A RISK ASSESSMENT OF HUMAN-ROBOT INTERFACE OPERATIONS TO CONTROL THE POTENTIAL OF INJURIES/LOSSES AT THE XYZ MANUFACTURING COMPANY

By

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A Research Paper

Submitted in Partial Fulfillment of the
Requirements for the
Master in Science Degree in
Risk Control

Approved for Completion of 3 Semester Credits
RC-735 Field Problem in Risk Control

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ABSTRACT

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A Risk Assessment of Human-Robot Interface Operations to Control the Potential of Injuries/Losses at the XYZ Manufacturing Company
(Title)

M.S. in Risk Control	Elbert Sorrell, Ph.D.	May, 2002	84
(Graduate Major)	(Research Advisor)	(Month/Year)	(No. of Pages)

APA Format
(Name of Style Manual Used in this Study)

The purpose of this study was to assess the robot palletizing operation at XYZ Manufacturing Company using the risk assessment methodology recommended by the ANSI/RIA R15.06 standard. XYZ Manufacturing Company is a food processing company located on the Midwest, U.S. Just two years ago they installed five industrial robots, automating a significant part of their packaging operations. Since then risk assessments of the operation have not been performed. The lack of robot operations assessment is placing employees at risk of injuries. Even though XYZ Manufacturing Company had not had any accidents, there is a great potential of occurrence within the operation.

Data on robot-related accidents is difficult to find, nevertheless studies have reported accidents in France, Sweden, Japan, and USA, including fatalities (Beauchamp & Stobbe, 1995). There have been five fatal accidents involving industrial robots since 1978 (Dhillon, 1991). In order to control these accidents and reduce losses, standards have been developed as well as recommendations of preferred practices, including the American National Standards Institute (ANSI), the National Institute of Occupational Safety and Health (NIOSH), the Department of Energy (DEO), and the Occupational Safety and Health Administration (OSHA).

This study utilized several of these standards and guidelines in developing its approach and providing recommendations. The robot palletizing operation at XYZ Manufacturing Company was assessed considering employees' previous experiences, current procedures and practices, and human factors. Identification and analysis of hazards inside and outside the work cell was provided through the ANSI/RIA Risk Assessment. The results of the study identified various deficiencies or areas of opportunity in the palletizing operation. Recommendations to these situations at XYZ Manufacturing Company were presented. Moreover, the methodology utilized on this study provides a guideline to perform further analysis in existent and new operations.

Acknowledgments

I would like to thank the University of Wisconsin-Stout, Risk Control Staff including Gene Ruenger, Brian Finder, Craig Jameson, and Mary Fandry for being great facilitators and guiders for the students in the Program. Special thanks to Steven Senor for his assistance with this research paper. Finally, I would like to thank my advisor, Dr. Elbert Sorrell, for his advise and support during the development of this research paper and throughout my studies.

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CHAPTER I

STATEMENT OF THE PROBLEM

After Japan, the United States manufacturing industry has the next highest robot population. The use of robots in industry is growing at a significant rate; for example, in the period from 1992 to 1997, the robot population in U.S. increased 78%, from 46,000 to 82,000. The actual U.S. robot population is estimated at 105,000 units (RIA, 2000). In fact, robots have been used by decades in a wide variety of manufacturing industries, ranging from car assembly plants and carton building to circuit board manufacture (RIA, 1986). Robots have many different applications such as material handling, welding, painting, machine tool load and unload, assembly, and so forth (OSHA, 1999). They are generally used to perform tasks, in hazardous environments, highly repetitive, and requiring heavy lifting. Therefore, the introduction of robots into the workplace reduces exposures to some common industrial hazardous situations with the potential to cause workers injuries. Nevertheless, it has also introduced new risks.

Robots are complex and sophisticated machines with the ability to move at various speeds along many axes. Such characteristics increase their flexibility and functions, but they also increase the hazards and the potential of accidents. Data on robot-related accidents is difficult to find, however there are several studies that analyze robot-related accidents using reported data from France, Sweden, West Germany, Japan, and USA. These reported accidents include non-injuries, injuries and fatalities (Beauchamp & Stobbe, 1995). Accidents in the manufacturing industry have lead to several losses such as days out of work because of injuries, workers compensation, equipment damage, and production downtime.

In order to control these accidents and reduce losses, standards have been developed as well as recommendations of preferred practices related to robot operations. Each of these publications recommends a comprehensive hazard analysis or risk assessment, prior the installation and operation of a robot. The risk assessment provides the best tool to determine safeguards, safety procedures, training, and any other requirements necessary to control the risk and the potential losses. However, not all companies perform a risk assessment on their robot operations. This is the case of XYZ Manufacturing Company, a food processing company located on the Midwest, U.S. Just two years ago they installed five industrial robots, automating a significant part of their packaging operations. Since then risk assessments of the operation have not been performed. Hence, a lack of robot operations assessment at XYZ Manufacturing Company is placing employees at risk of injuries.

Purpose of the study

The purpose of this study was to assess the robot palletizing operation at XYZ Manufacturing Company using the risk assessment methodology recommended by the ANSI/RIA R15.06 standard.

Goals of the study

1) Assess previous experiences regarding losses and near hits, as well as, current practices followed by the company.

2) Identify and analyze existing risks as related to entries and inside the robot envelope.

3) Evaluate factors that affect human performance during robot operations.

Background and Significance

Accident-report data related to robot operations is difficult to find. Over the last few years some research has been done; however, there is no comprehensive database available in robot operations injuries (UAW, 2000). Based on the existing information, there have been five fatal accidents involving industrial robots since 1978 (Dhillon, 1991). The first robot-related fatality reported in the U.S. occurred on July 21, 1984, in a small die-casting plant with approximately 280 employees. The victim was found pinned between the back end of the robot arm and a steel pole. In more recent information reported, a maintenance worker died in 1995; the worker had climbed under a barrier fence while the robot was running. In 1997, there was another fatality involving a maintenance operator. In this case, the robot was off, but the operator did not release the hydraulic pressure. When he tried to change a hose, the robot hit his head (UAW, 2000).

Although the frequency of accidents in robot operations seems to be low, the sizes and sources of energy of the robot make it very dangerous resulting in serious injuries. The awareness of these risks associated with robotic systems has encouraged the publication of recommended practices and standards. For instance, the American National Standards Institute (ANSI) in conjunction with the Robot Industry Association (RIA) published a standard with safety requirements for Industrial Robots and Robots Systems, ASNI/RIA R15.06. Moreover, the National Institute of Occupational Safety and Health (NIOSH) developed a publication on safe maintenance guidelines for robotic workstations as a result of the first fatality in U.S in 1984. Recently, the Occupational Safety and Health Administration (OSHA) published a technical manual for industrial robots and robot system safety. Although there are some other guidelines/standard specifications to robot related operations, these mentioned above seem to be the most outstanding ones.

These publications in robot safety provide guidelines for specific tasks that expose workers to risky situations. XYZ Manufacturing Company has three shifts; three employees per shift performing regular operations and two maintenance employees get exposed every day. Employees get into the robot working envelope to clean up jams and material from the floor, to fill the area with material, and to do preventive maintenance, repair, and programming tasks. Even though XYZ Manufacturing Company has not had any accidents related with the operation yet, the great potential of occurrence clearly justifies the assessment of the operation.

Limitations of the study

There are five industrial robots at XYZ Manufacturing Company. Due to the scope of this study and time limitations, just one operation consisting of two robots was assessed.

Definition of terms

Barrier A physical means of separating persons from the restricted envelope (OSHA, 1999).

Emergency Stop The operation of a circuit with hardware-based components that override all other robot controls, remove drive power from the robot actuators, and causes all moving parts to stop (DOE, 1998).

Industrial Robot A reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks (OSHA, 1999).

Industrial Robot System The system includes not only industrial robots but also any devices and/or sensors required for the robot to perform its tasks, including communication interfaces for sequencing or monitoring the robot (DOE, 1998).

Interlock An arrangement whereby the operation of one control or mechanism brings about or prevents the operation of another (OSHA, 1999).

Maximum Envelope The volume of space encompassing the maximum designed movements of all robot parts. This includes the workpiece, end-effector, and attachments (DOE, 1998).

Operating Envelope That part of the restricted envelope used by the robot while performing its programmed motions (DOE, 1998).

<u>*Pendan*</u>t Any portable control device, including teach pendants, that permits an operator to control the robot from within or without the restricted envelope of the robot (DOE, 1998).

<u>*Restricted envelope*</u> That part of the maximum envelope to which a robot is restricted by limiting devices. The boundaries of the restricted envelope are defined by the maximum distance that the robot and associated tooling can travel after the limiting device is actuated.

<u>*Risk assessment*</u> A comprehensive evaluation of the possible injury or damage to health in a hazardous situation in order to select appropriate safeguards (ANSI/RIA, 1999).

<u>*Safeguard*</u> A barrier guard, device or safety procedure designed for the protection of personnel (ANSI/RIA, 1999).

Abbreviations

ANSI/RIA: American National Standards Institutes/Robotics Industrial Association.

OSHA: Occupational Safety and Health Administration.

NIOSH: National Institute for Occupational Safety and Health.

AFOSH: Air Force Occupational Safety and Health.

NECO: National Electrical Code.

NFPA: National Fire Protection Agency.

DOE: Department of Energy.

CHAPTER II

LITERATURE REVIEW

Risk Assessment

Risk assessment is a formal process of increasing the understanding of the risk associated with an activity. It intends to develop information on sources of risks, hazards, and exposures; evaluate those hazards and exposures; and measure its potential loss (Williams et. al., 1998). There are different methodologies presented throughout the literature, taking different approaches depending upon the application of the assessment. Afterwards, what is really important is to use a formal and consistent process to identify hazards and develop solutions that match the needs of the operation. The fundamental elements of risk assessment include the identification of risks, the measurement or estimation of risk and analysis of hazards (ANSI/RIA, 1999).

Risk identification

Only hazards that have been identified can be prevented or mitigated (Little, 2001). “Risk identification is the process by which an organization systematically and continuously identifies risks and uncertainties” (Williams, et. al., 1998). Once the hazards associated with the operation have been identified, it is easier to develop and implement appropriate mitigating measures, and to determine the necessity for formal written procedures. Several techniques are available for identifying the risk, some of these methods include:

1. Flow-chart method (listing all the operations of the organization, or the tasks of an specific operation);

2. On-site inspections;
3. Analysis of loss records;
4. Checklist

Measurement of risk

Risk measurement is the process of determining the likelihood of a loss from an exposure and its portable consequences (Williams, et. al, 1998). In other words, risk measurement is the estimation of the probability and severity of a possible loss. The probability of losses occurring depends on factors such as the number of people exposed to the hazards, the level of experience, and the frequency with which access to the area is required. Nonroutine operations are typically more hazardous than routine operations. On the other hand, the severity of the hazard depends on factors such as type and size of the robot, sources of energy, and type of hazards. The risk assessment must be able to recognize these different situations and provide the appropriate measures and controls (DOE, 1998).

The risk measurement can be either qualitative or quantitative. Among qualitative techniques, some of them are task-specific. The techniques have a broad application base such as preliminary hazards analysis, task analysis, failure mode and effects analysis, and system simulation. On the other hand, quantitative techniques use an index of probability to estimates the cost of accidents. There are a few quantitative safety analysis techniques such as fault tree analysis, management oversight, and risk tree analysis (Williams, et. al, 1998). There is a certain amount of subjectivity in the estimation of risk, but it is important that all risks be treated consistently.

Analysis of hazards

Hazard analysis is the process of evaluating the conditions that create risks, and perils associated with these hazards (Williams, et. al, 1998). Its final objective is to devise a method to minimize that risk. During the analysis phase the risks are prioritize based on its allocated probability and severity. After this, different alternatives are developed and evaluated to control the hazards (e.g. safeguards, written procedures, warning signs, PPE), (OSHA, 1999).

In general, the goal of a risk assessment is to determine the appropriate measures to control actual or potential losses for both new tasks and tasks already in place. For new tasks, it is one way to determine the need for engineering controls, formal written procedures, or personal protective equipment; for existing tasks, it is one way to determine the appropriateness and urgency of abatement actions. Risk assessment is a continuous process that needs to be revised as system hazards and the stage of development changes. Risk assessments are used in a wide variety of applications; for instance, they are used in toxicology, in social science, and in natural or environmental affairs. Robotic operations utilize risk assessments to identify, control, and document the hazards within the operation as well.

Industrial Robots

Robots are programmable multifunctional mechanical devices designed to move material, parts, tools, or specialized devices through variable programmed motions to perform a variety of tasks (Dhillon, 1991). A robot system consists of three elements: human operator, the industrial robot, and a communication system or human-robot interface (Graham, 1991). They are available in a wide range of shapes, sizes, and forms to perform a variety of functions.

