indicated that employees working in

Assembly Area A4 and Assembly Area A20 had experienced the highest number of PFDT acute injuries at Company XYZ.

PFDT safety audit for assembly area A4. In this work area, four total employees were assessed while operating eight PFDTs collectively. On average, each employee operated two different PFDTs to complete their job task. The types of PFDTs at this specific assembly area were full sequential and single sequential trigger systems. The full sequential PFDT discharged a nail fastener whereas the single sequential trigger system discharged a staple fastener.

Prior to operator usage, PFDTs were inspected to answer the questions on the safety audit that addressed the PFDT conditions and safety features (requirements 1-3). The inspection revealed that requirements one through three were compliant with the audit form within this assembly area for all eight PFDTs.

Statement four of the audit asked if the PFDT was operated in the presence of flammable liquids, gasses, combustible dusts, or other explosive atmospheres. Upon surveying the work area in relation to PFDT operation, no observed risk of uncontrolled flammable liquids, gasses, or combustible dusts were identified.

The fifth requirement of the audit asked if work operations were arranged so workers were not in the line-of-fire when the PFDT was utilized. All four operators were observed with hands, fingers, thumbs, or arms of their adjacent work partner in the line-of-fire at some point during assembly tasks.

The requirement for number six asked if operators inspected materials for knots, nails, straps, hangers, etc. that could cause recoil or ricochet prior to discharging the PFDT. This question was inconclusive and could not be verified without interaction with the operator, which may have skewed the findings.

To comply with question seven, the operator had to maintain eyes-on-task when discharging the PFDT. One hundred percent of the observed operators were inattentive at some time while operating the PFDT to complete their job task due in large part to conversation with other co-workers in the area.

Requirement eight needed operators to maintain the proper footing and balance and not overreach when using any of their PFDTs. All four operators were in non-compliance during the audit.

Item nine of the audit detailed the operator and other nearby employees must don safety glasses with side shields prior to handling the PFDT. All operators were in compliance with the safety requirement prior and during the handling of the PFDT.

Element ten specified that the operator’s free hand/arm maintain approximately 12 inches or more away from the discharge point. Each operator displayed at-risk behaviors and were at least 12 inches or closer from the discharge point of the PFDT based on visual estimation.

Element 11 of the PFDT Safety Audit form stated the PFDT operator must disconnect the compressed air hose when performing maintenance (i.e. clearing jam, cleaning, inspecting), passing the PFDT to a co-worker, and/or traveling up and down a ladder or stairs. During the audit for this assembly area, no such tasks were observed to identify an answer to this audit requirement.

Requirement 12 stated the operator must not carry the PFDT with a finger on the trigger. All four operators were witnessed complying with this statement during the observation period.

Element 13 required the operator not lift/maneuver the PFDT by the air hose. None of the operators were observed lifting or maneuvering the PFDT by the air hose which demonstrated compliance.

The 14th requirement stated the PFDT must be stored in a secure position when not in use. The PFDTs in this assembly area were placed in a holster or retracted by an overhead tool balancer. Seventy-five percent of the PFDTs were hanging from an overhead tool balancer. Of these PFDTs, all were observed swinging to varying degrees during the observation once the operator let go of the PFDT upon completion of the job task. For this reason, six of eight PFDTs were deemed non-compliant with this statement.

PFDT safety audit for assembly area A20. In this assembly area, four employees were assessed with each employee only using one PFDT each. The types of PFDTs at this work area were contact actuation and single sequential trigger systems. The contact actuation PFDT discharged a staple fastener whereas the single sequential trigger system discharged a nail fastener.

Prior to operator usage, PFDTs were inspected to answer questions pertaining to the PFDT Safety Audit form that addressed the conditions and safety features of each PFDT (requirement 1-3). None of the safety features for any of the four PFDTs were bypassed, tampered with, or disabled with regard requirement one. However, one PFDT had a noticeable air hose leak near the connection point of the PFDT and did not meet compliance with obligation two of the audit form. All PFDTs maintained compliance by releasing air pressure when the air hose was disconnected.

Statement four of the audit asked if the PFDT was operated in the presence of flammable liquids, gasses, combustible dusts, or other explosive atmospheres. Upon surveying the assembly area in relation to PFDT operation, there was no observed risk of uncontrolled flammable liquids, gasses, or combustible dusts were identified.

