A Structured Methodology for Adjusting Perceived Risk

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ABSTRACT

This papers details the background and the use of a structured analysis for risk assessment based on the Risk Homeostasis Theory. The general global theory of perceived risky behavior is examined and is shown to be applicable to a specific task, as opposed to theoretical constructs only. The Risk Homeostasis Theory is used here as a basis, for conducting a detailed risk analysis of aviation activities.

INTRODUCTION

A 1999 OSHA (Occupational Safety and Health Administration) census shows 21,283 reported cases of job related injuries while using handheld power tools, despite training and warnings located on machines and within procedures. (OSHA website, statistics). For a person to perform a task effectively, both education and training are needed, because training targets the actions. The purpose of a lecture class (education) is to grasp the conceptual theory, and the lab (training) is an opportunity to convert the theory into practical application or training. To perform a job task safely, the same approach utilizing both education and training should be taken. Training may only consist of how to do the act, and focus less on the conceptual theory of "why" certain acts are done, but without the "why" the determination of the adverse outcomes can not be internalized. An increase in the perception of the cost of risky behavior acts as a motivator to behave safely. Motivation to avoid risky behavior is driven by an individual's target level of risk (TLR). TLR is the perception level that describes, intuitively, the amount of risk accepted by an individual (Wilde, 1994). It is established based on perceived costs and benefits of both risky and safe behavior. In a given situation, the TLR is compared to its counterpart, the perceived level of risk (PLR). The PLR is the amount of risk perceived while performing an activity. When there is a disparity between the TLR and the PLR, individuals adjust their actions to bring both perceptions into balance.

This process of continuously balancing the perceptions of risk is called Risk Homeostasis Theory (Wilde, 1982). Performing a job safety analysis can be a key for adjusting the target level of risk. The job safety analysis can systematically identify task hazards, and the information from the analysis can be used to provide information to enable people to make adjustments in their perceptions of what is risky and what is not, based on knowledge of potential outcomes.

BACKGROUND

Risk Homeostasis Theory (RHT) was developed to explain behaviors of individuals and the propensity to experience a traffic accident. The model stated that road users perceived a certain level of accident risk in a given situation, (PLR), which was compared with the level of accident risk they were willing to accept, (TLR). Whenever there was a discrepancy between the two perception levels, the individual would make behavioral adjustments to re-establish the balance (Wilde, 1986). An individual would not have continued to experience more risk than they wanted intuitively.

Traditionally, countermeasures implemented to reduce accidents, such as speed restrictions or seatbelt use, were believed to be fully effective based on engineering calculations. The generally accepted belief was that the driving environment could have been made safer by manipulating external controls and adding restrictions that limit the opportunity to take risks. With the traditional view, the responsibility for controlling the accident rate resided with the traffic legislators, rather than the drivers. 4-way stops at dangerous intersections, safety bags in cars, child safety seats, and anti-lock brakes, were all designed to be barriers between the person and the negative outcome. Within an industrial setting, these external countermeasures were represented by personal protective equipment such as, fall harnesses, hearing protection, machine guards, pull-out devices, and new processes that inherently prevented the possibility of injury. These measures were designed to be a barrier between the person and the negative consequence.

Implementing countermeasures has a lesser effect than calculated because drivers transfer the risk associated with the newly regulated behavior to other unregulated behaviors. In the instance of driving, a person driving a car with anti-lock brakes may decide to drive faster and begin stopping later during the rain because of the car's highly advanced braking system. The same could be said on a worksite when implementing a pull out device on a press. A pull out is a safety device physically connecting the operator to the moving part of the press by means of a lightweight cable (Brauer, 1994, 159). On the downward stroke, the motion of the press acts on the straps causing the operator's hands to be pulled out of the path of the press. Implementing this safety device may cause the operator's behavior to change, since the operator may try and quickly adjust die pieces while the press is on its downward stroke. The operator may logically believe that because there is no resistance on the straps, there is still time to make a quick adjustment. This change of behavior is readjustment of the risk experienced. A more radical view of the compensation theory is represented by the RHT model of driver behavior developed by Dr. Gerald Wilde, shown in Figure 1.

With the comparison action depicted in Figure 1, "…apart from temporary fluctuations, time-averaged accident risk is independent of factors such as the physical features of the environment and operator skills, and ultimately depends upon the level of accident risk accepted by the road user population in return for the benefits received from mobility in general and from specific risky acts in mobility in particular (Wilde, 1984)." The accident rate in the jurisdiction is the output of the PLR closed-loop process, which is determined by the person's pre-established TLR. The levels of risk described in the RHT model are intuitive and cannot be depicted by actual numbers (Wilde, 1994).

To clarify the PLR closed-loop process, consider the following scenario where numbers are used to illustrate how the comparison process would work. An individual has a pre-established TLR rated as a five, which means the person is willing to accept a risk level that they rate as a five. If the person is in a situation in which he/she perceives a risk level rate of eight, then he/she adjusts the actions so as only to perceive a risk level rate of five. In the event of disparity, the PLR adjusts to match the TLR. A person analyses their actions, predicts an outcome, and compares the assessment to their personal idea of what should be done. For example, Daimon, an accomplished welder, is given the assignment to weld two steel pieces. Daimon analyses the task, then, proceeds to retrieve a welding helmet, a pair of gloves, an apron, and a fire extinguisher, and remove his contacts. Based on his knowledge of the task, his understanding of the hazards, and various experiences, Daimon performs the safety actions because he does not want to accept the amount of risk if the actions are not performed. Not performing the safety acts exposes Daimon to possible accidents: blindness from melting contacts, hot metal burns from not wearing gloves and apron, or a major fire because the fire extinguisher is not located nearby causing a slower response. Each possibility of an accident raises the perceived level of risk. Adequate education, training, and experiences lead Daimon to understand the task and the hazards. He does not want to risk loosing his eyesight, or getting burned, or loosing his job because the shop burned down. Daimon performs the safe actions to balance his perceived level of risk with his pre-established level of risk.

Figure 1 also depicts the risk level of the TLR as not determined by skill or the environment; rather, the TLR is determined by the **perceived** costs and benefits of risky and safe behavior. For instance, Bob is driving down the highway behind Ted. Both are driving at a speed of 70 miles per hour (mph). If it starts to rain and Bob slows to a speed of 65 mph while Ted maintains his speed of 70 mph.

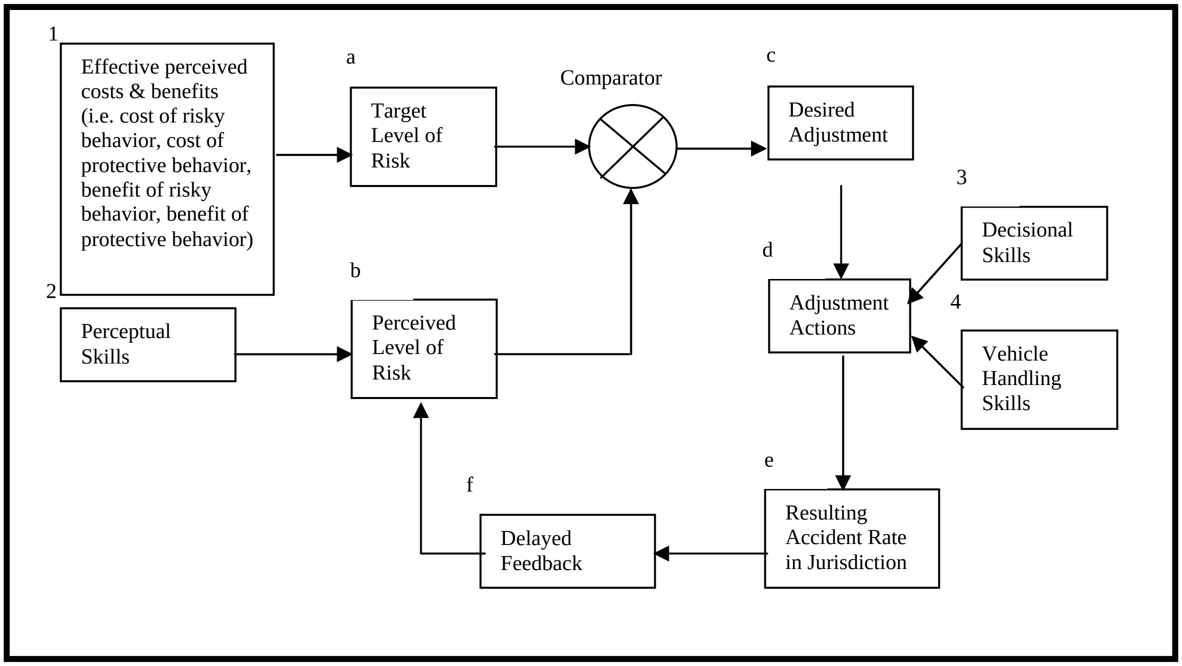

Figure 1. RHT Model of Driver Behavior.