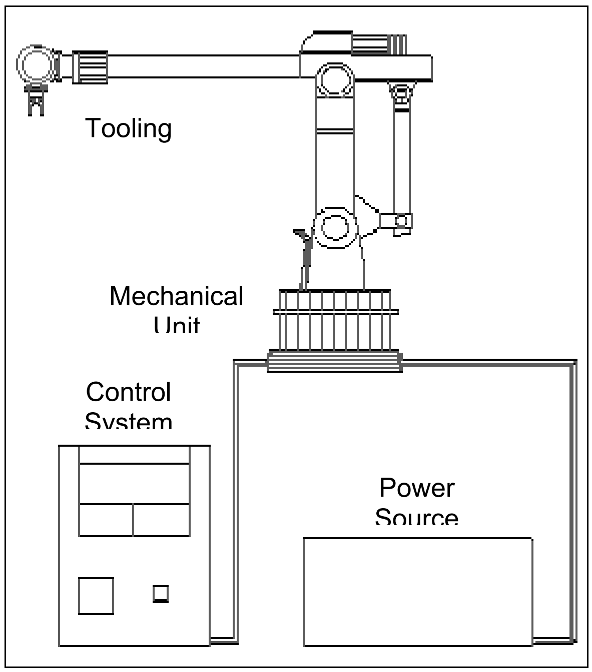
The robotic arm can have from one to six axes of movement: Roll (clockwise or counterclockwise at the wrist), yaw (left or right at the wrist), pitch (up or down at the wrist), elbow extension (in or out), shoulder swivel (up or down) and arm sweep (left or right of the entire arm). The number of axes is normally refers as the number of degrees of freedom of the robot. "Degrees of freedom" refer to the directions of motion inherent in the design of robot mechanical systems (DOE, 1998). A robotic arm may be driven by hydraulic, pneumatic or electric power. The way the robot moves is controlled by computerized systems (RIA, 1986).

This mode of operation points at unique characteristics of robots compared to other automated devices, addressing a very common confusion between those terms. The difference between robots and traditional automated machines are 1) its flexibility in spatial movement for a quick and inexpensive change and 2) its programmability to perform a wide variety of complex tasks. The entire movement of robots needs to be programmed and record in advance for each operation they perform (Nagamachi, 1986).

Robot components

Industrial robots have four major components: the mechanical unit, power source, control system, and tooling. Figure 1 presents a diagram of the robot major components. Each component of the robot must be considered in the risk assessment to identify its associated hazards (RIA, 1986).

Figure 1: Industrial Robot Major Components



Source: OSHA Technical Manual, 1999

Mechanical unit

“The mechanical unit refers to the robot's manipulative arm and its base. The mechanical unit consists of a fabricated structural frame with provisions for supporting mechanical linkage and joints, guides, actuators, control valves, limiting devices, and sensors. The physical dimensions, design, and loading capability of the robot depend upon the application requirements” (DOE, 1998).

Power Source

“Most new robots use electric drives. Pneumatic drives have been used for high speed, nonservo robots and are often used for powering tooling such as grippers. Hydraulic drives have been used for heavier lift systems, typically where accuracy was not also required. Electric drive systems can provide both lift and/or precision, depending on the motor and servo system selection and design. An ac [alternative current] or dc [direct current] powered motor may be used depending on the system design and applications” (DOE, 1998).

Control Systems

“Most industrial robots incorporate computer or microprocessor-based controllers. These perform computational functions and interface with and control sensors, grippers, tooling, and other peripheral equipment. The control system also performs sequencing and memory functions associated with communication and interfacing for on-line sensing, branching, and integration of other equipment. Controller programming may be done on-line or from remote, off-line control stations. Programs may be on cassettes, floppy disks, internal drives, or in memory; and may be loaded or downloaded by cassettes, disks, or telephone modem” (DOE, 1998).

Tooling

“Tooling is manipulated by the robot to perform the functions required for the application. Depending on the application, the robot may have one functional capability, such as making spot welds or spray-painting. The robot may use multiple tools that may be changed manually (as part of set-up for a new program) or automatically during a work cycle. Tooling and objects that may be carried by a robot's gripper can significantly increase the envelope in which objects or humans may be struck. Tooling manipulated by the industrial robot and carried objects can cause more significant hazards than motion of the bare robotic system. The hazards added by the tooling should be addressed as part of the risk assessment" (DOE, 1998).

Classification of robots

Industrial robots can be classified as either servo or nonservo controlled. Servo robots are controlled through the use of sensors that continually monitor the robot's axes for positional and velocity feedback information. This feedback is different from pretaught information, which is programmed and stored in the robots' memory. Nonservo robots do not have the feedback capability, and their axes are controlled through a system of mechanical stops and limit switches (OSHA, 1999).

Robot programming/teaching

Robots perform tasks for a given application by following a programmed sequence of directions from the control system. When programming the robot, it is necessary to establish a physical or geometrical relationship between the robot and other equipment or work to be service by the robot (DOE, 1998). During this operation, the programmer instructs the robot when, how, and where to position its arm throughout the work cycle. The movements are transferred to the memory of the robotic control system as electric signals and stored there. Three different teaching or programming techniques are lead-through, walk-through, and off-line programming. A description of each is provided below (OSHA, 1999).

- *Lead-Through Programming or Teaching* – Lead-through programming usually uses a teach pendant. This allows the teacher to lead the robot through a series of positions and to enter associate commands and other information. The operator teaches the positions. When using this programming technique, the teacher may need to enter the robot's working envelope. This introduces a high potential for accidents because safeguarding devices may have to be deactivated to permit such entry.
- *Walk-Through Programming or Teaching* – The teacher physically moves the robot through the desired positions within the robot's working envelope. During this time, the robot's controller scan and store coordinate values on a fixed-time interval basis. These values and other functional information are replayed in the automatic mode. This method places the teacher in a potentially hazardous position because the operational safeguarding devices are deactivated or inoperative.
- *Off-Line Programming or Teaching* – Off-line programming uses a remote programming computer. The required sequence of functional and positional steps is written on the remote computer and is transferred to the robot's controller by disk, cassette, or network link. After the program has been completely transferred to the robot’s

controller, either the lead-through or walk-through technique may be used to obtain actual positional information.

Robot hazards

There are many hazards associated with the robot operation; some of them are presented in *Table 1* below (DOE, 1998).

Table 1. Robot Operation Hazards

Hazards	Description
Energy Sources	Robots are capable of high-energy movements and energy accumulation through a large volume of workspace beyond their base dimensions. Some common sources of energy are: electrical, pneumatic pressure, hydraulic pressure, heat and/or thermal.
Contact Injury	Injury from the robot's arm or peripheral equipment can result from unpredicted movements, component malfunctions, or unpredicted program changes.
Crushing or trapping	Part of the body can be trapped between the robot's arm and other peripheral equipment if the proper precautions are not taken.
Mechanical components	Mechanical failure of components is associated with the robot or its power source, drive components, tooling or end effector, and/or peripheral equipment. The failure of gripper mechanisms can result from the release of parts and/or the failure of end-effector power tools such as grinding wheels, buffing wheels, deburring tools, power screwdrivers, and nut runners.
Other hazards	Equipment that provides power and control to the robot system represents potential electrical and pressurized fluid hazards. For instance, ruptured hydraulic lines could create dangerous

Table 1. Robot Operation Hazards (Continuation)

Hazards	Description
	high-pressure cutting streams or whipping hose hazards. In addition, environmental hazards are associated with arc flash, metal spatter, dust, or electromagnetic or radio-frequency interference. Tripping hazards from cables on the floor and noise exposure are equally important.

Sources of hazards

Most robot operation hazards result from the following potential sources (Dhillon & Fashandi, 1997).

- Human errors – These hazards may arise as a result of the psychological behavior of the worker or the software errors of the programmer. The incorrect activation of the teach pendant or the control panel is a common human error. Unauthorized access into the robot working area, along with disregard of established procedures are examples of human behaviors that may place the working in a hazardous situation.
- The robot itself – These hazards may occur from losses of the robot's structural integrity such as joint failure, material fatigue, and erosion. It can also originate from control errors due to hydraulic, pneumatic, mechanical or electrical faults in the subcontrols. Pneumatic, hydraulic, or electrical power sources with malfunctioning controls can disrupt electrical signals to the control and/or power-supply lines.
- The environment in which human-robot interacts – This may be caused by the accumulation of dust in the joints and motors, which may result in

> the robot malfunctioning. Also, electromagnetic or radio-frequency interference should be considered to exert an undesirable influence on robotic operation and increase the potential for injury to any person working in the area.

The characteristics and functions of industrial robots make their operations complex and vulnerable to a variety of risks. Several sources and types of hazards that may lead into accidents have been identified in this section. The next section discusses available data related to accidents on robot operations.

Robot Accidents

As defined by Dhillon (1991), an accident is an undesired and unplanned event. Accident-report data related to robotic operations is difficult to find; only a limited amount of data is currently available (Jarvinen & Karwowski, 1995). A reason may be that these data are hard to distinguish from general industrial accident statistics. Although some research has been done over the last few years, there is no comprehensive database available on robot operations injuries (UAW, 2000). A discussion of some of the available data follows.

Reported accidents

During the period of 1983 to 1988, a survey on robot-related accidents was conducted in France. The results, which were based on 54 accidents, revealed that 46% of the accidents involved line operators, 46% involved maintenance personnel, and 8% involved other personnel. In 1984, Carlsson described 36 robot-related accidents that occurred in Sweden between 1979 and 1983. He reported that 15 out of the 36 accidents occurred during programming, repair, or preparation for start-up. Carlsson reported in a previous study another survey conducted in Sweden at 21 branches of the Swedish Metal Workers' Union. Results revealed that the principal causes of the unexpected robot movements were attributable to human error and electrical faults. In 1986, Nicolaisen observed that, in 87% of the cases reported in the Institute for Production and Automation survey, the individual was performing programming, repair, or maintenance operations (Beauchamp & Stobbe, 1995).

The first robot-related fatality reported in the U.S. occurred on July 21, 1984, in a small die-casting plant with approximately 280 employees. The victim was found pinned between the back end of the robot arm and a steel pole. It is presumed that the operator entered the workstation to remove scrap metal which had accumulated on the floor. The primary safeguard was an interlocked gate in a partial perimeter safety railing, which had two unguarded openings that permitted undesired access to the robot workstation while the system was in operation (Donald, 1984). In more recent information reported, a maintenance worker died in 1995; the worker had climbed under a barrier fence while the robot was running. In 1997, there was another fatality involving a maintenance operator. In this case, the robot was off, but the operator did not release the hydraulic pressure; when he tried to change a hose, the robot hit his head (UAW, 2000).

In addition, a study conducted in 1995, analyzed 103 case reports that were collected using a questionnaire. Results revealed that in 38% of the accidents the human error factor was present, and in 44% improper procedures were followed. Moreover, 10% of the robots' accidents, based on a population of 20 accidents, occurred during maintenance or repair operations. Finally, 75% of the accidents involved robots used for part handling (Jarvinen & Karwowski, 1995).

Cause and effect analysis

Jiang and Gainer (1987) analyzed 32 robot-related accidents reports, which included fatalities, injuries, and non-injuries. The study considered accidents that occurred in the U.S., West Germany, Sweden, and Japan. The authors classified the accidents by injury person, type of injury, and cause of injury. The following are the cause/effect results:

- *Injury person*: 72% Robot operator; 19% Maintenance personnel; 9% Programmer
- *Type of injury*: 56% Pinch point; 44% Impact
- *Cause of injury:* In only 24 of the 32 cases the specific cause was determined. For most accidents more than one cause was assigned. In 13 out of 24 (54%) accidents, the primary cause determined was human error. However, an adequate safeguarding would restrict the entrance of the worker into the robot work area during normal robot operations. Authors determine the major cause of accidents to be the inadequate, poor, or non-existent safeguarding methods.

Overall, as presented in the literature review, robot-related accidents illustrate the considerable risk for injury when workers are performing maintenance and/or regular operations within the robot's operating envelope. The analysis of accidents clearly shows the negative impact of lacking safeguarding and of human factors in the aforementioned incidents. In order to prevent these accidents from occurring, it is important that a number of safety considerations be studied.

Robot Safety

Safety should be considered in all modes of operation, programming/teaching, normal operation, and maintenance (Graham, 1991). In brief, methods of preventing industrial robots accidents can be divided into those for safeguarding workers and those for preventing errors that might lead to accidents. Existing standards concentrate efforts on providing the industrial activities with guidelines that ensure the success of high-automated operations at a very low risk and cost (Graham, 1991). Next sections present some of the most relevant guidelines and safety considerations.