The fifth requirement of the audit asked if work operations were arranged so workers were not in the line-of-fire when the PFDT was utilized. No PFDT operators were observed in the line-of-fire when the PFDT was utilized.

The requirement for number six asked if operators inspected materials for knots, nails, straps, hangers, etc. that could cause recoil or ricochet prior to discharging the PFDT. This question was inconclusive and could not be verified without interaction with the operator, which may have skewed the findings.

To comply with question seven, the operator had to maintain eyes-on-task when discharging the PFDT. Two out of the four operators did not maintain eyes-on-task while operating the PFDT during the observation period due to conversation with another employee working alongside them. The two operators who maintained compliance with this requirement worked by themselves during the PFDT safety audit.

Requirement eight needed operators to maintain the proper footing and balance and not overreach when using their PFDT. All four operators observed maintained compliance throughout the length of the audit.

Obligation nine of the audit detailed the operator and other nearby employees must don safety glasses with side shields prior to handling the PFDT. All operators followed this safety requirement prior and during the handling of the PFDT.

Element ten specified that the operator’s free hand/arm maintain approximately 12 inches or more away from the discharge point. Each operator displayed at-risk behaviors and were at least at 12 inches or closer from the discharge point of the PFDT based on visual estimation. Furthermore, two operators were seen approximately one inch away from the discharge point of the PFDT at their assembly area.

Element 11 of the PFDT Safety Audit form stated the PFDT operator must disconnect the compressed air hose when performing maintenance (i.e. clearing jam, cleaning, inspecting), passing the PFDT to a co-worker, and/or traveling up and down a ladder or stairs. During the audit for this assembly area, one operator passed the PFDT to a co-worker without disconnecting the compressed air hose prior to initiating the hand-off. All other operators were not observed performing the listed tasks, so the question was not applicable for auditing purposes.

Requirement 12 stated the operator must not carry the PFDT with a finger on the trigger. All four operators were witnessed complying with this statement during the observation period.

Element 13 required the operator not lift/maneuver the PFDT by the air hose. One of the four operators demonstrated nonconformance after their PFDT dropped to the ground and was retrieved by lifting it by the air hose.

The 14th requirement specified the PFDT be stored in a secured position when not in use. All PFDTs were observed to be compliant. None of the PFDTs were overhanging in this assembly area.

Discussion

Results from workers compensation cases for Company XYZ related with the U.S. CDC (2007) findings in which more than 75% of PFDT injuries were diagnosed as a puncture wound or wound with a foreign body. Company XYZ’s loss run report did not indicate the number of loss workdays each compensable case incurred and therefore no comparisons could be made with Lipscomb et al.’s (2003) active surveillance study that half of puncture wounds resulted in lost time beyond the date of injury. In addition, Company XYZ incurred no fractures due to a PFDT incident which was low when compared to 8% of PFDT fractures documented by Lipscomb and Schoenfisch (2015) and 4% listed by the U.S. CDC (2007).

Baggs et al. (2001) identified the body part most likely to be injured by pneumatic nail guns in eight Washington Industrial Classification (WIC) codes were fingers (42.7%) and hand (23.3%) between 1990 and 1998. Comparable results were observed from Company XYZ's compensable claim data which showed fingers accounting for 35.7% of all body parts injured and hands receiving 16.7% of PFDT acute injuries.

A heavy distribution of acute PFDT injuries occurred in the last six months of the year (69%) during the studied period. This aligned with increased production commonly recognized by Company XYZ throughout the second half of the year to meet demand for new home construction in the United States.

In addition, Company XYZ experienced the least amount of acute PFDT injuries in 2010 and 2011. Lipscomb and Schoenfisch (2015) reviewed NEISS-Work between 2006 and 2011 and found work-related nail gun injuries to be significantly lower than what was reported by the U.S. CDC between 2001 and 2005. Lipscomb and Schoenfisch (2015) attributed the decline of their data to weakening of the residential housing market as part of the Great Recession which left many residential construction workers unemployed and unexposed to PFDTs. Since Company XYZ is directly affected by the residential construction industry, it could be assumed that a reduction in Company XYZ's PFDT acute injuries in 2010 and 2011 corresponded to Lipscomb and Schoenfisch's (2015) observation regarding U.S. economy during this period.