The rain means nothing here except in the context of each driver's mind and their resultant PLR. The consequences are predicted based on the current situation, meaning both individuals observe their actions and assess a risk level. Bob feels that if he maintains his speed, he runs the risk of crashing. This consequence is a result of Bob recalling when he skidded and crashed in the past, recalling one of his friends crashing in such weather, or not feeling his tires are adequate for the road. When Bob assess the risk level based on his current actions, he compares it to his target level of risk. Bob decides to slow down in order receive an acceptable risk level. Ted slowly pulls away from Bob because he maintains his speed of 70 mph. Ted assesses his risk level and determines that the risk received is not greater than the risk willingly accepted. Ted's prediction of the consequence does not include crashing because he has never experienced, either directly or indirectly, that action.

Perception is a cognitive function, meaning to apprehend with the mind, or to understand (Oxford, 1997). To directly affect perception, a method must be used that targets the cognitive and thinking processes. A common approach to teaching tasks in industry, is training. People either watch someone perform a future task, or perform the task themselves while being observed by an "expert." "Behavior is learned and can be changed by providing people with new learning experiences" (Geller, 2001, 115). During training, learning occurs when the behavior has changed as a result of the direct and indirect experiences. The training approach requires the employee to practice the desired behavior and receive pertinent feedback to support what is correct and incorrect (165). The findings of two feedback studies (Jagdeep, Chhokar & Wallin, 1984; Komaki, Heinzmann & Lawson, 1980) conclude that performance improves with the introduction of feedback, declines when withdrawn, and improves again when reintroduced.

Safe behavior, like any other behavior, is learned through the repetitive interaction of action and consequence. Training "acts a person into thinking a certain way" (Geller, 2001, 115). Therefore, safety training is a way to act a person into thinking safely. A more direct path to having people think "safe" would be to control the end result. For a person to understand, to know "why", activities of repetition should be supported by education. In college, the lecture is designed to teach the conceptual theory, the "why", and the lab is designed to teach the practical "how" application actions.

"Education targets thought processes directly and might indirectly influence what people do" (Geller, 2001, 165). The cognitive processes pertain to a person's attitudes, beliefs, values, intentions, and perceptions (165). Rather than "acting into a certain way of thinking", a person "thinks into a certain way of acting" (165), thus requiring analytical skills, and not just the surplus of repetitive action. A person's behavior adjusts because they perceive an understanding of why certain actions are performed. In a safety situation, a person's behavior adjusts because their target level of risk is altered. A person now has the cognitive ability to understand the ramifications of performing certain actions. "If we do not educate people about the principles or rationale behind a particular safety policy, program or process, they might participate only minimally" (163) in following the safety policy, program, or process. To motivate individuals to performing safe actions, training should involve informing about the negative consequences and personal physical ramifications when performing activities unsafely (Re Velle, 1980). Safety instructions should be more in tune with the educational approach. They should assist in the development of the conceptual "why" as well as add pertinent information to the knowledge base.

A Job Safety Analysis, JSA, is a technique that can be used to develop safety instructions more in tune with RHT. A JSA is a systematic technique used to identify inherent hazards associated with a task (Re Velle, 1980; Job Safety Analysis, 1999). The technique consists of analyzing the task by breaking it down into successive steps, investigating the hazards associated with each step, and developing solutions that can either eliminate or guard against the hazards.

In industry, the JSA can be performed proactively or retroactively (Feyen, 2002). The goal of the JSA is to accomplish the first level of accident prevention: learning the basic causes of each accident (1997, Accident Prevention). Once a cause has been identified, proper countermeasures can be implemented. The most common result of the JSA is the creation of a Job Safety Procedure, JSP.

The combination of information in the JSP affects the information stored in the knowledge-based level. It notifies of the hazards associated with the task, rather than trusting that the technician knows the risks, based on prior experiences. The JSP also informs how to decrease the probability of having an accident, which is information for the knowledge base when making decisions. However, the JSP does not strongly affect the mental model because it does not target the conceptual "why" associated with the safety act. To target the "why", possible accidents, and their probabilities should be included along with notification of the hazard. In the JSP, under the heading, Required/Recommended Personal Protective Equipment, it prohibits wearing rings. The JSP should also state that wearing a ring while operating an air tool might lead to amputation of the finger. The mental model is described as an individual's internal representation of two aspects: its procedural and conceptual attributes (Riding and Rayner, 2000, 202). Notification of the "why", the conceptual attribute, affects the mental model. The combination of the stored information and the mental model results in a perception of costs and benefits associated with compliance or deviance from the recommended practice. In accordance with RHT, the target level of risk is established.

A JSA is a **systematic** approach used to control large amounts of subjective information. Completion of the following steps is required for the JSA: 1) select the job to be analyzed 2) breakdown the job into successive steps 3) identify the hazards and potential accidents 4) develop ways to eliminate hazards and potential accidents (Re Velle, 1980; Job Safety Analysis, 1999).

Selection of the job is the first task. The selection JSA can be performed proactively or retroactively (Feyen, 2001), and can be selected based on the number of historical accidents or incidents at the company. Another method of selecting the job is to analyze where workers are exposed to excessive hazards or hazardous materials. New procedures are also considered good candidates for a JSA for two reasons. It is cheaper, to implement something correctly the first time, and secondly, a proactive approach can be taken because employees start out with the proper safety procedures and behaviors.

Next, separate the task into successive steps. Too much detail causes the analysis to become unnecessarily long and trivial. Too little detail leaves holes in the procedure and counteracts the effectiveness of the JSA. A general rule of thumb is that most jobs separate into 10 – 15 basic steps (Accident Prevention, 1997). The instructional list should have enough steps to accurately describe the work, but no more than are actually needed. After the instructional steps are created, identify the hazards, determine the potential accidents for each step, and analyze the causes of those accidents. Accidents are categorized into 13 basic types (Accident Prevention; 1997, Job Safety Analysis, 1999):

1. Fall to same level
2. Fall to lower level
3. Caught in
4. Caught on
5. Caught between
6. Contact with electricity
7. Contact with heat
8. Contact with cold
9. Contact with radiation
    a. Contact with toxic or noxious substances
10. Overexertion
11. Struck by
12. Strike against

Finally, effort is put forth to develop a way to eliminate the hazard. The first hazard control method to be considered should be elimination (Brauer, 1994). If there is no hazard present, then there is no chance of an accident. If elimination is impractical, choices of reducing the hazard and implementing safety devices, warnings devices, and procedures are considered. The U.S. Department of Labor, Mine Safety and Health Administration (1999) concludes that solutions are normally from one of the following categories: Environmental change, Job frequency, Protective apparel, and Job procedures. For every hazard identified, a solution is needed to offset its potential.

