Ergonomics Motives in Lock-Out and Tag-Out Implementation, An applied research

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Résumé:

Sri Lanka's apparel export industry has enjoyed epic growth levels over the past four decades and is today the primary foreign exchange earner accounting to 40% of the total exports, heavily contributing the island elevated to a middle-income country. The industry has been positioned as a socially responsible and safety complying destination for apparel sourcing. Plant maintenance plays a major role on efficiency of manufacturing process and to have apparel sectors' recognition over safe plant operations, maintenance functions have to be well complying with safety standards. "Lockout and Tag out" sequentially are the placement of a device on an energy isolator to ensure that the energy isolator and the equipment being controlled cannot be operated until the device is removed and the equipment being tagged out shall not be operated until the tag is removed. Lockout/Tagout being very human intense, role of ergonomics in Lockout/Tagout would be inevitable. This research outlines an applied research of some of the human factor issues involved in Lockout/Tagout implementation and suggests how ergonomics would improve such issues. Being an applied research, task decomposition was performed in 3 apparel accessories manufacturing plants in south Asia including Sri Lanka where Lockout/Tagout out is being implemented to identify ergonomics gaps throughout different phases of risk assessment, formulating Lockout/Tagout procedures and providing staff training. As the outcome of this research, a series of ergonomic focus points were identified that would improve Lockout/Tagout implementation. Those focus points are presented in form of a check list that can be used as an applied tool in evaluating Ergonomics of Lockout/Tagout in manufacturing field in general.

1. Introduction

While the promotion of occupational safety and health has improved over the past decades, the level of workplace fatalities, injuries and illnesses still remains unacceptably high and takes an enormous toll on men, women and their families. Economies lose out as well; the cost of accidents and ill health amounts to an estimated 4 per cent of the world's GDP. ILO (2009)

Transfer of technology and industrial development without consideration for the characteristics of the local users and the environmental conditions of the recipient countries has proved to be not only socially destructive but economically expensive in terms of human suffering and material losses. Most developing countries are paying an unacceptably high price in terms of suffering, sickness and also loss of production due to work-related accidents. Poor working conditions and non-existence of an effective injury prevention program in many developing countries has resulted in a very high sickness and accident rate. Shahnavaza, H (2010)

1.1. Maintenance and influence on safety

Historically, management has devoted much of its effort in improving manufacturing productivity by probing, measuring, reporting and analyzing manufacturing costs. Similar efforts in regard to maintenance function productivity are long overdue. It is observed that there has been a general lack of synergy between maintenance management and quality improvement strategies in the organizations, together with an overall neglect of maintenance as a competitive strategy. Wireman, T. (1990)

Safe performance of maintenance tasks is an essential responsibility of all manufacturing facilities. Workers may be exposed to hazardous energy in several forms during installation, maintenance, service or repair work. Major forms of hazardous energy are Kinetic energy in the moving parts of mechanical systems, potential energy stored in pressure vessels, gas tanks, hydraulic or pneumatic systems, and springs, electrical energy from generated electrical power, static sources or electrical storage devices such as batteries or capacitors, thermal energy, radiation, chemical reaction or electrical resistance.

1.2. Significance of Lockout / Tag out

For many maintenance tasks, it is necessary and prudent to remove sources of energy from equipment and lock or secure the equipment to prevent the unexpected release of hazardous energy during the maintenance activity. This technique, often referred to as "lockout," is usually done in conjunction with a tagging process that displays essential information surrounding the lockout process. In many countries, this lockout/tagout (LOTO) activity is regulated by the government, which prescribes many of the basic expectations for safe job performance.

LOTO is accomplished by placing a lockout and/or a tag out device on a switch, valve, breaker, etc. to prevent reactivation of the equipment and to warn that maintenance activities are in progress. Equipment is considered "locked out" when the flow of hazardous energy has been blocked and operation of the equipment is prevented until the lockout device is removed. Equipment is considered "tagged out" when a warning tag is placed on the equipment warning others that the equipment is being serviced and must not be operated. These safety measures should be used together to provide the maximum level of protection for those performing the service.