Standards and guidelines

National standards were established quite early in the history of industrial robots, and many were in place by the early 1980s. They are essentially an extension of machine safety principles associated with industrial machines such as mills, punches, and presses (DOE, 1998). Traditionally, safety standards have been developed in a reactive fashion after accidents have occurred. These standards tend to be narrow; attempting to specify in detail what should and should not be done. A list of the most frequently used and accessible standards and guidelines are presented in *Table 2*.

Table 2. Industrial Robots Recommended Standards & Guidelines

Source	Standard	Name
ANSI/RIA	R15.06-1999	American national standards for industrial robots and robot systems - Safety Requirements
	R15.02-1990	American national standard human engineering design criteria for hand-held robot control pendants
NSC	Safety Data Sheet 1-717-85, 1985	Robots
OSHA	Technical Manual, TED 1-0.15A (1999)	Industrial Robots and Robot System Safety
	Pub. 2254 (Revised)	Training Requirements in OSHA Standards and Training Guidelines
	Pub. 8-1.3, 1987	Guidelines for Robotics Safety.
	Pub. 3067, 1983	Concepts and Techniques of Machine Safeguarding
	29 CFR 1910.147	Control of Hazardous Energy Source (lockout/tagout final rule)
	29 CFR 1910.333	Selection and Use of Work Practices
NIOSH	Pub. 88-108, 1988	Safe maintenance guidelines for robotics workstations
	Pub. 85-103, 1984	Preventing the Injury of Workers by Robots
AFOSH	127-12, 1991	Occupational safety machinery
NECO / **ANSI/NFPA**	79, 1997	Electrical Standard for Industrial Equipment

Note: See abbreviation in Chapter I

Safeguard methods

Safeguards devices are probably the most important consideration on robot safety and its related standards. They address a significant part of the risk; however, they are not the final solution to the problem. Safeguards could be fixed barriers with interlocked gates or presence-sensing devices. ANSI/RIA R15.06 set specific requirements for each safeguarding device. *Table 3* lists different safeguards and describes each item in detail.

Table 3. Robot Safeguards

Safeguard	Description
Physical Barriers	Prevent personnel reaching over, under, around, or through the barrier into the prohibited robot work area. It is an efficient technique to safeguard humans, however in many cases. They are not the absolute solution to the problem (Dhillon, 1991).
Interlocked Barriers	Access gates to the work envelope, which stop the robot and any other associated equipment that may cause a hazard, and remove drive power to robot activator (Cheng & Jiang, 1995).
Flashing Lights	Awareness devices that alert personnel of an emergency or cautious situation. Flashing lights are used on yellow and red colors. They can be installed on the robot itself or at the perimeter of robot working area. Awareness devices are mainly used in conjunction with other safeguarding devices (Cheng &Jiang, 1995).
Warning Signs	Usually for situations where the robot cannot injure people because of their size, speed, and other characteristics. However, warning signs are useful for all applications complementing other safeguards. (Dhillon, 1991).

Table 3. Robot Safeguards (Continuation)

Pressure Mat	A presence-sensing device that activates when it senses excessive of pressure. Pressure mats are usually placed on the floor around the working area to protect access to the work envelope (Cheng & Jiang, 1995).
Infrared light arrays (Light Curtain)	Photoelectric sensing system, interlocked with the machine operating control mechanism. If any worker enters the area by breaking the light field, the safety system will send the signal to the robot controllers, which then take appropriate actions (Dhillon, 1991).
Buzzer	Auditory signal usually used for situations requiring immediate action and the receiver is overburdened by visuals (Cheng & Jiang, 1995).

Although, there are many types of safeguarding devices and sensors available, there is no doubt that safety requirements on robot operations will increase as advancement in technology continues to become more complex. Good safeguarding methods will use the present technology and apply it to the particular robot system.

Hazardous energy lockout is also of importance in robot safety. It is always expected to be part of the robot service procedures. This is a list of precautionary actions by which hazardous energy sources are controlled when possible, during maintenance, by shutting off drive power and putting a lock on the main energy supply switch (Etherton, 1990). Moreover, emergency stop of the system is part of the safety planning process. Compliance of the emergency stop circuit lies under the NFPA 79. The stop circuit should stop the motion, remove the drive power from the actuators, and remove all other energy sources.

Currently, most present robot installations focus robot safety on installation of safeguards, operator training in safety practices, and the preventive maintenance of the system. While all these approaches are necessary and essential for a safe operation, there are other situations not fully addressed. Particularly, when operations require the workers to be physically close to the robot. Therefore, controlling hazards in a system with a human interface requires knowledge of the overall operation of the system and also an understanding of how human factors relate to the robot (Graham, 1991).

Human Factors in Robotics

"Human factors in robotics is the study of principles concerning human behavior and characteristics for efficient design, evaluation, operation and maintenance of robots" (Rahimi & Karwowski, 1992). Human factors is a label for the study of relationships between processes and products of modern technology and the individuals who use them, in the case of industrial robotics, robot operators, maintenance personnel, programmers/teachers, and supervisors (Parsons, 1986). Human errors and component failures make man-robot interaction dangerous and costly at times (Dhillon & Fashandi, 1997).

Human errors can result in hazards both to personnel and equipment. Errors in programming, interfacing peripheral equipment, connecting input/output sensors, can all result in unpredicted movement or action by the robot which can result in personnel injury or equipment breakage. Judgment error results frequently from incorrectly activating the teach pendant or control panel. The greatest human judgment error results from becoming so familiar with the robot's redundant motions that personnel are too trusting in assuming the nature of these motions and place themselves in hazardous positions while programming or performing maintenance within the robot's work envelope (OSHA, 1999).

Consequently, from a proactive risk control standpoint during robot operations, several factors that affect human performance have to be considered. Some of these factors are: speed of the robot, diameter and location of the stop buttons, lighting, noise levels, and teach pendant (Graham, 1991). Though it is not possible to experiment on humans by involving them in actual accidents, several experiments suggest how approximations can produce at least some useful information about human behavior that might result in a robotic accident (Parsons, 1986). Several Design of Experiments (DOE) have been developed. Nevertheless, actual studies in human performance on man-robot interface are relatively small (Beauchamp & Stobbe, 1995). A summary of some of the available data follows.

Human performance studies

- An experiment performed by Sugimoto (1984) measured the time necessary to react to an unexpected robot arm motion. The subjects were instructed to press a button to make the robot arm rise up and release it to stop the motion. The robot arm moved toward the subjects instead of rising up.

Dependent variable- Robot overrun distance (distance covered by the robot before being stopped)

Independent variable- Robot arm motion speed, Gender

Results - No effect in gender or age

The overrun distance of the robot arm was proportional to the speed. Recommended arm motion of 14 cm/s (5.5 in/s) during maintenance or programming operations. (Authors suggest that during maintenance and programming operations the operator normally approach the robot arm to a distance of 20-30cm (7.9-11.8in). They estimated that at a speed of 14 cm/s (5.5 in/s) the robot overrun distance would be below 20 cm (7.9 in).

- In 1987, Lemay investigated the effect of a teach pendant control design in the task completion and errors made. An ASEA pendant, equipped with joystick controls, and a PUMA 560, equipped with push button controls, were used for the comparison. The subjects were divided in two groups to operate each robot.

Dependent variable- number of errors, task completion time

Independent variable- operation cycles (training), teach control pendant design (push button vs. joystick)

Results- Average number of errors decrease with training (Over 30 cycles of operation, the errors decrease from more than 8 to about 3)

Completion time decreases with training (Depending on the precision of the task, the completion time decreases from more than 4 min to between 2 and 1.5 min)

Errors and completion time decrease with the joystick control design.

- Etherton (1988), among others, studied the human response to unexpected robot movements at different speeds. In this experiment the subjects needed to push an emergency button in order to stop the robot movement.

Dependent variable- Robot overrun distance

Independent variable- Robot arm motion speed (15, 25, 35, and 45 cm/s; 5.9, 9.8, 13.7, and 17.7 in/s), age groups (20-30, 31-40, and 41-60), standing angle from axis of robot motion (0, 45 and 90 degrees)

Results- Analysis of variance (ANOVA) on the reaction time revealed significant age and speed effects.

Robot overrun distance increases with higher speeds

Robot overrun distance increases with younger groups

No significant effect on the angle from the axis of motion

No changes in the standard speed (At 25 cm/s; 9.8 in/s) the mean and maximum overrun distance were 7.77 and 16 cm (3 and 6.3 in), respectively)

- Another study in which Etherton (1990) participated investigated the effects of luminance contrast and of giving the subject information about the cost (due to downtime) of a false alarm on the subject's response time. The experiment was a 4 x 3 x 3 nested factorial design.

Dependent variable- Robot overrun distance

Independent variable- Robot arm motion speed (15, 25, 35, and 45 cm/s; 5.9, 9.8, 13.7, and 17.7 in/s), Robot arm luminance contrast (-46%, 64%, and 83%), cost of false alarm (low, medium, and high false alarm cost)

Results- Robot overrun distance increases with higher speeds

No effects in the robot arm luminance contrast

Robot overrun distance increases with higher cost importance

- Collins (1989) investigated the effect of diameter and location of the emergency stop button as it relates to the time it took subjects to release a touch pad button, reach to the stop button and press it. The touch pad button was located on the bottom of the teach pendant simulator.

Dependent variable- Time to reach an emergency stop button

Independent variable- Stop button location on teach pendant (left hand-side, right-hand side, top side, and front surface), Button diameter (0.5 and 1 inch)

Results- Time to reach the emergency button increases with stop button located on the sides (left, right, and top side). The highest response time was observed with the stop button located in the left-hand side (all the subjects were right-handed).

Time to reach the emergency button increases with a smaller button diameter (At all locations, the average response time was 7% faster with the 1" button)

- In 1990, Beauchamp and Stobbe evaluated possible factors that effect human performance in an unexpected robot motion. Observational surveys in various facilities and experimental literature reviews were used in order to identify the inherent variables affecting the human performance. The levels of each variable were selected to represent the best and worst conditions. A pilot study was conducted including six variables: illumination, background-to-robot arm luminance contrast radio, noise level, task demand, robot motion speed, and motion field. The variables of the main experiment were selected from the results of the pilot study. A factorial design main experiment was conducted with a total of 36 treatments. The subjects were university students and mechanical technicians. No significant difference between the occupations was found.

Dependent variable- Robot overrun distance

Independent variable- Illumination (10, 100, and 1000 lux), luminance contrast (low and high), robot motion speed (10, 25, 40 cm/s; 4, 9.8,15.7 in/s), and motion field variables (peripheral and central)

Results- Robot overrun distance increases with higher speeds

No effect in the noise levels

Low illumination adversely affected subject response time and produced longer overrun distances

However, overrun distance remained unaffected with illumination levels over 100 lux.

Overrun distance increases with robot motions initiated in the peripheral visual field

Overrun distance increases as the task demand increases

Authors recommended a maximum robot speed of 17 cm/s (6.7 in/s) for operations performed in the robot envelope not equipped with enabling devices.

- Fernandez (1991), investigated the effects of noise levels and motion speed on the subjects' reaction time to detect the robot arm moving toward him. Each of the twenty subjects participating in the experiment was exposed to 30 two-dimensional rectangular robot arm movements. The subjects were instructed to push the emergency stop button as soon as they notice an unexpected motion (Beauchamp & Stobbe, 1995).

Dependent variable- Reaction time

Independent variable- Robot arm motion speed (10, 15, 20, 25, 30, and 35 cm/s;3.9,5.9,7.9,9.8,11.8, and 13.7 in/s) noise level (60, 75 and 85 dB)

Results- Reaction time decreases with higher speeds (However, after 30 cm/s (11.8 in/s) the reaction time increased)

Reaction time decreases with lower noise levels

Human unsafe conduct studies

- Nagamachi (1986) conducted three experiments to study the conditions under which unsafe behaviors occurred, and the safety distance between the robot and the worker. The first two experiments had the same response variable. The first experiment required the estimation of how easily the subjects could complete a correction on a part held by a robot arm. In the second experiment, the subjects estimated how easily they could reach under the robot arm to retrieve a part dropped by the robot.

Dependent variable- Perception of danger (using a 5 point psychological scale)

Independent variable- Robot arm motion speed (ten speeds varying from 10-50 cm/s (3.9-20 in/s), robot arm motion direction (back and forth, right and left, up and down, and the three axes combined), robot waiting time (temporary stops)

Results- Perception of danger decreases with lower speeds

Perception of danger decreases in the back and forth direction

Perception of danger decreases with longer robot waiting time

The third experiment studied the perceived minimum safe distance from a moving robot.