PERFORMING THE JSA

The JSA requires the completion of four major steps; scope development, task analysis, amalgamation, and countermeasures. The researcher had previously taken the training course analyzed in this study, completed the complete aviation technology program, received an FAA Airframe and Powerplant mechanic's certificate, and had been involved with safety research projects with industry in the past. The researcher had experience in observing people in an aviation setting and gathering data used to assess safe behavior. The job safety analysis procedure was performed in accordance with the Job Safety Analysis procedurals (Feyen, 2002).

Scope development

A job safety analysis was performed on riveting a patch repair in a sheet metal fabrication training laboratory in a technology based aviation program at a major U.S. university. The general function of the laboratory studied was to develop a basic knowledge in undergraduate students of the different tools used for aircraft manufacture and repair. The subjects were freshmen students in the aviation technology program.

Scope development consisted of: formulating the analysis limitations by identifying general information, sketching the major tools used in the task, and identifying all tools needed along with a brief description of their operation. The following general information was documented prior to the analysis to avoid irrelevant information: Analysis Limit, Job Identification, Work Objective Job Location, Operator ID, and Shift Length. The general information for the task was summarized in Table1.

A hazard was defined as a "…potential or inherent characteristic of an activity, condition, or circumstance which can produce adverse or harmful consequences (Brauer, 1994, 80)." The analysis was limited to including hazards associated with physical injury and avoided identifying hazards associated with aircraft damage, environmental damage, or failure of the equipment.

Three computer sketches were created, giving a general depiction of the environment and primary tools used. These included the shop floor layout, the work stand, and the rivet gun (Figure 2) and an illustration of the work stand (Figure 3).

The work stand was 73 inches tall x 48 inches long x 36 inches wide, and held two sections of aircraft skin. The aircraft skin was connected to the work stand by four tabs located along the base bar of the work stand and at the top of the center bar. The task required the students to work in pairs; two students per work stand.

The rivet gun was a Taylor T-4x aircraft pneumatic riveting hammer (Figure 4). For operation, the student squeezed the trigger of the rivet gun allowing pressurized air into the handle of the gun. The rivet gun was also designed so that the pressurized air pushed the piston forward, toward the barrel, when in the back position (near the handle), repeatedly. This design created the reciprocating motion for the piston and the vibration of the rivet gun. The regulator knob was used to control the amount of air used within the rivet gun. Adjustment of the knob controlled in the speed of the piston and thus the force of the piston's impact. A pneumatic air hose, rivets, a bucking bar, and a wood block were also used in the riveting task. The air hose used in lab was 10 feet long, had a female quick connect adapter located on each end, and was reinforced with aluminum coils on the ends to prevent damage to the adaptor/hose connection area. A bucking bar, a piece of steel, was used as a hard surface to press against the rivet shaft when riveting. Wooden blocks were also observed in the lab to be used for testing and setting the rivet gun regulator setting prior to using the rivet gun on the actual aluminum structure under construction. The regulator setting was tested by: placing the rivet gun header on the wood, squeezing the trigger, and noting the piston speed both audibly and tactily. The safety equipment items were: gloves, hearing protection, and safety glasses.

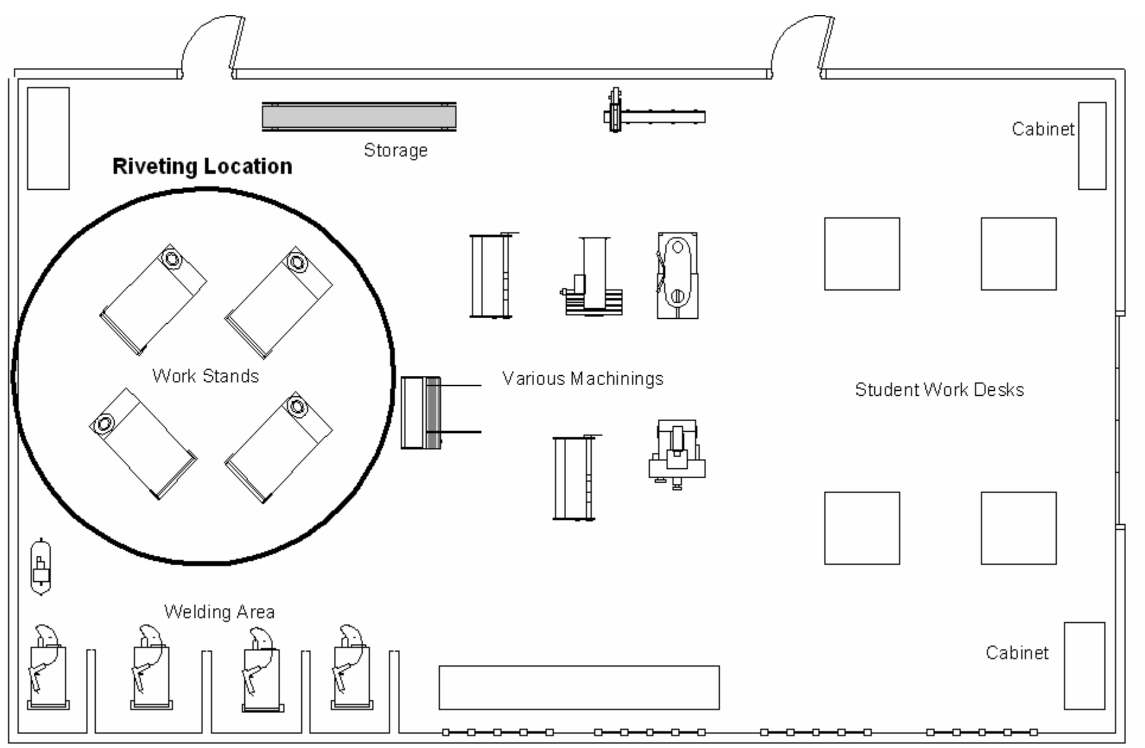

Figure 2. Work area layout

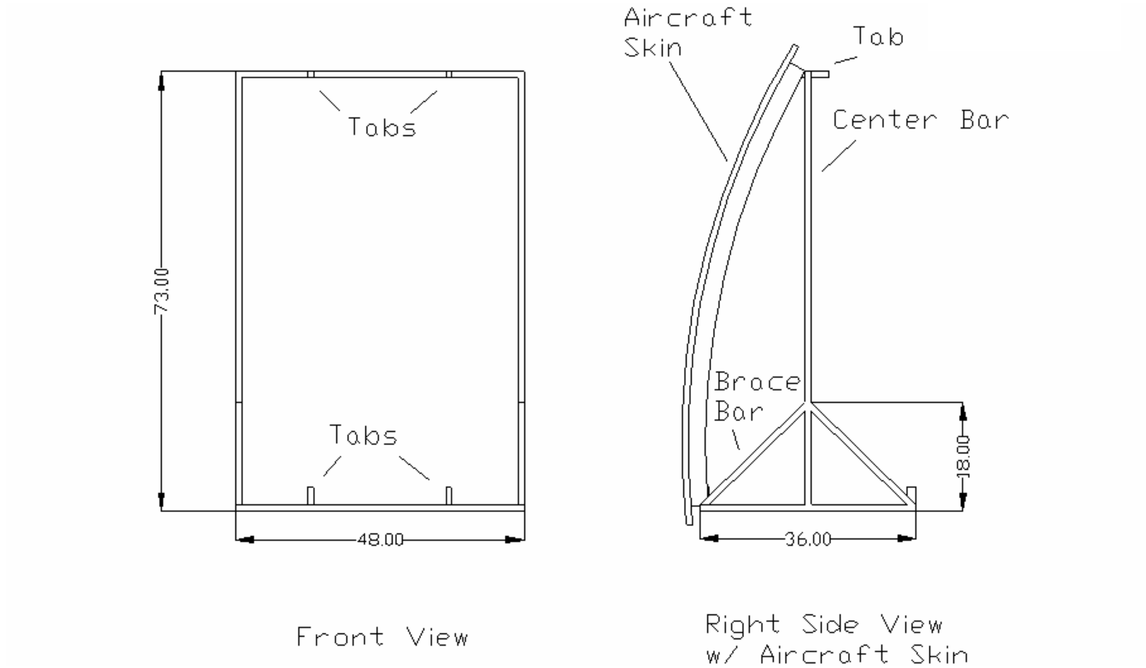

Figure 3. Work Stand.