Previous research outlined in Chapter II indicated reasons for PFDT injury included nail penetration through a lumber work piece, nail ricochet after striking a hard surface or metal feature, missing the work piece, awkward position nailing, and bypassing safety mechanisms (DHHS & DOL, 2011). The U.S. CPSC (2002a) also listed a jammed nail gun, operator tripping on the air hose, and picking up the gun by the air hose as other explanations for accidental discharge. Upon review, corresponding details were documented in Company XYZ's claim data but also included incidents where the PFDT fell or swung into the operator when hanging from an overhead tool balancer and making accidental contact with the operator after the PFDT slipped off the worksurface while discharging fasteners.

The worker compensation records at Company XYZ did not specify what type of PFDT trigger system was involved in acute PFDT incidents. The report also did not reveal the level of PFDT experience operators had at the time of their acute injury. Therefore, comparisons could not be made with findings that 78% of apprentice carpenters who sustained a nail gun injury did so when using a CAT gun (Lipscomb et al., 2006) or the fact that apprentices in residential construction had a three times higher nail gun incidence rate than journeyman in residential construction (Lipscomb et al., 2003).

The loss record analysis at Company XYZ found assembly areas A4 and A20 to be the highest risk for PFDT acute injuries. To understand attributed reasons leading to a higher frequency of injuries in these areas, a PFDT Safety Audit form was organized based on findings in Chapter II to establish PFDT requirements for how assembly area conditions and operator behaviors would be evaluated. Specifically, in both assembly areas the PFDT safety audit revealed a high rate of nonconformance regarding operators maintaining eyes-on-task when discharging their PFDT(s). In addition, both assembly areas revealed operators not maintaining 12 inches or more away from their free hand/arm when discharging the PFDT. Lipscomb et al. (2003) had noted that placement of the hand not holding the tool was a highly prevalent characteristic for injuries across both types of CAT and SAT nail guns.

Though question six of the PFDT Safety Audit form was deemed inconclusive for both assembly areas during the audit, it is suspected operators did not always inspect their material prior to discharging fasteners due to the high frequency of ricochet incidents recorded in Company XYZ's worker compensation claim data.

Chapter V: Conclusions and Recommendations

Employees at Company XYZ have experienced acute injuries from PFDTs in assembly operations, leading to direct and indirect unplanned costs to the business and an outcome misaligned with the organization's goal to provide a safe and secure workplace for all employees. The purpose of this study was to identify actions which would eliminate or reduce acute injuries experienced by employees that utilized PFDTs in assembly operations at Company XYZ. To accomplish this purpose, the following two objectives were established:

1. Analyze acute PFDT-related incident history of Company XYZ to identify factors inherent to previous injuries.
2. Conduct a PFDT safety audit for assembly areas at Company XYZ that possessed the highest risk for PFDT acute injury.

The methodology utilized to review the extent of PFDT acute injuries included a review of Company XYZ's worker compensation claim records as well as performing a PFDT safety audit for two assembly areas which incurred the highest number of PFDT acute injuries over an approximate nine-year period.

Conclusions

The following major findings were a result of this study:

- Acute PFDT injuries resulted in a puncture to the body 69% of the time while a foreign body was significantly lower at 9.5%. Company XYZ applies many finishing nails and staples during the construction of window and door products which is believed to contribute to the high rate of puncture incidents and low rate of foreign body incidents.

- Seventy percent of the acute PFDT injuries were incurred to parts of the hands, thumbs, or fingers. The highest proportion of injuries were to the fingers (35.7%), followed by the thumb (19%), and then the hand (16.7%). These body parts are generally closest to the point of discharge for the opposite hand holding the PFDT at Company XYZ.
- A heavy distribution of acute PFDT injuries occurred in the last six months of the year (69%) during the studied time period. Company XYZ's production increases throughout the second half of the year to meet demand for new home construction meaning more hours worked by employees and more exposure to PFDTs.
- The cause of acute PFDT injuries at Company XYZ was well dispersed among various reasons. Though not documented in the research in Chapter II, being struck by a falling/swinging PFDT accounted for five acute incidents at Company XYZ.
- Area A4 had double the frequency of PFDT acute injuries between 2010 and 2018 compared to the next highest assembly location, Area A20. Upon auditing these assembly areas using the PFDT Safety Audit form, both areas revealed a high rate of nonconformance regarding operators maintaining eyes-on-task when discharging their PFDT(s) as well as operators not maintaining 12 inches or more away from their free hand/arm when discharging the PFDT which previous research indicated as a highly prevalent characteristic for injuries across both types of CAT and SAT nail guns.