Dependent variable- Perceived minimum safe distance from a robot

Independent variable- Robot arm motion speed (14, 22, 30, 38, 46 cm/s; 5.5,8.7,11.8,15,18 in/s), robot waiting periods (0,1,2,3 s)

Results- Subjects approached closer to the robot as the speed was reduced

No significant difference in waiting time

- An experiment was conducted by Karwowski (1987) and others to determine the maximum robot motion speeds considered safe by the subjects. The subjects' task consisted of observing, from outside the robot envelope, simulated assembly operations performed by two industrial robots. The subjects communicated verbally their preference about a maximum safe robot speed (Beauchamp & Stobbe, 1995).

Dependent variable- Perceived maximum safe robot arm motion speed

Independent variable- Previous experience with robots

Size of the robot

Robot motion speed pre-exposition

Results- Perceived maximum safe robot arm motion decreases with experience (female)

Perceived maximum safe robot arm motion increases with experience (male)

Perceived maximum safe robot arm motion decreases with smaller robot

Perceived maximum safe robot arm motion decreases when pre-exposed to a lower speed

- Karwowski participated in other study of human perception of the robot work envelope (Graham, 1991).

Dependent variable- Perceived maximum reach of an industrial robot

Independent variable- Pre-exposition to a simulated accident

Robot motion speed pre-exposition

Angle of approach toward the robot

Results- Perceived maximum reach increases when pre-exposed to a simulated Accident

Perceived maximum reach decreased when pre-exposed to a lower speed

Perceived maximum reach decreased when approaching directly in front of the robot

In the past, robot safety did not receive as much attention as it deserved from both users and manufacturers. Now, this scenario is changing, and robot related accidents could be one of the factors behind this change (Dhillon, 1991). Diverse industrial administrations and organizations have been expending efforts developing guidelines and best practices to provide safe robot operations. Moreover, experts in automation and robotic systems have recognized the significance of the human factors in the system, and have performed related research. Manufacturing companies using robots in their operations shall perform a comprehensive evaluation of their risks and utilize all available tools to provide a safeguarded operation and the use of best practices. The risk assessment at XYZ Manufacturing Company and recommendations provided were based on this literature review. The next chapter explains the methodology used in this study.

CHAPTER III

METHODOLOGY

The purpose of this chapter is to present the procedures and data gathering methodology used in the risk assessment of the robot palletizing operation at XYZ Manufacturing Company.

Goal 1: Assess Previous Experiences and Current Practices

To evaluate employees' previous experiences and current practices, the followings were performed:

1. Recordable incidents and injuries were reviewed (OSHA 200 Log).
2. Employees were interviewed in regards to previous near hits or not reported incidents.
3. An evaluation of current conditions and practices was performed based on the review of written programs and procedures. *Table 4* presents the guideline questions.

Table 4. Current Procedures and Practices Questions

Questions	Yes	No	Comments
Is there a Lockout/Tagout program? If yes, when is used?			
Are there different speeds set for maintenance and teaching operations?			
Is a prescribed start-up procedure used by the operator to restart the robot following an emergency stop?			

Table 4. Current Procedures and Practices Questions (Continuation)

Questions	Yes	No	Comments
Do all incorporated barriers and interlocking barriers prevent personnel from reaching over, around, under, or through the barrier to access the restricted envelope?			
Is there a standard procedure for cleanup/clearing jams? Explain			
Is the following documentation maintained and made available, upon request, to personnel associated with the robotic system: • Installation instructions and specifications • Function and location of all controls • Robot specifications, including range and load capacity • Manufacturer's system-specific safety-related information • Operating instructions • Maintenance and repair procedures, including lockout/tagout procedures • Robot system testing and start-up procedures, including initial start-up procedures			

Table 4. Current Procedures and Practices Questions (Continuation)

Questions	Yes	No	Comments
• Electrical requirements • System-specific safety documentation, including risk assessment documentation • System-specific robot safety training lesson plans and associated materials			

<u>Goal 2: Risk Assessment of the Robot Palletizing Operation</u>

The robot operation was assessed based on a validated methodology developed by the Robotics Industry Association (RIA), published in the ANSI/RIA R15.06-1999 standard. Minor changes were implemented to allow more accurate data gathering. Its methodology follows.

1. The first step of the risk assessment assumed no safeguards in placed. Tasks performed on the robot area were identified, including, operation, maintenance, clean-up tasks, daily and non-daily tasks.
2. All hazards associated with each task were identified and listed on *Table 8*, Chapter 4.
3. The risk associated with each hazard was estimated. For each hazard identified, the severity of injury, frequency of exposure, and likelihood of avoidance was identified. The criteria utilized to set these parameters are in Appendix A, *Table A.1*.

4. Based on the severity, exposure and avoidance criteria, the risk reduction category was determined for each task. This category was determined following across the matrix in Appendix A, *Table A.2*.
5. Minimum safeguards were determined from Appendix A, *Table A.3*, based on the risk reduction category. Safeguarding categories go from R1, for hazard elimination or substitution, to R4, for administrative and awareness means.
6. The safeguards selected were validated, reanalyzing the severity, exposure, and avoidance for each task. An evaluation of the hazards was conducted assuming safeguards in place to determine if each identified hazards has been partially/totally eliminated. The avoidance, severity and exposure of hazards were re-evaluated to determine a new risk reduction category. The criterion used is in Appendix A, *Table A.4*. The data was collected using *Table 5.*

Table 5. Risk Assessment Data Collection

Sequence No.	Task Description	Hazards	Prior to safeguard				Solution	Validation			
			Severity	Exposure	Avoidance	Risk Category		Exposure	Avoidance	Severity	Risk Category

<u>Goal 3: Human Factors Assessment</u>

Factors that may increase human errors were identified from previous studies on human performance in robot operations. These risk factors, compiled in the literature review, were identified and measured at XYZ Manufacturing Company with the purpose of providing recommendations based on the experimental results of the studies. The factors measured were:

- Robot arm speed
- Illumination
- Location of the emergency stop button on the teach pendant
- Diameter of the emergency stop button
- Noise

The next chapter, Chapter IV, presents the results using the methodology described above. The data utilized in the evaluation of the robot palletizing operation was collected through several visits to the company.

CHAPTER IV

RESULTS OF THE STUDY

The operation evaluated in this study is a palletizing operation, which involves two industrial robots. The robots are in work cells enclosed by fences. The palletizing operation is completely automated; there is no robot operator during production cycle. However, the operation needs to be monitored. Operators are around the robot's work cell to assist on any stop, pause, or failure during the operation cycle. This chapter describes the operation, the work area, the specifications of the robots, and the safety devices in place. In addition, it presents the results of the assessment conducted in the operation at XYZ Manufacturing Company.

Description of the Palletizing Operation

Overhead conveyors coming from two production rooms feed the palletizing operation. The product enters into the robot work cells in boxes. The robot is programmed to palletize the boxes using either pallets or slip-sheets depending on the incoming product. Operators just select the product specification from the options in the teach pendant menu. There are two box sizes, each built in three different unit loads. For each unit load, the boxes' stacking pattern varies; some use cross stacking (one level of boxes placed in one direction and the next level turned to the opposite direction), and others use column stacking (all levels in the same direction). *Table 6* presents the packaging criteria and arrangement for the different products. When the boxes are palletized on the slip-sheets, white glue (Lock-N-Pop) is applied from a nozzle located in the head of the robot.

Table 6. Packaging Criteria for each product

Size of Box	Unit Load	Packaging	Boxes Arrangement
Large Box	50	Slip-Sheet	Cross-Stacked
	51	Pallet	Cross-Stacked
	53	Pallet	Column
Small Box	60	Slip-Sheet	Cross-Stacked
	61	Pallet	Cross-Stacked
	63	Pallet	Column

Once the operator has selected the product from the teach pendant's menu, the palletizing program selects the operational and packaging parameters. *Figure 2* shows the palletizing work area. The sequence of the operation follows:

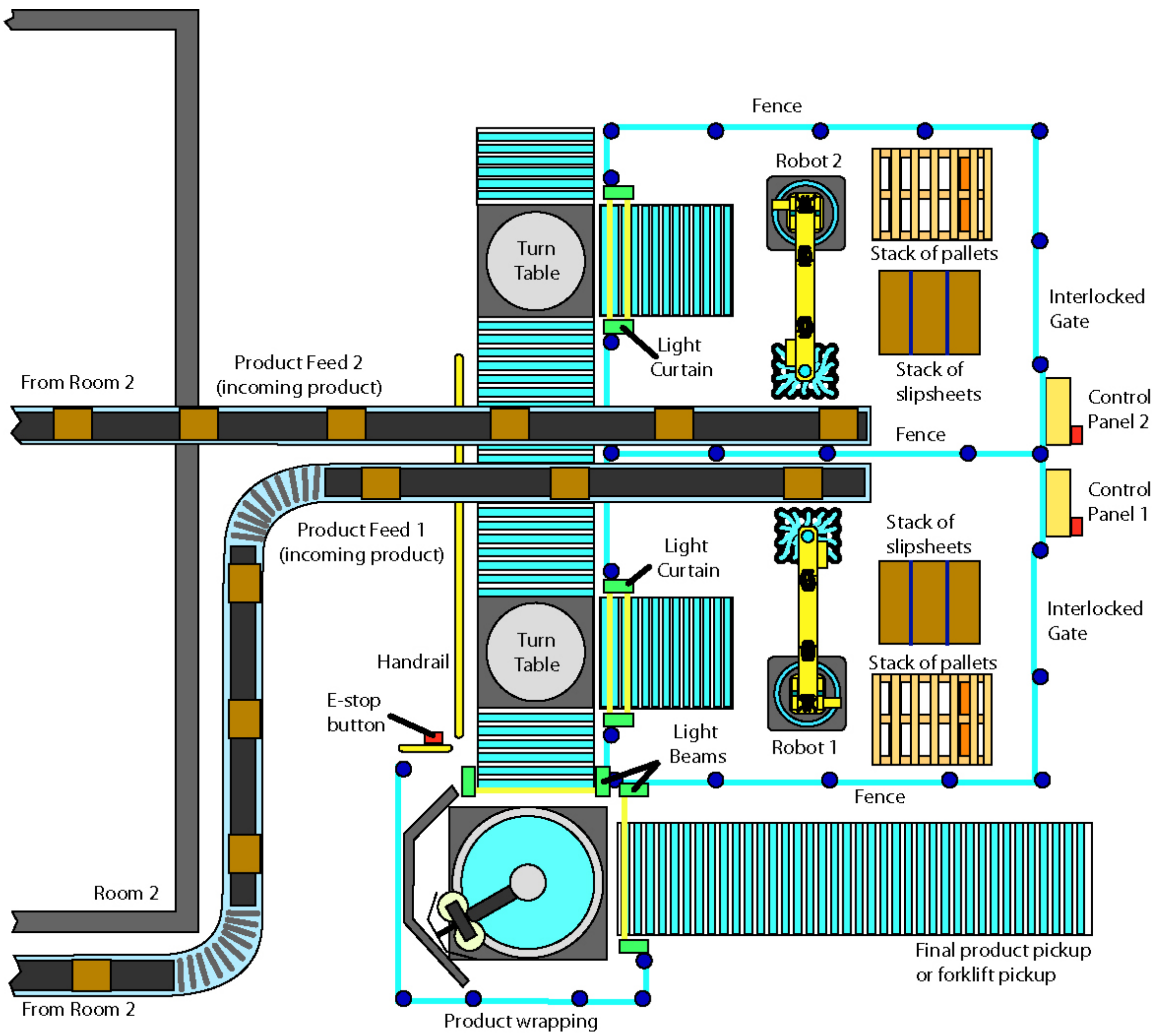
1) The robot's end-arm-tooling picks-up a pallet or slip-sheet from the stack.
2) The pallet or slip-sheet is transferred to the roller surface.
3) If a slip-sheet is used, glue (Lock-N-Pop) is deposited from a nozzle installed in the head of the robot.
4) The robot's end-arm-tooling picks-up three boxes of product from the overhead conveyor.
5) Boxes of product are transferred and dropped into the pallet or slip sheet in the roller surface.

6) The pick-drop cycle continues until programmed unit load is built.

7) At the completion of the pick-drop cycle, the loaded pallet or slip-sheet is transferred from the roller surface to the turntable and transported by the roller conveyor to the wrapping station.

8) The palletized product is wrapped up and transferred in a roller conveyor to the end of the operation where it is picked-up by a forklift.

Figure 2: Robot's Work Area



The capacity and limitations of production are directly related with the specifications of the robots utilized in the operation. In addition, the robot's specifications and functions have a significant impact on the hazards associated with the operation.