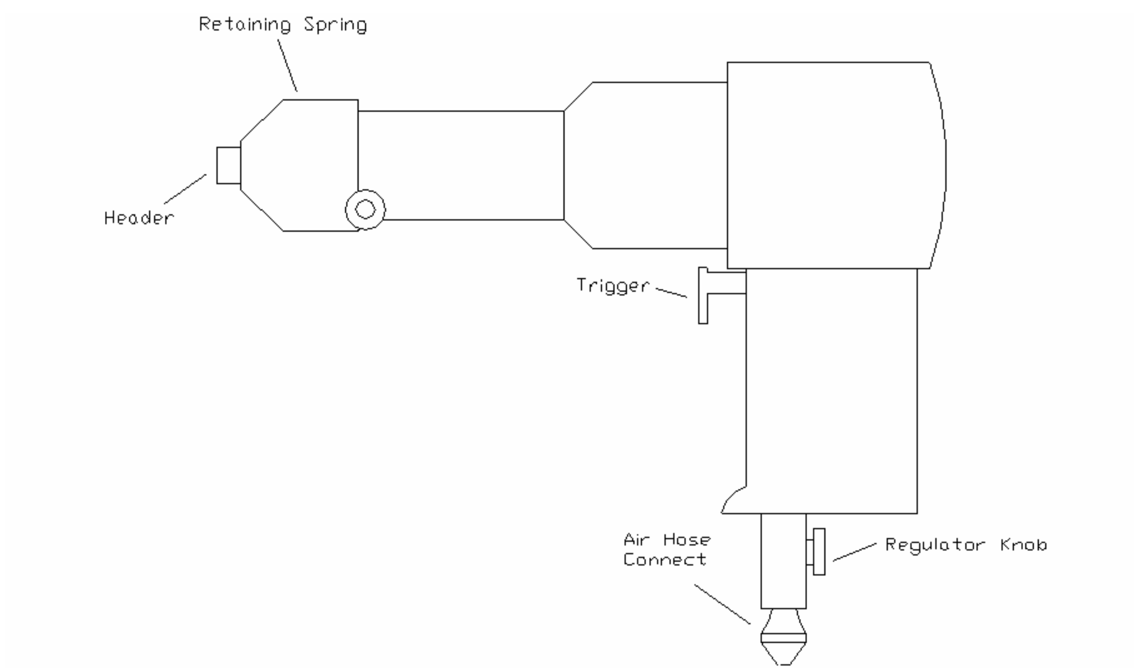

Figure 4. Rivet Gun.

Task Analysis

The question when observing the students was: "What are the hazards associated with this task?" The question was not, "Did the student perform any unsafe activities while performing this task?"

Two people were needed to rivet a patch repair and a method of tapping on the aircraft skin was used to communicate intention, and success or failure. One student (technician one) operated the rivet gun and the other student (technician two) held the bucking bar. The aircraft skin was positioned on the work stand (Figure 3). The student holding the bucking bar positioned himself or herself, between the skin and the work stand center bar. Task analysis consisted of: itemizing the task into successive steps and identifying the hazards associated with the task. The students had been taught the procedure previously by demonstration of the laboratory instructor. A total of 12 hours were used for this investigation. The task was observed 15 times: 10 student observations, 2 instructor observations, and 3 researcher performances.

Observation of the task revealed 19 primary sequential steps:

1. Remove spring from end of rivet gun
2. Install header into rivet gun
3. Screw spring to end of rivet gun
4. Connect air hose to rivet gun
5. Test rivet gun regulator setting on wood block
6. If needed, adjust regulator setting on rivet gun
7. Insert rivet into hole
8. Technician one places rivet gun header on rivet head
9. Technician two stand on backside of aircraft skin
10. Technician two places bucking bar on rivet shaft
11. Technician one, communicate intention to squeeze trigger
12. Technician one squeeze rivet gun trigger
13. Technician two removes bucking bar
14. Technician two checks height of bucked rivet shaft
15. Disconnect air hose
16. Hand hose above head height
17. Unscrew spring from end of rivet gun
18. Remove header
19. Screw spring to end of rivet gun

After development of the sequential steps, hazards and accidents were identified for the task utilizing nomenclature and categories from the accident types and the general hazards checklist located in Appendix A.

- Contact with cold
- Contact with radiation
- Contact with toxic or noxious substances
- Overexertion
- Struck by
- Identified hazards: Fall to same level
- Fall to lower level
- Caught in
- Caught on
- Caught between
- Contact with electricity
- Contact with heat
- Strike against

The general hazard categories, located in Appendix A, were kinetic/mechanical energy, pressure, acceleration/deceleration/gravity, physiological, and human factors. The basic operation of the tools used for the task was studied in order to effectively identify the hazard categories. For the task, the items used were: a rivet gun, a work stand, pressurized air hose, rivets, and rivet gun accessories. The rivet gun piston moved in a reciprocating fashion, therefore, the general hazards associated with Kinetic/Mechanical Energy hazards were used. Pressure hazards category was used because the task involved utilizing pressurized air. The task also involved handling of small parts and vibrating parts, which could have resulted in a student dropping tools and items. The Acceleration/ Deceleration/Gravity hazards were reviewed. The task involved moving in and out of a confined area: therefore, Physiological hazards were used and were summarized in Table 2. Human Factors is a subset of Physiological hazards.

The following hazards were determined to occur during the riveting process:

1. Falling Object
2. Noise Exposure
3. Prolonged exposure to vibration

4. Struck by
5. Fall to lower level
6. Awkward Position
7. Pinching
8. Slipping/Tripping

Amalgamation

Amalgamation required: identifying when the hazard occurred and generating ideas of possible consequences related to the hazard or accident. The steps were observed being performed, and from the list of hazards and accidents created from the task analysis step, labeled with the hazard. It was possible for there to be more than one hazard associated with a step, it was possible for there to be no hazards associated to a step, it was possible that the same hazard was associated to several steps, and it was possible that the existence of one hazard to generate the existence of another. The results were listed in Table 3.

Consequences of hazard/accident occurrence were also generated based on the researcher's expertise at this technical task. The researcher used information from several company job safety analyses, previous safety courses, cumulative trauma injury research, military aviation experience from the course instructor, and personal experience. Ideally, a group of safety observers would have been used to allow for a wider breadth of consequence possibilities. "What if" scenarios were assessed. The researcher asked the following questions in the development of the consequences: "What are the possible consequences of this hazard?" and "What type of injury will be sustained if this hazard occurs?"

The purpose of identifying the consequences is to give the future student an idea of the possible ramifications associated with performing a risky act. According to RHT, perception of the cost of risky behavior affects the target level of risk. Notification of the physical cost associated with performing a risky act, meaning the possible outcomes from the hazard condition, affected perception and thus, the target level of risk. The information is displayed in Table 4. The table lists the hazard/accident and the physical result of such an accident occurring. The method displayed in this procedure for generating ideas is not the best way; however, due to the characteristics of the study, the method is best for completion within the allotted time frame.