Recommendations

In accordance with the hierarchy of controls, the following recommendations are provided as part of a continuous improvement effort to reduce acute PFDT injuries and improve employee performance in assembly environments:

- Engineering controls. To prevent PFDTs from slipping when discharging a fastener, Company XYZ could install PFDTs on a fixed guiderail or design a mounting bracket which would fit the profile of the substrate to ensure the fastener discharges at the same angle and is secured every time. In addition, a guiderail system could be moved to the side when the PFDT is not needed while still securing the PFDT in a safe location which would eliminate possible ergonomic risk factors and struck by hazards from PFDTs hanging overhead. Incorporating sequential actuation triggers whenever possible in assembly areas where PFDTs are required must be established if Company XYZ is serious about injury reduction.
- Administrative controls. PFDT training should be expanded to include both classroom and hands-on training by a qualified person. Classroom and hands-on training should be a requirement for any new PFDT operator and any PFDT operator observed performing an at-risk behavior while handling the PFDT or as a result of a PFDT acute injury. Refresher classroom training should be conducted for all existing PFDT operators on an annual basis. Supervision should conduct a PFDT safety audit using the PFDT Safety Audit form monthly, at minimum. For any existing CAT guns that are in the process of being replaced with the safer SAT gun or is deemed needed for assembly operations, supervision should distinguish the difference between these two types of guns through a different color paint or tape somewhere on these devices.

- Personal protective equipment. Company XYZ already requires all employees to wear safety glasses in the facility at all times. However, ensuring safety glasses adequately fit and protect the side of the eyes for PFDT operators may be an opportunity for Company XYZ to consider.

Areas of Further Research

The following several areas of further research were apparent upon the conclusion of this study and may contribute to the knowledge base for the safety of PFDT operators:

- Conduct a risk assessment to identify ergonomic risk factors for PFDT operators performing assembly operations in manufacturing and compare whether a SAT or CAT system poses increased risk for acquiring an MSD.
- Identify the cycle times required at different PFDT workstations to investigate if shorter cycle time requirements result in higher rates of PFDT injuries.
- Examine operator experience utilizing a PFDT and the associated frequency of PFDT acute injuries among different levels of experience in a manufacturing environment.
- Conduct research in manufacturing environments to evaluate the extent of PFDT injuries and the root cause of incidents.
- Investigate alternative engineering controls which would decrease the chance of PFDT operator injury to the hand, fingers, thumb, and arm.

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Appendix: PFDT Safety Audit

Date completed: ____/____/____ Work Area: ________________________

Trigger System: Full Sequential Single Sequential Contact Actuation Other:

Fastener Type: Nail Staple Other:

Requirements	Compliant (Yes or No)	If no, explain:
1. PFDT safety features were not bypassed, disabled, or tampered with (tampering includes removing the spring from the safety contact tip and/ or tying down, taping or otherwise securing the trigger so it does not need to be pressed).		
2. PFDT and air hose were free of air leaks and misalignment/ binding/ inoperable parts.		
3. Air hose coupling dissipated air within the PFDT when disconnected.		
4. PFDT was not operated in the presence of uncontrolled flammable liquids, gasses, combustible dusts, or other explosive atmospheres.		
5. Work operations were arranged so workers were not in the line-of-fire when the PFDT was utilized.		
6. Operator inspected materials for knots, nails, straps, hangers, etc. that could cause recoil or ricochet prior to discharging the PFDT.		
7. Operator maintained eyes-on-task when discharging the PFDT.		
8. Operator maintained proper footing and balance and did not overreach when using the PFDT.		
9. Operator and other nearby employees donned safety glasses with side shields prior to handling the PFDT.		
10. Operator's free hand/arm maintained approximately 12 inches or more away from discharge point.		
11. Operator disconnected compressed air hose when performing maintenance (i.e. clearing jam, cleaning, inspecting), passing the PFDT to a co-worker, and/or traveling up and down a ladder or stairs.		
12. Operator did not carry the PFDT with a finger on the trigger.		
13. Operator did not lift/maneuver the PFDT by the air hose.		
14. PFDT is stored in a secured position when not in use.		

Completed by: ______________________________________ Job Title: ________________________