<u>Robot Specifications</u>

The robots used in the palletizing operation are FANUC Robot M-410iHS, specification A05B-1037-B211, with a RJ2 controller. *Figure 3* shows a FANUC Robot M-410iHS. This robot from FANUC Robotics is engineered for precision, high-speed/high payload operation, user-friendly setup, and maximum reliability. The M-410iHS is a four-axis, modular construction, and electric servo-driven robot with an integrated mechanical and control unit designed for a variety of manufacturing processes.

Figure 3: FANUC Robot M-410iHS

Source: FANUC Robotics, http://www.fanucrobotics.com

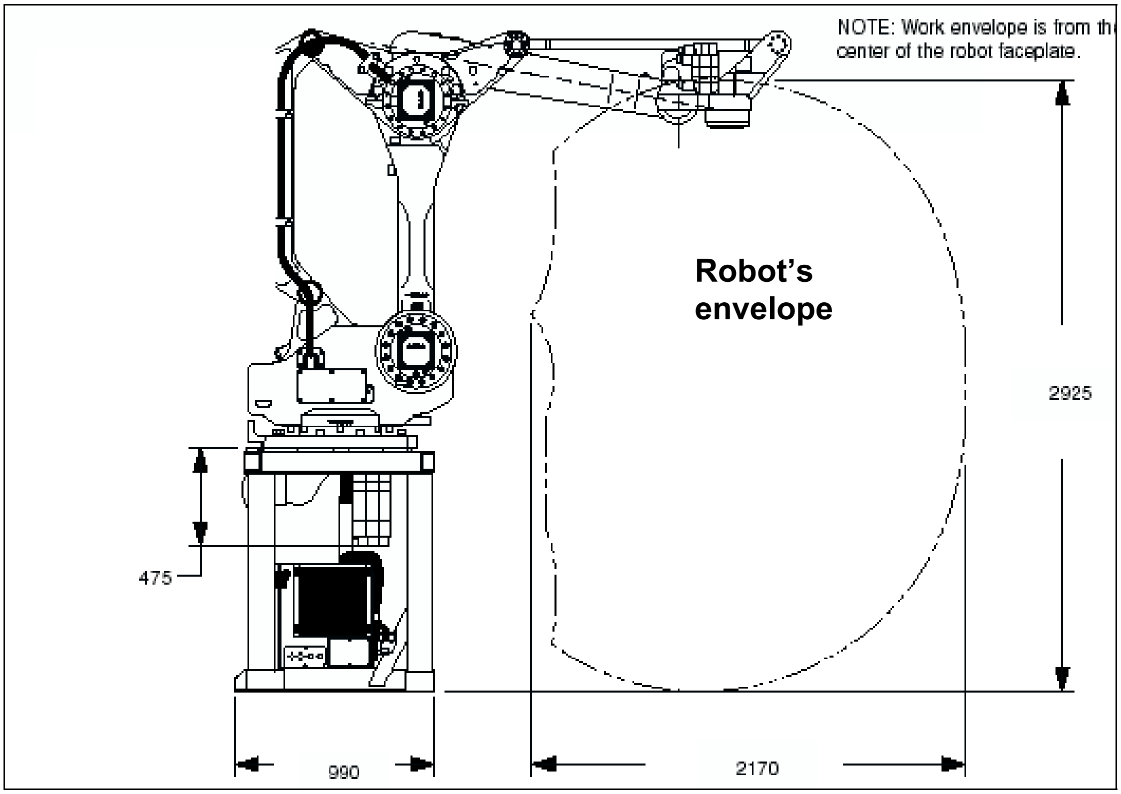
Other specifications of the FANUC M-410iHS are presented in Table 7. The mechanical and control unit are integrated and mounted in the robot's base. This robot has a large work envelope to provide variety and flexibility to the customers. Several applications of the FANUC M-410iHS are palletizing, depalletizing, machine load/unload, and order picking.

Table 7. Specifications of the FANUC M-410iHS

Item	Specification
Number of axes	4
Dimensions	See *Figure 4*
Motors	4
Mechanical Brakes	All axes (on each motor)
Payload (Maximum Load)	100 kg
Maximum Reach	3139 mm
Repeatability	± 0.5 mm
Mechanical Weight	1570 kg
Energy Sources	Electrical, Pneumatic

Source: Information from FANUC Robotics

Figure 4: Dimensions of the FANUC Robot M-410iHS



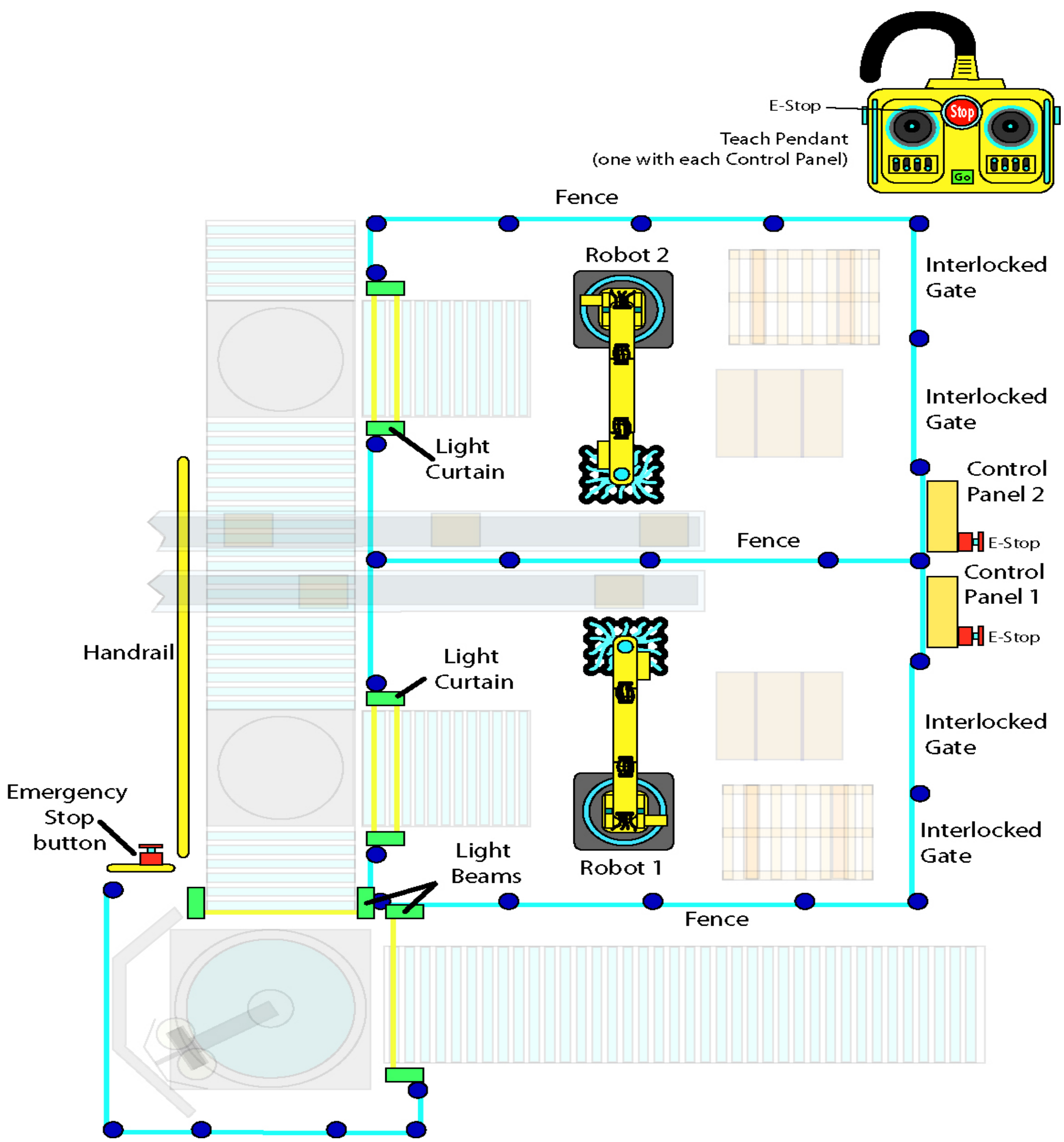
Source: FANUC Robotics, http://www.fanucrobotics.com

FANUC Robotics provides installation services through a third party. The installer provides installation, and teaching and programming of the operational movements. In addition, the installer provides generic safeguards and safety training to employees.

Safety Devices

The palletizing operation is enclosed by a fence that restricts undesired access to the robot's envelope. There are two open areas, one on each work cell, which are guarded by light curtains. Access into the work cell is provided through interlocked gates, two on each work cell. *Figure 5* shows the safety devices currently in the work area and their location. There are E-stops located on the panels outside the robot's cell, the teach pendants have E-stops as well. In addition, there is an E-stop for work cell 1 by the wrapping station, which is at the opposite side of the other E-stops. Light curtains are installed at the entrance and exit of the wrapping station to restrict undesired access to the area.

Figure 5: Safety Devices in the in the work area



Moreover, a lockout/tagout program is in place. As mention before, there are two sources of energy, electric and pneumatic. Therefore there are two lockout points on each robot. The electric energy is locked-out on the panel outside the robot cell and the pneumatic energy is locked-out on the robot's base. Even though lockout/tagout program is part of the company's policy, it is not always followed due to production time or employees decision.

There are different modes of operation and status of the system. When an E-stop is activated, the robot stops immediately. This is known as a hard stop, emergency stop situation, or programmed parameter violation. There are other situations that may cause a hard stop (e.g. open an interlocked door, pass the light curtain). In this situation, all control power is dead; the brakes on motors are activated, and no movement occurs. A different stop is in a non-emergency situation, e.g. cleanup jams. This is called the soft stop. In this situation, the robot's movement is properly stopped. Other modes of operation follow.

Modes:

1) Production – normal operation, the robot is running or ready to run.
2) Program – deenergize except the main computer, breaks are locked.
3) Maintenance – pre-selected maintenance position, everything energized, accessible but not able to move.
4) Perch – cleaning, product removal, breaks are locked.

The understanding of the operation was fundamental to conduct the assessment and to accomplish the goals. Each goal will be address in the subsequent sections. Results were collected following the methodology presented in Chapter III.

Goal 1: Assess Previous Experiences and Current Practices

Records on OSHA recordable injuries at XYZ Manufacturing Company were reviewed. No injuries related with robot operations were found, but it is important to consider the age of the operation. Just two years ago, the industrial robots were introduced at the company. Moreover, manufacturers and installers jointly provide prescribed safeguards to the operation.

Beyond record reviews, production and maintenance employees were interviewed in regards to near misses involving the robot operation. One of the maintenance employees stated that he experienced a near miss while inside the robot's cell with the door closed, inspecting a robot's fail. A second employee was at the control panel, following instructions from the maintenance operator. During the communication between the two employees, one of the instructions became confused, causing the robot to move towards the maintenance employee. Fortunately, he reacted quickly and avoided the hit. This incident could have resulted in a very serious injury though. Disregard for company policies was the cause of this near miss. In *Table 7*, specific questions addressing procedures and practices followed at XYZ Manufacturing Company are presented.

Table 7. Current Procedures and Practices

Questions	Yes	No	Comments
Is there a Lockout/Tagout program? If yes, when is used?	X		The company's lockout/tagout program is followed during maintenance and production operations. During production operations (clearing jams, loading material, etc.), the robot energy sources are not locked out.
Are there different speeds set for maintenance and teaching operations?	X		The robot operates at maximum speed; most maintenance operations are performed with no motion. The installer, not the company's employees, performs teaching operations.
Does the operator use a standard start-up procedure to restart the robot after an emergency stop?		X	Standard procedure is followed from the manufacturer's manual and the installer's instructions. Written procedures are not readily accessible to the employees.

Table 7. Current Procedures and Practices (Continuation)

Questions	Yes	No	Comments
Do all incorporated barriers and interlocking barriers prevent personnel from reaching over, around, under, or through the barrier to access the restricted envelope?		X	The robot cell is enclosed and has interlocked access doors. The opposite side is open to allow the transfer of product to the roller conveyor. Light curtains are installed in this open area to prevent access into the robot envelope during operation. One of the light curtains was not working at the time of the assessment. It is possible to climb from outside of the cell trough the overhead conveyor.
Is there a standard procedure for cleaning-up/clearing jams? Explain.	X		There is a given procedure to enter the robot cell. This procedure is in the manufacture's manual, but it is not posted in the working area.
Is the following documentation maintained and made available, upon request, to personnel associated with the robotic system: • Installation instructions and specifications	X		

Table 7. Current Procedures and Practices (Continuation)

Questions	Yes	No	Comments
• Function and location of all controls	X		
• Robot specifications, including range and load capacity	X		All instructions, functions, and specifications of the FANUC Robot are contained in the manufacturer’s manuals. These manuals are located in the maintenance shop and are available to all workers upon request.
• Manufacturer's system-specific safety-related information	X		
• Operating instructions	X		
• Maintenance and repair procedures, including lockout/tagout procedures	X		
• Robot system testing and start-up procedures, including initial start-up procedures	X		
• Electrical requirements	X		

Table 7. Current Procedures and Practices (Continuation)

Questions	Yes	No	Comments
• System-specific safety documentation, including risk assessment documentation		X	A Risk Assessment or Job Hazard Analysis has not been performed in the robotic system.
• System-specific robot safety training lesson plans and associated materials		X	The installer conducted training for robot operators and maintenance employees. There was no further safety training conducted by the company; therefore, there is no training documentation.