Excessive noise is a cumulative trauma disorder. The result of constant exposure to excessive noise may result in a reduced hearing capability. This injury is non-recoverable. Cumulative trauma disorders are also associated with prolonged vibration exposure. Three main injuries are Hand-Arm Vibration syndrome, carpel tunnel syndrome, and trigger finger. Hand-Arm Vibration syndrome (HAVS), also known as white hand, is when feeling is lost in the hand. The hand takes on a pale whitish color in this condition. White hand is a result of prolonged exposure to holding a vibrating object. Carpel Tunnel syndrome is inflammation of a tendon located in the wrist. Inflammation occurs after prolonged exposure to working with the hands, with the wrist bent or deviated in the ulnar position. Trigger Finger is when the tendon located above the middle joint of the finger squeezing the rivet gun wears and as a result the finger has no angular deflection. It can only move to the straight position or the bent position. The results of the tripping/slipping hazard are stumbles, sprains, fractures, bone breaks, and concussions. Awkward position, primarily occurring for Technician two and occasionally for Technician one, can result in stiffness, muscle aches and strains from maintaining a static position for prolonged periods of time. Falling to a lower level is a hazard only relevant when utilizing a ladder or other elevation device. The consequences are similar to tripping/slipping. Falling objects is listed as a hazard because its occurrence generates another hazard. The consequence of a falling object hazard is the generation of a tripping/slipping hazard. Pinching occurs when the skin on the hand gets caught between the coils on the retaining spring. Possible consequences were welts and broken skin. Finally, consequences of being struck by flying objects result in minor bruises and, if contacting the eyes, eye irritation.

Countermeasures

The safety procedures were the result of both the hazard identification and the amalgamation steps in the JSA process. The recommended countermeasures were the actions necessary for the student to avoid the negative consequence. The actions involved using existing safety equipment or performing certain steps prior to the activity (Table 5).

Ordering of the consequence column and the recommended countermeasure column are in accordance with the ordering of the hazards in the hazard/accident column. Step 12 exposes the student to the following hazards: prolonged vibration, noise exposure, awkward posture when kneeling, struck by objects, pinching, and fall to lower level. Prolonged vibration exposure can cause HAVS, trigger finger, and carpel tunnel syndrome. The recommended countermeasure is wearing gloves. The gloves in the lab are not vibration resistant gloves; however do provide a degree of protection from the vibration effects. Extended periods of noise exposure can cause a reduction in audible capability. The recommended countermeasure for avoiding the negative consequence is wearing hearing protection. When kneeling for extended periods of time stiffness develops in the knee joint. The recommended countermeasure for awkward position hazards, as well as prolonged vibration exposure, is to take frequent breaks. The breaks should consist of walking around or simply both students changing positions. Getting struck by flying objects can leave a bruise or contact the student's eye. To avoid contact with the eyes, recommended countermeasure is wearing eye protection. Pinching, occurring on the hand can cause welts and broken skin. It is recommended that gloves be worn when performing the riveting task. Finally, falling to a lower level can cause broken bones, fractures, sprains, and concussions. During conditions when a ladder is needed to gain height, check the ladder for stability and operation prior to use. The purpose of the job safety procedures is to assist with the development accurate and complete reasons "why" certain safety actions are performed. Instead of a student simply wearing gloves, or hearing protection because it was read on a warning label or list of instructional steps, a student can now understand why the safety equipment is used, and have a better understanding of the costs when not using the recommended countermeasures.

A priority system was established to suggest safety improvement. A probabilistic risk assessment technique, MIL-STD-882D, was used to identify the hazard's probability of occurrence. MIL-STD-882D was a qualitative assessment tool that involved ranking the severity of the hazard/accident consequence, and ranking the hazard/accident frequency, taking into account the exposure time interval. Although some guidelines were defined, the technique was subjective and ranking had a degree of reliance on the analyst's experience and skill. The two rankings, probability and severity, were then combined in a matrix, shown in Table 6, and the urgency of elimination or reduction to exposure was determined.

The chart compares the probability of mishap ranking to the severity of consequence ranking and results in a recommended action. The recommended action is divided into three risk code actions. Code 1, requires immediate suppression of the risk. Code 2, allows the activity to occur only if regulated by management. Code 3, allows the activity to occur and is not considered needing immediate attention. As a general rule, do not expose employees to risks resulting in a code 1 or code 2. Identification of risks resulting in those areas is considered first when recommending a countermeasure.

Severity of consequence was divided into four categories: catastrophic, critical, marginal, and negligible. The definition of each category was listed in Table 7.

Probability of mishap was divided into six levels: frequent, probably, occasional, remote, improbable, and impossible. The definition for each level was itemized below.

- Frequent = Likely to occur repeatedly in lab life cycle (multiple events every week).
- Probable = Likely to occur several times in lab life cycle (one event every week).
- Occasional = Likely to occur sometime in lab life cycle (one event every semester).
- Remote = Not likely to occur in lab life cycle, but possible (one event every two semesters).

- Improbable = It can be assumed occurrence may not be experienced (less than one event for every four semesters).
- Impossible = Physically impossible to occur (no accident events).

The scope of the study was also to identify hazards that caused physical injury and avoid hazards that caused damage to the equipment and the environment. The definitions of the severity categories were a combination of personnel illness/injury and down time. The down time column signified the recuperation time for the type of injury sustained. A catastrophic injury or illness was one that caused permanent loss or required a recuperation time greater than 4 months, such as amputation, severe head trauma, and burns. Critical injuries resulted in a recuperation time of 2 weeks to 4 months, as with bone fractures and sprains. A marginal injury was an occupational injury or illness that resulted in a recuperation time of 1 day to 2 weeks, such as cuts, abrasions, bruises, and minor crushing injuries. Finally, negligible injuries were those that required a recuperation time of less than a day. Such conditions resulted in no injury or illness. The modified severity categories were illustrated in Table 8.

The severity of consequence was identified, and the frequency, based on the reduced probability scale, was estimated. The ranking was put into the MIL-STD-882D, Table 6, and the resulting risk code and recommended action was noted. A similar analysis was conducted for all hazards identified. Table 9 listed the results of the individual rankings. The priority column coincided with MIL-STD-882D risk action levels. Level 1 was high, Level 2 was medium, and Level 3 was low.

Excessive exposure to noise and vibration were the major hazards to be avoided while riveting a patch repair in the lab. The probability for exposure was listed as frequent because the hazard of vibration and loud noises was repeated when performing the task. The severity was ranked as critical because, unlike most other outcomes listed, the cumulative trauma disorders were unrecoverable. Some symptoms eventually would subside after sufficient rest; however, there was a permanent disabling effect due to susceptibility of recurring injuries and regenerative capabilities of the body. Prevention was considered the better approach for controlling such hazards. The resulting priority rating was identified as high. This meant that some form of countermeasure should be implemented soon that would reduce the affects of the hazard.

A list of recommended safety controls was created. The safety controls, Table 10, were: generation of job safety procedures, spare ear muffs, impact absorbing (IMPACTO) gloves with elastic support, mobile work tables, additional training, kneel pads, and interval inspections. The recommendations were listed in the order of hazard importance as concluded with the probabilistic assessment technique.

FINDINGS AND DISCUSSION

Given the existence of differing cognitive styles, introducing instructions by textual information, targets only a select group of individuals. The individuals targeted have a cognitive style applicable to learning the information within the mode of transmission. The implementation of instruction suggests an educational approach. In order to educate about hazards using instruction, the information presented should have an affect on an individual's awareness, mental model, perception of cost, and rules and assumptions governing behavior. In education, a person is informed on how to perform a task, why a task is performed, the end result, and "what if" scenarios. The mental model is affected by explaining how, and why the task is performed. Informing of the end result establishes goals and expectations. Finally, "what if" scenarios formulate the rules and assumptions that govern behavior.

The information required for education of the hazards can be obtained through a job safety analysis presented in the Table 11.

CONCLUSIONS AND RECOMMENDATIONS

This study argued that education of the costs and benefits associated with performing risky actions would adjust the target level of risk. Essentially, education about the cost would increase their perception of the cost, and reduce the amount of risk willingly accepted. If students were informed of the consequences of risky behaviors, then they would have been educated on the cost of performing risky behaviors. The hazard/accident-consequence table developed during the JSA amalgamation step determined the information needed to be included in educational approach.