<u>Goal 2: Risk Assessment of the Robot Palletizing Operation</u>

The risk assessment covered all tasks performed on the robot including daily, weekly, monthly, and annually tasks. These tasks were divided into normal operations, preventive maintenance, and maintenance operations. The risk of the present situation was determined based on the severity, exposure, and avoidance levels. For instance, a severity rated as “S2” represents a “Serious Injury”, while an “S1” represents a “Slight Injury” (Please refer to the Appendix A for the levels of each category).

After safeguards and recommendations were provided, a validation was conducted to determine and control the residual risk. Again, the validation was based on the severity, exposure, and avoidance of the risk. Once the risk reduction category was R3 or R4, meaning non-interlocked barriers or awareness means, the risk assessment was completed. Data gathered and results follow in *Table 8*.

Table 8. Risk Assessment Data

Sequence No.	*Task Description*	*Hazards*	*Prior to safeguard*				*Recommendation/Solution*	*Validation*			
			Severity	Exposure	Avoidance	Risk Category		Exposure	Avoidance	Severity	Risk Category
Production Operations											
1	Clearing conveyor jams	Sharp edges (cardboards, tools, bearings, aluminum)	S1	E2	A1	R3A	Engineer out sharp edges and use of PPE-gloves.	E1	A1	S1	R4
1	Clearing conveyor jams	Electric shock (from cords on the floor)	S2	E2	A2	R1	Interlocked gate to drop out controller power (In place)	E1	A1	S1	R4
1	Clearing conveyor jams	Slip/fall same level (product and cables on the floor)	S2	E2	A2	R1	Immediate clean up and use ramped non-slip cover over cables.	E2	A1	S1	R3A
1	Clearing conveyor jams	Muscle strain from moving material in awkward positions.	S2	E2	A2	R1	Training on proper lifting techniques and get help when necessary.	E2	A1	S1	R3A
1	Clearing conveyor jams	Fall from height (using ladders)	S2	E2	A2	R1	Use of platform and taller ladders.	E2	A1	S1	R3A
1	Clearing conveyor	Struck by the robot in the	S2	E2	A2	R1	Install a light curtain or fence between the two	E1	A1	S1	R4

	jams	adjacent cell.					conveyors.				
1	Clearing conveyor jams	Eye hazard (from dust, cardboard, parts, glue, etc.)	S1	E2	A1	R3A	Use of PPE-safety glasses.	E2	A1	S1	R3A
2	Clearing robot jams	Sharp edges (cardboards, tools, bearings, aluminum)	S1	E2	A1	R3A	Engineer out sharp edges and use of PPE-gloves.	E1	A1	S1	R4
2	Clearing robot jams	Electric shock (from cords on the floor)	S2	E2	A2	R1	Interlocked gate to drop out controller power (In place)	E1	A1	S1	R4
2	Clearing robot jams	Slip/fall same level (product and cables on the floor)	S2	E2	A2	R1	Immediate clean up and use ramped non-slip cover over cables.	E2	A1	S1	R3A
2	Clearing robot jams	Muscle strain from moving material in awkward positions.	S2	E2	A2	R1	Training on proper lifting techniques and get help when necessary.	E2	A1	S1	R3A
2	Clearing robot jams	Fall from height (using ladders)	S2	E2	A2	R1	Use of platform and taller ladders.	E2	A1	S1	R3A
2	Clearing robot jams	Struck by the robot in the adjacent cell.	S2	E2	A2	R1	Install a light curtain or fence between the two conveyors.	E1	A1	S1	R4
2	Clearing robot jams	Eye hazard (from dust, cardboard, parts, glue, etc.)	S1	E2	A1	R3A	Use of PPE-safety glasses.	E2	A1	S1	R3A
3	Clearing slip sheets/pallet jams	Muscle strain from moving material in awkward	S2	E1	A2	R2B	Training on proper lifting techniques and get help when necessary.	E2	A1	S1	R3A

		positions.									
3	Clearing slip sheets/pallet jams	Slip/fall same level (product and cables on the floor)	S2	E1	A2	R2B	Immediate clean up and use ramped non-slip cover over cables.	E2	A1	S1	R3A
3	Clearing slip sheets/pallet jams	Electric shock (from cords on the floor)	S2	E1	A2	R2B	Interlocked gate to drop out controller power (In place)	E1	A1	S1	R4
3	Clearing slip sheets/pallet jams	Eye hazard (from dust, cardboard, parts, glue, etc.)	S1	E1	A1	R4	Use of PPE-safety glasses.	E2	A1	S1	R3A
3	Clearing slip sheets/pallet jams	Sharp edges (cardboards, tools, bearings, aluminum)	S1	E1	A1	R4	Engineer out sharp edges and use of PPE-gloves.	E1	A1	S1	R4
4	Clearing/Cleaning dropped product	Muscle strain from moving material in awkward positions.	S2	E2	A2	R1	Training on proper lifting techniques and get help when necessary.	E2	A1	S1	R3A
4	Clearing/Cleaning dropped product	Slip/fall same level (product and cables on the floor)	S2	E2	A2	R1	Immediate clean up and use ramped non-slip cover over cables.	E2	A1	S1	R3A
4	Clearing/Cleaning dropped product	Electric shock (from cords on the floor)	S2	E2	A2	R1	Interlocked gate to drop out controller power (In place)	E1	A1	S1	R4
4	Clearing/Cleaning dropped product	Eye hazard (from dust, cardboard, parts, glue, etc.)	S1	E2	A1	R3A	Use of PPE-safety glasses.	E2	A1	S1	R3A
4	Clearing/Cleaning dropped product	Sharp edges (cardboards, tools, bearings, aluminum)	S1	E2	A1	R3A	Engineer out sharp edges and use of PPE-gloves.	E1	A1	S1	R4

5	General housekeeping	Sharp edges (cardboards, tools, bearings, aluminum)	S1	E1	A1	R4	Engineer out sharp edges and use of PPE-gloves.	E1	A1	S1	R4
5	General housekeeping	Electric shock (from cords on the floor)	S2	E1	A2	R2B	Interlocked gate to drop out controller power (In place)	E1	A1	S1	R4
5	General housekeeping	Slip/fall same level (product and cables on the floor)	S2	E1	A2	R2B	Immediate clean up and use ramped non-slip cover over cables.	E2	A1	S1	R3A
5	General housekeeping	Muscle strain from moving material in awkward positions.	S2	E1	A2	R2B	Training on proper lifting techniques and get help when necessary.	E2	A1	S1	R3A
5	General housekeeping	Fall from height (using ladders)	S2	E1	A2	R2B	Use of platform and taller ladders.	E2	A1	S1	R3A
5	General housekeeping	Struck by the robot in the adjacent cell.	S2	E1	A2	R2B	Install a light curtain or fence between the two conveyors.	E1	A1	S1	R4
5	General housekeeping	Eye hazard (from dust, cardboard, parts, glue, etc.)	S1	E1	A1	R4	Use of PPE-safety glasses.	E2	A1	S1	R3A
6	Reload the slip sheet/pallet stack	Muscle strain from lifting sleep sheets and pallets	S2	E1	A2	R2B	Reload stack using a forklift through the interlock gate. (Training on proper lifting techniques and get help when necessary).	E1	A1	S1	R4
6	Reload the slip sheet/pallet stack	Slip/fall same level (product and cables on the floor)	S2	E1	A2	R2B	Immediate clean up and use ramped non-slip cover over cables.	E2	A1	S1	R3A

6	Reload the slip sheet/pallet stack	Electric shock (from cords on the floor)	S2	E1	A2	R2B	Interlocked gate to drop out controller power (In place)	E1	A1	S1	R4
6	Reload the slip sheet/pallet stack	Eye hazard (from dust, cardboard, parts, glue, etc.)	S1	E1	A1	R4	Use of PPE-safety glasses.	E2	A1	S1	R3A
6	Reload the slip sheet/pallet stack	Sharp edges (cardboards, tools, bearings, aluminum)	S1	E1	A1	R4	Engineer out sharp edges and use of PPE-gloves.	E1	A1	S1	R4
7	Replace Lock-N-Pop barrel (glue) Note: Outside the robot cell	Muscle strain from moving material in awkward positions.	S2	E1	A2	R2B	Training on proper lifting techniques and get help when necessary.	E2	A1	S1	R3A
7	Replace Lock-N-Pop barrel (glue)	Slip/fall same level (product and cables on the floor)	S2	E1	A2	R2B	Immediate clean up and use ramped non-slip cover over cables.	E2	A1	S1	R3A
Preventive Maintenance operations												
8	Greasing	Slip/fall same level (from grease spill, product, and cables on the floor)	S2	E1	A2	R2B	Immediate clean up and use ramped non-slip cover over cables.	E2	A1	S1	R3A
8	Greasing	Eye hazard (from dust, grease, parts, etc.)	S1	E1	A1	R4	Use of PPE-safety glasses.	E2	A1	S1	R3A

8	Greasing	Sharp edges (tools, parts, bearings, aluminum)	S1	E1	A1	R4	Engineer out sharp edges and use of PPE-gloves.	E1	A1	S1	R4
8	Greasing	Fall from height (using ladders)	S2	E1	A2	R2B	Use of platform and taller ladders.	E2	A1	S1	R3A
8	Greasing	Struck by the robot (when moving the robot manually)	S2	E1	A1	R2B	Move the robot manually from the outside of the cell	E1	A1	S1	R4
8	Greasing	Head injury (hit by bearing and other surfaces)	S1	E1	A1	R4	Awareness	S1	E1	A1	R4
9	Maintain Lock-N-Pop system Note: Outside the robot cell	Eye hazard (from dust, glue, parts, etc.)	S1	E1	A1	R4	Use of PPE-safety glasses.	E2	A1	S1	R3A
9	Maintain Lock-N-Pop system	Sharp edges (parts, aluminum)	S1	E1	A1	R4	Engineer out sharp edges and use of PPE-gloves.	E1	A1	S1	R4
10	Clean Nozzle/Inspect glue lines	Slip/fall same level (from product, and cables on the floor)	S2	E1	A2	R2B	Immediate clean up and use ramped non-slip cover over cables.	E2	A1	S1	R3A
10	Clean Nozzle/Inspect glue lines	Eye hazard (from dust, glue, parts, etc.)	S1	E1	A1	R4	Use of PPE-safety glasses.	E2	A1	S1	R3A

10	Clean Nozzle/Inspect glue lines	Sharp edges (tools, parts, bearings, aluminum)	S1	E1	A1	R4	Engineer out sharp edges and use of PPE-gloves.	E1	A1	S1	R4
10	Clean Nozzle/Inspect glue lines	Fall from height (using ladders)	S2	E1	A2	R2B	Use of platform and taller ladders.	E2	A1	S1	R3A
10	Clean Nozzle/Inspect glue lines	Struck by the robot (when moving the robot manually)	S2	E1	A1	R2B	Move the robot manually from the outside of the cell	E1	A1	S1	R4
11	Refill air oiler Note: Air oiler for the robot	Slip/fall same level (from product, and cables on the floor)	S2	E1	A2	R2B	Immediate clean up and use ramped non-slip cover over cables.	E2	A1	S1	R3A
11	Refill air oiler	Eye hazard (from dust, oil, parts, etc.)	S1	E1	A1	R4	Use of PPE-safety glasses.	E2	A1	S1	R3A
11	Refill air oiler	Sharp edges (tools, parts, bearings, aluminum)	S1	E1	A1	R4	Engineer out sharp edges and use of PPE-gloves.	E1	A1	S1	R4
11	Refill air oiler	Head injury (hit by bearing and other surfaces)	S1	E1	A1	R4	Awareness	S1	E1	A1	R4
12	Clean or replace air filter	Slip/fall same level (from product, and cables on the	S2	E1	A2	R2B	Immediate clean up and use ramped non-slip cover over cables.	E2	A1	S1	R3A

		floor)									
12	Clean or replace controller filter	Eye hazard (from dust, oil, parts, etc.)	S1	E1	A1	R2B	Use of PPE-safety glasses.	E2	A1	S1	R3A
12	Clean or replace controller filter	Sharp edges (tools, parts, bearings, aluminum)	S1	E1	A1	R4	Engineer out sharp edges and use of PPE-gloves.	E1	A1	S1	R4
12	Clean or replace controller filter	Head injury (hit by bearing and other surfaces)	S1	E1	A1	R4	Awareness	S1	E1	A1	R4
12	Clean or replace controller filter	Electric shock (from cables on the controller)	S2	E1	A2	R2B	Interlocked gate to drop out controller power (In place)	E1	A1	S1	R4
13	Inspect cables, hoses, sensors	Slip/fall same level (from product, and cables on the floor)	S2	E1	A2	R2B	Immediate clean up and use ramped non-slip cover over cables.	E2	A1	S1	R3A
13	Inspect cables, hoses, sensors	Eye hazard (from dust, oil, parts, etc.)	S1	E1	A1	R4	Use of PPE-safety glasses.	E2	A1	S1	R3A
13	Inspect cables, hoses, sensors	Sharp edges (tools, parts, bearings, aluminum)	S1	E1	A1	R4	Engineer out sharp edges and use of PPE-gloves.	E1	A1	S1	R4
13	Inspect cables, hoses, sensors	Head injury (hit by bearing and other surfaces)	S1	E1	A1	R4	Awareness	S1	E1	A1	R4
13	Inspect cables, hoses, sensors	Electric shock (from cables on the controller)	S2	E1	A2	R2B	Interlocked gate to drop out controller power (In place)	E1	A1	S1	R4

13	Inspect cables, hoses, sensors	Fall from height (using ladders)	S2	E1	A2	R2B	Use of platform and taller ladders.	E2	A1	S1	R3A
Maintenance Operations											
14	Replacing the operator box (Note: Outside the cell)	Electric shock (from cables on the panel)	S2	E1	A2	R2B	Interlocked gate to drop out controller power (In place)	E1	A1	S1	R4
14	Replacing the operator box	Sharp edges (tools, parts, aluminum)	S1	E1	A1	R4	Engineer out sharp edges and use of PPE-gloves.	E1	A1	S1	R4
14	Replacing the operator box	Slip/fall same level (from teach pendant cable)	S2	E1	A2	R2B	Immediate clean up and use ramped non-slip cover over cables.	E2	A1	S1	R3A
14	Replacing the operator box	Eye hazard (from dust, parts, etc.)	S1	E1	A1	R4	Use of PPE-safety glasses.	E2	A1	S1	R3A
15	Replacing the teach pendant (Note: Outside the cell)	Slip/fall same level (from teach pendant cable)	S2	E1	A2	R2B	Immediate clean up and use ramped non-slip cover over cables.	E2	A1	S1	R3A
15	Replacing the	Eye hazard (from dust,	S1	E1	A1	R4	Use of PPE-safety glasses.	E2	A1	S1	R3A

	teach pendant	parts, etc.)										
15	Replacing the teach pendant	Electric shock (from cables on the panel)	S2	E1	A2	R2B	Interlocked gate to drop out controller power (In place)	E1	A1	S1	R4
15	Replacing the teach pendant	Sharp edges (tools, parts, aluminum)	S1	E1	A1	R4	Engineer out sharp edges and use of PPE-gloves.	E1	A1	S1	R4
16	Replacing the fan motor of the control unit	Eye hazard (from dust, oil, parts, etc.)	S1	E1	A1	R4	Use of PPE-safety glasses.	E2	A1	S1	R3A
16	Replacing the fan motor of the control unit	Sharp edges (tools, parts, bearings, aluminum)	S1	E1	A1	R4	Engineer out sharp edges and use of PPE-gloves.	E1	A1	S1	R4
16	Replacing the fan motor of the control unit	Head injury (hit by bearing and other surfaces)	S1	E1	A1	R4	Awareness	S1	E1	A1	R4
16	Replacing the fan motor of the control unit	Electric shock (from cables on the controller)	S2	E1	A2	R2B	Interlocked gate to drop out controller power (In place)	E1	A1	S1	R4
17	Replacing fuses	Sharp edges (tools, parts, bearings, aluminum)	S1	E1	A1	R4	Engineer out sharp edges and use of PPE-gloves.	E1	A1	S1	R4
17	Replacing fuses	Eye hazard (from dust, oil,	S1	E1	A1	R4	Use of PPE-safety glasses.	E2	A1	S1	R3A

		parts, etc.)									
17	Replacing fuses	Slip/fall same level (from teach pendant cable)	S2	E1	A2	R2B	Immediate clean up and use ramped non-slip cover over cables.	E2	A1	S1	R3A
17	Replacing fuses	Electric shock (from cables on the controller)	S2	E1	A2	R2B	Interlocked gate to drop out controller power (In place)	E1	A1	S1	R4
17	Replacing fuses	Stored energy	S2	E1	A2	R2B	Shut off and lockout/tagout electric energy source	E1	A1	S1	R4
18	Replacing a relay	Sharp edges (tools, parts, bearings, aluminum)	S1	E1	A1	R4	Engineer out sharp edges and use of PPE-gloves.	E1	A1	S1	R4
18	Replacing a relay	Eye hazard (from dust, oil, parts, etc.)	S1	E1	A1	R4	Use of PPE-safety glasses.	E2	A1	S1	R3A
18	Replacing a relay	Electric shock (from cables on the controller)	S2	E1	A2	R2B	Interlocked gate to drop out controller power (In place)	E1	A1	S1	R4
18	Replacing a relay	Stored energy	S2	E1	A2	R2B	Shut off and lockout/tagout electric energy source	E1	A1	S1	R4
19	Replacing the battery	Sharp edges (tools, parts, bearings, aluminum)	S1	E1	A1	R4	Engineer out sharp edges and use of PPE-gloves.	E1	A1	S1	R4
19	Replacing the battery	Eye hazard (from dust, oil, parts, etc.)	S1	E1	A1	R4	Use of PPE-safety glasses.	E2	A1	S1	R3A
19	Replacing the battery	Slip/fall same level (from product and cables on the floor)	S2	E1	A2	R2B	Immediate clean up and use ramped non-slip cover over cables.	E2	A1	S1	R3A

19	Replacing the battery	Electric shock (from cables on the controller)	S2	E1	A2	R2B	Interlocked gate to drop out controller power (In place)	E1	A1	S1	R4
19	Replacing the battery	Stored energy	S2	E1	A2	R2B	Shut off and lockout/tagout electric energy source	E1	A1	S1	R4
20	Replacing servo amplifier	Sharp edges (tools, parts, bearings, aluminum)	S1	E1	A1	R4	Engineer out sharp edges and use of PPE-gloves.	E1	A1	S1	R4
20	Replacing servo amplifier	Eye hazard (from dust, oil, parts, etc.)	S1	E1	A1	R4	Use of PPE-safety glasses.	E2	A1	S1	R3A
20	Replacing servo amplifier	Slip/fall same level (from product and cables on the floor)	S2	E1	A2	R2B	Immediate clean up and use ramped non-slip cover over cables.	E2	A1	S1	R3A
20	Replacing servo amplifier	Electric shock (from cables on the controller)	S2	E1	A2	R2B	Interlocked gate to drop out controller power (In place)	E1	A1	S1	R4
20	Replacing servo amplifier	Stored energy	S2	E1	A2	R2B	Shut off and lockout/tagout electric energy source	E1	A1	S1	R4
21	Replacing the transformer	Sharp edges (tools, parts, bearings, aluminum)	S1	E1	A1	R4	Engineer out sharp edges and use of PPE-gloves.	E1	A1	S1	R4
21	Replacing the transformer	Eye hazard (from dust, oil, parts, etc.)	S1	E1	A1	R4	Use of PPE-safety glasses.	E2	A1	S1	R3A
21	Replacing the	Slip/fall same level (from	S2	E1	A2	R2B	Immediate clean up and use ramped non-slip	E2	A1	S1	R3A

	transformer	product and cables on the floor)					cover over cables.				
21	Replacing the transformer	Electric shock (from cables on the controller)	S2	E1	A2	R2B	Interlocked gate to drop out controller power (In place)	E1	A1	S1	R4
21	Replacing the transformer	Stored energy	S2	E1	A2	R2B	Shut off and lockout/tagout electric energy source	E1	A1	S1	R4
21	Replacing the transformer	Electric shock from incoming energy	S2	E1	A2	R2B	Lockout main panel	E1	A1	S1	R4
22	Replacing the modular input/output unit	Sharp edges (tools, parts, bearings, aluminum)	S1	E1	A1	R4	Engineer out sharp edges and use of PPE-gloves.	E1	A1	S1	R4
22	Replacing the modular input/output unit	Eye hazard (from dust, oil, parts, etc.)	S1	E1	A1	R4	Use of PPE-safety glasses.	E2	A1	S1	R3A
22	Replacing the modular input/output unit	Slip/fall same level (from product and cables on the floor)	S2	E1	A2	R2B	Immediate clean up and use ramped non-slip cover over cables.	E2	A1	S1	R3A
22	Replacing the modular input/output unit	Electric shock (from cables on the controller)	S2	E1	A2	R2B	Interlocked gate to drop out controller power (In place)	E1	A1	S1	R4

22	Replacing the modular input/output unit	Stored energy	S2	E1	A2	R2B	Shut off and lockout/tagout electric energy source	E1	A1	S1	R4
23	Replacing the I/O interface unit	Sharp edges (tools, parts, bearings, aluminum)	S1	E1	A1	R4	Engineer out sharp edges and use of PPE-gloves.	E1	A1	S1	R4
23	Replacing the I/O interface unit	Eye hazard (from dust, oil, parts, etc.)	S1	E1	A1	R4	Use of PPE-safety glasses.	E2	A1	S1	R3A
23	Replacing the I/O interface unit	Slip/fall same level (from product, cables on the floor)	S2	E1	A2	R2B	Immediate clean up and use ramped non-slip cover over cables.	E2	A1	S1	R3A
23	Replacing the I/O interface unit	Electric shock (from cables on the controller)	S2	E1	A2	R2B	Interlocked gate to drop out controller power (In place)	E1	A1	S1	R4
23	Replacing the I/O interface unit	Stored energy	S2	E1	A2	R2B	Shut off and lockout/tagout electric energy source	E1	A1	S1	R4
24	Replacing air lines	Eye hazard (from dust, oil, parts, etc.)	S1	E1	A1	R4	Use of PPE-safety glasses.	E2	A1	S1	R3A
24	Replacing air lines	Slip/fall same level (from product and cables on the floor)	S2	E1	A2	R2B	Immediate clean up and use ramped non-slip cover over cables.	E2	A1	S1	R3A
24	Replacing air lines	Sharp edges (air lines, tools, parts, bearings, aluminum)	S1	E1	A1	R4	Engineer out sharp edges and use of PPE-gloves.	E1	A1	S1	R4

24	Replacing air lines	Electric shock (from cables on the controller)	S2	E1	A2	R2B	Interlocked gate to drop out controller power (In place)	E1	A1	S1	R4
24	Replacing air lines	Laceration (Air pressure)	S2	E1	A2	R2B	Close air valve-lockout/tagout	E1	A1	S1	R4
24	Replacing air lines	Stored energy (Pneumatic, Electric)	S2	E1	A2	R2B	Lockout/tagout electric and pneumatic energy sources	E1	A1	S1	R4
24	Replacing air lines	Fall from height (using ladders)	S2	E1	A2	R2B	Use of platform and taller ladders.	E2	A1	S1	R3A

Goal 3: Human Factors Assessment

Experts on robotics have identified and studied several factors that affect human performance during robot's operations. Some of these factors were measured at XYZ Manufacturing Company. A comparison between measured and recommended values, from the literature review, assessed the robot palletizing operation. Measured and recommended values follow:

- Robot arm speed – During normal operations the robot is running at its maximum speed, 25 cm/s (9.8 in/s). Maintenance operations are performed with the power off or at lower speeds, approximately 15 cm/s (5.9 in/s).

  Recommended value – Beauchamp & Stobbe suggested 17 cm/s (6.7 in/s), while Sugimoto suggested 14 cm/s (5.5 in/s), when working within the robot envelope.
- Illumination – A range of 60-90 lux

  Recommended value – Greater than 100 lux
- Location of the emergency stop button on the teach pendant – The E-stops on the teach pendant are at the front side.

  Recommended value – In the front part of the teach pendant
- Diameter of the emergency stop button – From the five E-stops in the work area, two are 1", and the other three are 1 ½ ".

  Recommended value – At least 1" of diameter
- Noise – Between 74 and 76 dB.

Recommended value – One study found no significant effect in the noise levels. However, a second study found a significant effect of noise levels on the reaction time. This study reported that reaction time decreases with noise levels of 60 and 75 dB.