The educational safety awareness instruction should be similar to Table 11 and include: the hazard, the cause of the hazard, possible results of the hazard, and the action needed to avoid the hazard. Presentation of instruction in this manner affects the student educationally by adjusting their hazard awareness, safety mental model, perception of cost associated with the hazard, and their rules and assumptions that govern their behavior. To encourage education, both the procedural steps and the safety steps should be presented together. In industry, procedures list their warnings, cautions, and notes prior to listing the procedural steps. It is recommended that the industry format be used. The hazard information should be located prior to the procedural steps in order for the student to perceive and understand the hazard prior to performing the task.

Notification of the hazard frequency can also affect safety awareness. Without notification of frequency, the awareness is governed by previous experiences of perceiving the accident. As a result the student is trained to believe the hazard never occurs because it has not been perceived in the past.

A group should perform a JSA. A large percentage of a JSA is subjective assessment: hazard identification, consequences, probability assessment, and recommendations. Each of the subjective categories, however, can have an increase in validity by increasing the number of individuals assessing the task.

Table 1. *General Task Information.*

General Information	***Definition***
Analysis Limit	Analysis will be limited to including hazards associated to physical injury and avoid hazards associated with failure of the task.
Job Location	Sheet metal training laboratory
Job Identification	Riveting Lab
Work Objective	Rivet a patch repair on aircraft skin
Operator Identification	Students
Shift Length	4 hours /week

Table 2. *Physiological work hazards.*

Hazard Category	**Definition**
Kinetic/Mechanical Energy hazards	Hazards present as result of one or more objects in m colliding with another object under a degree of magnitude.
Pressure hazards	Hazards present as a result of a fluid (air or gas) maintained under a constant force.
Acceleration/Deceleration/Gravity hazards	Hazards present as a result of an object rapidly changing its state of motion.
Physiological hazards	Hazards present as a result of lack of compatibility between personnel capabilities and task requirements.
Human Factors	A subset of the Physiological hazards category.

Table 3. *Task steps and hazards.*

Task Step	**Hazard/Accidents**
1. Remove spring from end of rivet gun	Falling object Noise Exposure Tripping/Slipping
2. Install header into rivet gun	Falling object Noise Exposure Tripping/Slipping
3. Screw spring to end of rivet gun	Falling object Noise Exposure Tripping/Slipping
4. Connect air hose to rivet gun	Struck by Noise Exposure
5. Test rivet gun regulator setting on wood block	Struck by Noise Exposure
6. If needed, adjust regulator setting on rivet gun	Struck by Noise Exposure

7. Insert rivet into hole	Fall to lower level Falling object Noise Exposure Tripping/Slipping Awkward Posture
8. Technician one places rivet gun header on rivet head	Fall to lower level Noise Exposure Tripping/Slipping Awkward Posture
9. Technician two stand on backside of aircraft skin	Tripping/Slipping Awkward Posture
10. Technician two places bucking bar on rivet shaft	Awkward Posture Noise Exposure
11. Technician one, communicate intention to squeeze trigger	Noise Exposure Awkward Posture
12. Technician one squeeze rivet gun trigger	Fall to lower level Struck by Noise Exposure Pinching Awkward Posture Prolonged vibration exposure
13. Technician two removes bucking bar	Awkward Posture Noise Exposure
14. Technician two checks height of bucked rivet shaft	Awkward Posture Noise Exposure
15. Disconnect air hose	Struck by Noise Exposure
16. Hang hose above head height	Noise Exposure
17. Unscrew spring from end of rivet gun	Falling object Noise Exposure Tripping/Slipping
18. Remove header	Falling object Noise Exposure Tripping/Slipping
19. Screw spring to end of rivet gun	Falling object Noise Exposure Tripping/Slipping

Table 4. *Hazard Consequences*
.

Hazard	**Consequences**
Excessive noise	Reduced audible capability (non-recoverable)
Prolonged vibration exposure	Hand-Arm Vibration Syndrome (HAVS), Trigger Finger, Carpel Tunnel Syndrome (non-recoverable)
Tripping/Slipping	Concussions, broken bones, fractures, sprains, stumbling
Awkward position	Muscle strain, muscle aches, stiffness (recoverable)
Falling to lower level	Concussions, broken bones, fractures, sprains,
Falling objects	Generation of tripping and slipping hazard
Pinching	Pinching
Struck by flying objects	Eye irritation, bruise

Table 5. *Hazard Countermeasures.*

Sequential Step	***Hazardous/Accident***	***Consequence***	***Recommended Countermeasures***
1. Remove spring from end of rivet gun	• Tripping/Slipping • Noise Exposure • Falling object	Broken bones, fractures, sprains, stumbling, concussions, reduced audible capability (non-recoverable)	• Housekeeping/Keep floor clear of obstruction • Wear hearing protection
2. Install header into rivet gun	• Tripping/Slipping • Noise Exposure • Falling object	Broken bones, fractures, sprains, stumbling, concussions, reduced audible capability (non-recoverable)	• Housekeeping/Keep floor clear of obstruction • Wear hearing protection
3. Screw spring to end of rivet gun	• Tripping/Slipping • Noise Exposure • Falling object	Broken bones, fractures, sprains, stumbling, concussions, reduced audible capability (non-recoverable)	• Housekeeping/Keep floor clear of obstruction • Wear hearing protection
4. Connect air hose to rivet gun	• Noise Exposure • Struck by	Reduced audible capability (non-recoverable), bruise, eye irritation	• Wear hearing protection • Wear eye protection
5. Test rivet gun regulator setting on wood block	• Noise Exposure • Struck by	Reduced audible capability (non-recoverable), bruise, eye irritation	• Wear hearing protection • Wear eye protection
6. If needed, adjust regulator setting on rivet gun	• Noise Exposure • Struck by	Reduced audible capability (non-recoverable), bruise, eye irritation	• Wear hearing protection • Wear eye protection
7. Insert rivet into hole	• Tripping/Slipping • Noise Exposure • Awkward Posture (kneeling) • Fall to lower level • Falling object	Broken bones, fractures, sprains, concussions, stumbling, Reduced audible capability (non-recoverable), stiffness (recoverable)	• Housekeeping/Keep floor clear of obstruction • Wear hearing protection • Take frequent breaks to stretch legs • Check ladder stability and operation

8. Technician one places rivet gun header on rivet head	• Tripping/Slipping • Noise Exposure • Awkward Posture (kneeling) • Fall to lower level	Broken bones, fractures, sprains, concussions, stumbling, Reduced audible capability (non-recoverable), stiffness (recoverable)	• Housekeeping/Keep floor clear of obstruction • Wear hearing protection • Take frequent breaks to stretch legs • Check ladder stability and operation
9. Technician two stand on backside of aircraft skin	• Tripping/Slipping • Noise Exposure • Awkward Posture (arched back)	Broken bones, fractures, sprains, concussions, stumbling, reduced audible capability (non-recoverable), stiffness (recoverable)	• Housekeeping/Keep floor clear of obstruction • Wear hearing protection • Take frequent breaks to relax back
10. Technician two places bucking bar on rivet shaft	• Noise Exposure • Awkward Posture (arched back)	Reduced audible capability (non-recoverable), muscle strain, muscle aches, stiffness (recoverable)	• Wear hearing protection • Take frequent breaks to relax back
11. Technician one, communicate intention to squeeze trigger	• Noise Exposure • Awkward Posture (kneeling)	Reduced audible capability (non-recoverable), muscle strain, muscle aches, stiffness (recoverable)	• Wear hearing protection • Take frequent breaks to relax back
12. Technician one squeeze rivet gun trigger	• Prolonged vibration exposure • Noise Exposure • Awkward Posture (kneeling) • Struck by • Pinching • Fall to lower level	Hand-Arm Vibration Syndrome (HAVS), Trigger Finger, Carpel Tunnel Syndrome (non-recoverable), reduced audible capability (non-recoverable), stiffness (recoverable), bruise, eye irritation, welts, broken skin, broken bones, fractures, sprains, concussions,	• Wear gloves • Wear hearing protection • Take frequent breaks to stretch legs • Wear eye protection • Check ladder stability and operation
13. Technician two removes bucking bar	• Noise Exposure • Awkward Posture (arched back)	Reduced audible capability (non-recoverable), muscle strain, muscle aches, stiffness (recoverable)	• Wear hearing protection • Take frequent breaks to relax back
14. Technician two checks height of bucked rivet shaft	• Noise Exposure • Awkward Posture (arched back)	Reduced audible capability (non-recoverable), muscle strain, muscle aches, stiffness (recoverable)	• Wear hearing protection • Take frequent breaks to relax back