Discussion of Results

From the review of previous experiences and current practices, no injuries related with robot operations were found. However, a near miss was reported by a maintenance operator. This incident was caused by ignoring company's Lockout/Tagout policy. Production time also forces operators to disregard the Lockout/Tagout policy. In addition, it was found that procedures of start-up and cleaning/clearing jams were not posted outside the work area.

Moreover, one of the most significant findings of the ANSI/RIA Risk Assessment was the potentially hazardous exposure of employees working in the overhead conveyor inside the robot cell, e.g. removing product, clearing jams. As operators are performing these activities within one of the robot's cells, they may be unaware of the motion or reaching perimeter of the other robot at the adjacent cell. This situation can lead into a very serious injury; the adjacent robot may strike the employee while working from the other cell. It may also result in a fall from a ladder if the employee notices the robot and moves to avoid the strike. Another significant finding was the employees' exposures to the turntable and roller conveyor. For some reason, these areas are not guarded in one of the work cells. The conveyors and the turntable do not stop at the intrusion of a person. Therefore, employees could step into the turntable and get hurt when the table turns around. This situation represents a hazard not just for the robot's operators but also for any individual that may walk through that area. Additional findings of the assessment include minor risk/exposures to muscle strain, back injuries, slip/trip/falls, sharp edges, and eye hazards. A final observation is that one of the light curtains surrounding the area was not working during several visits.

Finally, the results of the human factors are not very different from the recommended values, provided in the literature review. For instance, the robot's speed during maintenance operations falls within the suggested range. The emergency stop buttons in the teach pendant are located in its front part and have more than 1" of diameter, as recommended. Also, the noise levels were very close to the suggested ones. However, the illumination slightly differs from the recommended value. Depending on the area of measurement, the reading was between 60 and 90 lux, while the literature review suggests illumination levels greater than 100 lux.

The risk assessment of the palletizing operation and other information gathered in this chapter are the basis for the conclusions and recommendations of this study, presented on the next chapter.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Summary of Study

The purpose of this study was to assess the robot palletizing operation at XYZ Manufacturing Company, using the risk assessment methodology recommended by the ANSI/RIA R15.06 standard. In addition to the risk assessment, other strategies were utilized, in order, to provide a comprehensive analysis of the operation and work area. The followings are the specific goals of the study.

1) Assess previous experiences regarding losses and near hits as well as current practices followed by the company.

2) Identify and analyze existing risks as related to entries and inside the robot envelope.

3) Evaluate factors that affect human performance during robot operations.

Restatement of the Problem

Two years ago XYZ Manufacturing Company installed five industrial robots, automating a significant part of their packaging operations. Since then assessments to identify existing risks in the operations have not been performed. The lack of robot operations assessment and written procedures is placing employees at risk of injuries.

Methods and Procedures

The robot palletizing operation at XYZ Manufacturing Company was assessed considering employees' previous experiences, reviewing the OSHA 200 Logs and interviewing employees regarding near hits or not reported incidents. In addition, the current procedures and practices were evaluated reviewing written programs and procedures. The risk assessment methodology from the ANSI/RIA R15.06 standard provided the identification and analysis of hazards inside and outside the robots' work cell. Finally, studies on factors affecting human performance during robot operations were compiled and presented in the literature review. Some of these factors were measured at XYZ Manufacturing Company and compared to the recommendations provided in the previous studies.

Major Findings

From the results of this study, presented in the previous chapter, various deficiencies or areas of opportunity were identified. Some of the major findings include the recurrent disregard of company's Lockout/Tagout policy, the risk placed by the robot in the adjacent cell to employees working in the overhead conveyor, and the hazards presented by the unguarded turntable and roller conveyor. Recommendations to these and other situations identified through the study are provided.

Conclusions

At present, robots' manufacturers provide specifications, safeguards, operational procedures, programming, training, in fact, all the information and support necessary to operate. What customers really overlook is that each process and layout represents specific needs. A risk assessment of a robot operation is the key for the identification, measurement, and analysis of hazards and the development of solutions.

The assessment in this study provided the opportunity to identify hazardous situations and behaviors that were placing employees to risk. Situations such as lack of hazard analysis, unguarded areas, disregard of company's policies, and use of improper equipment, lead to the conclusion that Safety and Health at XYZ Manufacturing Company need to be improved. The methodology utilized in this study should be used as a guideline to perform further analysis on existing and new operations.

Recommendations

- Install a light curtain or fence to prevent operators from crossing the adjacent robot work area.
- Extend handrail to cover the conveyor's area of Robot 2 (Refer to Figure 2, Chapter IV). This will protect employees from unexpectedly approach the roller conveyor or the turntable. Moreover, a light beam for the turntable is recommended to shut its power when someone crosses the restricted area.

- Install an emergency stop button on the extended handrail mentioned above. Currently, if the employees are at that side of the work area and an emergency situation occurs, they have to run to the opposite side in order to stop the robot's motion. An emergency stop button will not just protect employees, but it will also reduce product waste generated from jams and dropped material.
- Install a light beam on the roller conveyor to stop the robot's motion if someone enters the work cell. Currently, it is possible to climb from outside of the work cell and through the overhead conveyor.
- Provide taller ladders with platforms to reach the overhead conveyor and perform the task safely.
- Increase accountability of company's safety policies particularly to the Lockout/Tagout policy.
- Use ramped, non-slip covers over the cables inside the work cell. Currently, the cables¿ are covered only in one of the work cells.
- Provide immediate cleanup when product is dropped on the floor.
- Procedures for starting-up and stopping the robot's operation should be posted or available in the robot area.
- Maintain a daily log for emergency devices testing, e.g. E-stops, light curtains, interlocked doors. This daily inspection can be incorporated into the Preventive Maintenance. It is important to provide alternative protection until the safety device is replaced.

- Safety light curtains should be labeled with the maximum response time, maximum angle of divergence/acceptance at maximum gain, protected height, and minimum object sensitivity.
- The robot's restricted envelope should be identified to provide awareness for the operators inside of the robot's cell; it may be painted or taped.
- If the robot is manually moved (using the teach pendant) or repaired while its power is on, a second employee should be outside the robot's working envelope, providing assistance.
- Provide better illumination to the work area, greater than 100 lux.
- A documented risk analysis is recommended for other robot's operations onsite and when installing new operations.

REFERENCES

ANSI/RIA R15.06, (1999). American National Safety Standard for Industrial Robots and Robot Systems. Michigan: Robotic Industries Association

Beauchamp, Y. & Stobbe, T. (1995). A review of experimental studies on human-robot system situations and their design implications. International Journal of Human Factors in Manufacturing, 5(3)

Beauchamp, Y. & Stobbe, T. (1990). The effects of factors on human performance in the event of an unexpected robot motion. Journal of Safety Research, 21(3)

Cheng, O. & Jiang, B. (1995). Integrating safety in manufacturing systems. The International Journal of Human Factors in Manufacturing, 5 (3)

Collins, J.W. (1989). Analysis of effect of diameter and location of emergency stop button on hand-held robot teach pendant design. Unpublished master's thesis, West Virginia University, Morgantown, WV

Department of Energy (DOE) OSH Technical Reference. (1998). Industrial Robots. Available: Internet: http://tis.eh.doe.gov/docs/osh_tr/ch1.html

Dhillon, B.S. (1991). Robot reliability and safety. New York: Springer-Verlag

Dhillon, B.S., & Fashandi, A. (1997). Safety and reliability assessment techniques in robotics. Robotica, 15 (6)

Donald, J. (1984). Preventing the Injury of Workers by Robots. National Institute for Occupational Safety and Health, Publication #85-103

Etherton, J. & Sneckenberger, J.E. (1990). A robot safety experiment varying robot speed and contrast with human decision cost. Applied Ergonomics, 21(3)

Etherton, J. (1988). Safe Maintenance Guide for Robotic Workstations. National Institute for Occupational Safety and Health, Publication #88-108

Graham, J.H. (1991). Safety reliability and human factors in robotic systems. New York: Van Nostrand Reinhold

Jarvinen, J. & Karwowski, W. (1995). Analysis of self-reported accidents attributed to advanced manufacturing systems. International Journal of Human Factors in Manufacturing, 5(3)

Jiang, B. & Gainer, C. (1987). A cause and effect analysis of robot accidents. Journal of occupational accidents, 9(1)

Lemay, C. (1987). Comparative study on teach pendants and recommendations on their safety use. Unpublished Master thesis, Universite du Quebec a Trois-Rivieres, Canada

Little, A. (2001). Hazard Identification and Assessment. Available: Internet: http://www.process-safety.com/services/hazid.htm

Nagamachi, M. (1986). Human factors of industrial robots and robot safety Management in Japan. Applied Ergonomics, 17(1)

National Fire Protection Association. (1997). NFPA 79 – Electrical Standard for Industrial Machinery.

Occupational Safety and Health. (1999). OSHA Technical Manual, TED 1-0.15A. US Department of Labor. Available: Internet: http://www.osha-slc.gov/dts/osta/otm/otm_toc.html

Occupational Safety and Health. (1987). Pub. 8-1.3 – Guidelines for Robotics Safety. US Department of Labor. Available: Internet: http://www.osha-slc.gov/OshDoc/Directive_data/PUB_8-1_3.html

Parsons, H.M. (1986). Human factors in industrial robot safety. Journal of occupational accidents, 8(1-2),

Rahimi, M. & Karwowski, W. (1992). Human-Robot Interaction. Washington, DC: Taylor & Francis

Robotic Industries Association. (2000). Available:Internet: http://www.robotics.org/public/articles/

Robotic Industries Association. (1986). Working Safely with Industrial Robots. Michigan:Robotics International of SME

Sugimoto, A. (1984). Limits of industrial robots teaching speeds through teaching operations tests. Machinery Institute of Japan, #844-5

United Auto Workers (UWA) Health and Safety Department (2000). Review of robot injuries- One of the best kept secrets. Publication #248

Williams, A., Smith, M., & Young, P. (1998). Risk Management and Insurance. New York:McGraw-Hill

Williams, A., Smith, M., & Young, P. (1995). Risk Management and Insurance. New York:McGraw-Hill

APPENDIX A

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Table A.1. Hazard Severity/Exposure/Avoidance Categories

Factor	Category		Criteria
Severity	S2	Serious Injury	Normally irreversible; or fatality; or requires more than first-aid as defined in OSHA 1904.12
	S1	Slight Injury	Normally reversible; or requires only first-aid as defined in OSHA 1904.12
Exposure	E2	Frequent Exposure	Typically exposure to the hazard more than once per hour
	E1	Infrequent Exposure	Typically exposure to the hazard less than once per day or shift
Avoidance	A2	Not Likely	Cannot move out of way; or inadequate reaction time; or robot speed greater than 250 mm/sec
	A1	Likely	Can move out of way; or sufficient warning/reaction time; or robot speed less than 250 mm/sec

Table A.2. Risk reduction decision matrix prior to safeguard selection

Severity of Injury	Exposure	Avoidance	Risk Reduction Category
S2 Serious Injury	**E2** Frequent Exposure	**A2** Not Likely	**R1**
		A1 Likely	**R2A**
	E1 Infrequent Exposure	**A2** Not Likely	**R2B**
		A1 Likely	**R2B**
S1 Slight Injury	**E2** Frequent Exposure	**A2** Not Likely	**R2C**
		A1 Likely	**R3A**
	E1 Infrequent Exposure	**A2** Not Likely	**R3B**
		A1 Likely	**R4**

Table A.3. Safeguard Selection Matrix

Category	Safeguard Performance	Circuit Performance
R1	Hazard elimination or hazard substitution (9.5.1)	Control reliable (4.5.4)
R2A	Engineering controls preventing access to the hazard, or stopping the hazard (9.5.2), e.g. interlocked barrier guards, light curtains, safety mats, or other presence sensing devices (10.4)	Control reliable (4.5.4)
R2B		Single channel with monitoring (4.5.3)
R2C		Single channel (4.5.2)
R3A	Non-interlocked barriers, clearance, procedures and equipment (9.5.3)	Single channel (4.5.2)
R3B		Simple (4.5.1)
R4	Awareness means (9.5.4)	Simple (4.5.1)

Table A.4. Safeguard Selection Validation matrix

Exposure	Avoidance	Severity	Risk Reduction Category
E2 Frequent Exposure	**A2** Not Likely	**S2** Serious Injury	**R1**
		S1 Slight Injury	**R2C**
	A1 Likely	**S2** Serious Injury	**R2A**
		S1 Slight Injury	**R3A**
E1 Infrequent Exposure	**A2** Not Likely	**S2** Serious Injury	**R2B**
		S1 Slight Injury	**R3A**
	A1 Likely	**S2** Serious Injury	**R3B**
		S1 Slight Injury	**R4**