15. Disconnect air hose	• Noise Exposure • Struck by	Reduced audible capability (non-recoverable), bruise, eye irritation	• Wear hearing protection • Wear eye protection
16. Hand hose above head height	• Noise Exposure	Reduced audible capability (non-recoverable)	• Wear hearing protection
17. Unscrew spring from end of rivet gun	• Tripping/Slipping • Noise Exposure • Falling object	Broken bones, fractures, sprains, stumbling, concussions, reduced audible capability (non-recoverable)	• Housekeeping/Keep floor clear of obstruction • Wear hearing protection
18. Remove header	• Tripping/Slipping • Noise Exposure • Falling object	Broken bones, fractures, sprains, stumbling, concussions, reduced audible capability (non-recoverable)	• Housekeeping/Keep floor clear of obstruction • Wear hearing protection
19. Screw spring to end of rivet gun	• Tripping/Slipping • Noise Exposure • Falling object	Broken bones, fractures, sprains, stumbling, concussions, reduced audible capability (non-recoverable)	• Housekeeping/Keep floor clear of obstruction • Wear hearing protection

Table 6. *Severity and Probabilities.*

Severity of Consequence	**Probability of Mishap**					
	Impossible	Improbable	Remote	Occasional	Probable	Frequent
Catastrophic					1	
Critical				2		
Marginal			3			
Negligible						
Risk Code/ Actions	1	Imperative to suppress risk to lower level.	2	Operation requires written, time limited waiver endorsed by management.	3	Operation permissible.
Note: Personnel must not be exposed to hazards in Risk Zones 1 and 2						

Table 7. *Consequence categories.*

Severity of Consequences					
Category/ Descriptive Word	**Personnel Illness/ Injury**	**Equipment Loss ($)**	**Down Time**	**Product Loss**	**Environmental Effect**
Catastrophic	Death	>1Million	>4 mo	>1Million	Long-term (5 yrs or greater) environmental damage or requiring >$1M to correct and/or in penalties
Critical	Severe injury or sever occupational illness	250K – 1M	2 wks – 4 mo	250K – 1M	Medium –term (1-5 yrs) environmental damage or requiring $250K – 1M to correct and/or in penalties
Marginal	Minor injury or minor occupational illness	1K – 250K	1 day – 2 wks	1K – 250K	Short-term (<1yr) environmental damage or requiring $1K - $250K to correct and/or in penalties
Negligible	No injury or illness	>1k	<1 day	>1k	Minor environmental damage, readily repaired and/or requiring <$1K to correct and/or in penalties

Table 8. *Modified severity categories.*

Category/ Descriptive Word	Personnel Illness/ Injury	Down Time
Catastrophic	Death/Sever injury or sever occupational illness	>4 mo
Critical	Severe injury or sever occupational illness	2 wks – 4 mo
Marginal	Minor injury or minor occupational illness	1 day – 2 wks
Negligible	No injury or illness	<1 day

Table 9. *Individual safety rankings.*

Accident	**Causes**	**Probability**	**Severity**	**Priority**
Exposure to excessive noise	Actuating mechanism of the rivet gun (prolonged exposure)	Frequent	Critical	High
Exposure to excessive vibration	Actuating mechanism of the rivet gun, holding vibrating object, working with the wrist bent or deviated in the ulnar position (prolonged exposure)	Frequent	Critical	High
Tripping and Slipping	Work-stand is too small, Housekeeping	Probable	Critical	High
Awkward positioning	Prolonged exposure to kneeling or arching of the back when standing behind the aircraft skin	Frequent	Marginal	Medium
Falling to lower level	Improper use of stool/ladder	Occasional	Critical	Medium
Falling objects	Oily or damp hands, clumsiness, irregular surfaces	Frequent	Negligible	Low
Caught in retaining spring	Hand located to far down on rivet gun shaft	Occasional	Marginal	Low
Struck by flying objects	Elasticity on air hose, nearby hazardous activity, contacting loose metal chips while riveting	Remote	Marginal	Low

Table 10. *Recommended safety controls.*

Recommended Countermeasure	**Hazards Addressed**
Generation of Job Safety Procedures	All hazards addressed by informing the technician
Spare Ear Muffs	Decrease the risk of Cumulative Trauma Disorders (Hearing loss)
IMPACTO Gloves w/ elastic wrist support	Decrease the risk of Cumulative Trauma Disorders (HAVS, Carpel Tunnel Syndrome, and Trigger Finger)
Mobile Work Tables	Assist in keeping the environment clear of debris and reduce the hazard of tripping and slipping
Additional Training	Include the proper use of a ladder and proper positioning for leverage Include a philosophy of housekeeping and informing of the ramifications of slipping and tripping Include methods to reduce Cumulative Trauma Disorders (awkward positioning, vibration, noise) and encouraging the technicians to take frequent breaks, switch off between hands (i.e. using the left hand instead of the right) and task rotate
Kneel Pads	Encourage better posture for the technician driving the rivet by providing a comfortable area for the knee to contact the floor
Interval Inspections	Irregularities in the pneumatic line, including quick disconnects

Table 11. *Job safety analysis.*

Hazard	**Causes**	**Consequences**	**Countermeasure**
Excessive noise	Riveting	Reduced audible capability (non-recoverable)	Use hearing protection.
Prolonged vibration exposure	Riveting, Bucking	Hand-Arm Vibration Syndrome (HAVS), Trigger Finger, Carpel Tunnel Syndrome (non-recoverable)	Take frequent breaks. Rotate job with lab partner.
Tripping/Slipping	Moving around the work stand. Placing tools and other objects on the floor. Keeping a messy work area.	Concussions, broken bones, fractures, sprains, stumbling	Maintain good housekeeping. Keep floor clear of obstruction. Avoid placing tools on the floor. Be aware of objects rising from the floor. Walk instead of running.
Awkward position	Standing behind the aircraft skin. Riveting below the waist.	Muscle strain, muscle aches, stiffness (recoverable)	Take frequent breaks to stretch. Rotate jobs with lab partner.

			If kneeling, place knee on a soft surface.
Falling to lower level	Using the wrong equipment. Using broken equipment Using the ladder improperly.	Concussions, broken bones, fractures, sprains,	Check elevating devices prior use for basic operation and stability.
Falling objects	Dropping tools or items	Generation of tripping and slipping hazard	Be patient. Work with dry hands or gloves.
Pinching	Hand getting caught in the retaining spring.	Pinching	Wear gloves.
Struck by flying objects	Dislodging wood or metal from the wood block. Misalignment with the rivet gun header and the rivet.	Eye irritation, bruise	Wear eye protection. Use both hands when riveting.

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APPENDIX

A General Hazard Checklist

(Disclaimer: this list is incomplete and has been adapted from several sources.)

Electrical Energy

The inadvertent release or interruption of electrical energy may lead to:

– Shock
– Burns
– Overheating
– Ignition of combustibles
– Explosion/electrical (arc)
– Power outage
– Distribution back feed
– Unsafe failure to operate
– Inadvertent activation
– Destruction of electronic components
– Disruption of communications
– Failure of control systems
– Grounding failures
– Explosion/electrical (electrostatic)

Kinetic/Mechanical Energy

Objects and/or persons in motion can cause severe injury and/or property damage upon collision with other objects or persons. In general, the risk of injury is determined by the magnitude of the kinetic energy, the duration of the collision, the contours of the surfaces that collide, and the body part(s) involved in the collision. Effects on both humans AND equipment should be considered, particularly if damage to equipment is likely to create other hazards (e.g., disruption of control systems, grounding failures, etc.).

– Sharp edges/points
– Rotating equipment
– Reciprocating equipment
– Lifting weights
– Stability/toppling potential
– Ejected parts/fragments
– Pinch points
– Crushing surfaces

Pressure

High pressures can cause explosion and fragmentation of containers and vessels or the whipping of lines and hoses. Low pressures can cause containers to implode or collapse; rapid pressure changes can cause disorders such as embolisms or the bends (see also “Physiological”).

– Over pressurization
– Pipe/vessel/duct rupture
– Implosion
– Mislocated relief device
– Relief pressure improperly set
– Backflow
– Cross flow
– Hydraulic ram
– Inadvertent release
– Miscalibrated relief device
– Blown objects
– Pipe/hose whip
– Blast
– Dynamic pressure loading

Acceleration/Deceleration/Gravity

Problems are similar to those listed for kinetic/mechanical energy. In addition, rapid acceleration/deceleration of fluids can cause severe structural damage to piping and containers while certain explosive materials may detonate under shock or rapid changes in direction.

– Inadvertent Motion
– Loose Object Translation
– Impacts
– Fragments/Missiles
– Sloshing Liquids
– Slips, trips, and falls
– Falling Objects
– Elevated surfaces

Temperature Extremes

High or low thermal extremes can cause severe skin "burns", systemic disorders (e.g., heat stroke, hypothermia), and damage to equipment or materials. Rapid temperature changes can cause material damage due to expansion/contraction. High temperatures can ignite combustible materials and cause fire. Low temperatures may cause systems to fail, such as freezing of water sprinkler systems with subsequent loss of fire protection and water damage due to flooding.

– Heat source/sink
– Hot/cold surface burns
– Elevated reactivity
– Freezing
– Humidity/moisture
– Elevated volatility

– Confined gas/liquid	– Reduced reliability
– Pressure elevation	– Elevated flammability

– Altered structural properties (e. g., embrittlement)

Fire/Flammability

– Fuel	– Ignition source
– Oxidizer	– Propellant

Radiation

Ionizing radiation can cause severe damage (sometimes with delayed effects) to human tissues, chemical changes, and disruption of communications. Non-ionizing radiation can cause a variety of disorders, including cataracts, heating/charring/burning of organic tissues, disruption of electrical equipment, and chemical decomposition of materials.

Ionizing	*Non-Ionizing*
– Alpha	– Laser
– Beta	– Infrared
– Neutron	– Microwave
– Gamma	– Ultraviolet
– X-ray	

Explosives

Initiators:	*Sensitizers:*	*Presence of explosive:*	*Effects:*
– Heat	– Heat/cold	– Propellant	– Mass fire
– Friction	– Vibration	– Gas	– Blast overpressure
– Impact/shock	– Impact/shock	– Liquid	– Thrown fragments
– Vibration	– Low humidity	– Vapor	– Seismic ground wave
– Electrostatic discharge	– Chemical contamination	– Dust	– Meteorological reinforcement
– Lightning			
– Welding (stray current/sparks)			
– Radio frequency energy			
– Induced voltage (capacitive coupling)			

Leaks/Spills

Materials:	*Conditions:*		
– Liquids/cryogens	– Flammable	– Slippery	– Flooding
– Gases/vapors	– Toxic	– Odorous	– Run off
– Dusts	– Irritating	– Reactive	– Pathogenic
– Radiation sources	– Corrosive	– Asphyxiating	– Vapor

Chemical Reactivity

Slow destructive processes include corrosion, oxidation and material degradation.

Rapid chemical processes can produce high pressures (sometimes causing explosions), high temperatures (sometimes causing fire), and/or the release of toxic materials.

Contamination

This is a general problem caused by the introduction of foreign matter to equipment and or processes. Possible problems include: clogged filters, damaged bearings, and ruining of raw materials or finished products. Failure of safety systems such as fixed piping water sprinklers for fire protection may occur.

– System cross-connection	– Vessel/pipe/conduit rupture
– Leaks/spills	– Backflow/siphon effect

Physiological

Lack of compatibility between work requirements and human capabilities can lead to errors, accidents, and overstressing of human tissues. Toxic substances can produce a wide spectrum of localized and systemic disorders, with immediate or delayed effects. Virtually all of the body's systems can be adversely affected.

– Excessive force requirements
– Awkward postures
– Localized mechanical pressure
– Prolonged vibration exposure
– Cold exposure
– Heat exposure
– Fatigue
– Prolonged static muscular exertion
– Nuisance dusts/odors
– Asphyxiants
– Allergens
– Pathogens
– Radiation
– Repetitive tasks
– Lifted weights
– Baropressure extremes
– Mutagens
– Teratogens
– Toxins
– Irritants
– Cryogens
– Carcinogens
– Noise exposure

Human Factors (see also **Controls and Displays)**

– Failure of vigilance
– Operator error
– Inadvertent operation
– Failure to operate
– Temporal stressors
– Operation out of sequence
– Right operation/wrong control
– Early/late initiation
– Operate too long
– Operate too briefly

Controls and Displays (also see **Human Factors)**

– Nonexisting/inadequate warning systems
– Excessive information presentation and/or processing requirements
– Glare
– Inadequate/improper illumination
– Vibration (may impair ability to read display or actuate control)
– Inadequate control and/or display differentiation
– Inaccessibility of controls and/or displays
– Inappropriate control and/or display location
– Faulty/inadequate control and/or display labeling
– Nonexisting/inadequate "kill" switches

Automated Control Systems

– Power outage
– Interference (EMI/ESI)
– Grounding failure
– Moisture
– Short circuit
– Inadvertent activation
– Sneak software
– Lightning strike

Unexpected Utility Outages

– Electricity
– Steam
– Heating/cooling
– Ventilation
– Air conditioning
– Fuel
– Compressed air/gas
– Lubrication
– Exhaust
– Drains/sumps

Common Causes

– Utility outages
– Single-operator coupling
– Seismic disturbance/impact
– Faulty calibration
– Vibration
– Flooding
– Dust/dirt
– Fire
– Location
– Radiation
– Wear-out
– Maintenance error
– Animals/insects

Environmental

Temperature extremes can cause hyperthermia and hypothermia in humans while exposure to extreme weather can cause severe injuries and extensive property damage. Material degradation can result from long-term exposure (“weathering”).

– Moisture/humidity
– Air flow/circulation
– Sustained high winds
– Freezing/thawing cycle
– Flooding
– Lightning
– Sunlight exposure (UV)
– Dust, sand, and dirt
– Temperature extremes
– Wind gusts
– Hail

Contingencies

(i.e., emergency responses to abnormal events)

- "Hard" shutdowns/failures
- Freezing
- Fire
- Windstorm
- Hailstorm
- Utility outages
- Flooding
- Earthquake
- Snow/ice load

Operative phases

- Transport
- Delivery
- Installation
- Calibration
- Checkout
- Shakedown
- Activation
- Standard start
- Emergency start
- Normal operation
- Load change
- Coupling/uncoupling
- Stressed operation
- Standard shutdown
- Emergency shutdown
- Troubleshooting
- Maintenance