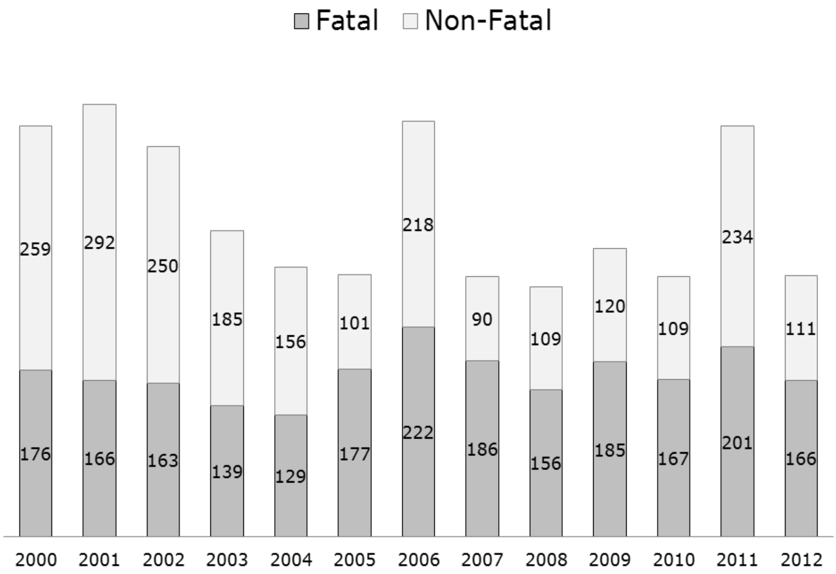
1.3. Ergonomics considerations in Maintenance

As defined by International Ergonomics Association (IEA) in their official web site http://www.iea.cc Ergonomics (or human factors) is the scientific discipline concerned with the understanding of the interactions among humans and other elements of a system, and the profession that applies theoretical principles, data and methods to design in order to optimize human wellbeing and overall system performance. Maintenance task in general is different from the routine machine operation task because it requires special problem solving skills, reach to unfavorable locations such as high places and narrow spaces, working in awkward postures, insufficient space for the hand movements or seeing, lack of free space, excessive force required for irregular operations, poor lighting and thermal conditions and high noise and vibration levels hazards. From an ergonomics standpoint, addressing issues associated with maintenance and repair activities is difficult due to the variable nature of the work, the changing location of the tasks, and the inherent complexity of accessing, diagnosing, and repairing various types of equipment. These complexities may partly explain why there has been comparatively little ergonomics research addressing maintenance.

1.4. Review of literature

As published in the official web site of International Labor Organization (ILO) (http://www.ilo.org), ILO estimates that approximately 2.2 million people die every year from occupational accidents and diseases, while some 270 million suffer serious non-fatal injuries and another 160 million falls ill for shorter or longer periods from work-related causes. The total cost of such accidents and ill health have been estimated at four percent of the worlds gross domestic product

Despite the fact that Sri Lanka's manufacturing sector has enjoyed epic growth levels over the past four decades heavily contributing the island elevated to a middle-income country, recent records on industrial accidents in Sri Lanka reveal some of the organizations are not merely complying with the basics of LOTO. Graph 1 illustrates the number of settled accidents and compensation paid to injured employees due to accidents while being engaged in service of both private & public sectors during the period of 2000 to 2012 in Sri Lanka. In 2012, occurred accidents are less than comparing with 2011, but paid compensations amount is highest during the period of 2000 to 2012. Department of Labor Ministry of Labor and Labor Relations, Sri Lanka (2013)



Graph 1: Number of settled Fatal and non-Fatal accidents and compensation paid during 2000 to 2012

Plant and equipment maintenance and repair tasks have long posed challenges ranging from human performance issues leading to acute traumatic injuries and fatalities (Cawley, 2003; Lind, 2008; Lind and Nenonen, 2008), reduced equipment availability during troubleshooting and repair, and equipment failure due to errors during maintenance. Not only is this work non-routine, there are, among other issues, machine and electrical hazards, materials handling exposures, falls, access issues that restrict posture and increase biomechanical demands, and injuries associated with hand tools. In published research, these problems have been approached from several viewpoints including engineering (Harring and Greenman, 1965; Unger and Conway, 1994), human error and ergonomics (Dhillon and Liu, 2006; Koli et al., 1998; Mason, 1990), and risk assessment (Lind et al., 2008). In a study of fatal or severe injuries sustained during plant maintenance, Lind (2008) found that 48 percent of 33 fatalities studied occurred during planned preventive operations. For fatalities, the leading causes were being crushed or caught between (27 %) and falls (27 %). For severe non-fatal injuries, the leading causes were being crushed or caught between (39 %) and jumping or falling (21 %).

In addition to falls and traumatic injuries from incursions with machinery or parts, maintenance tasks in aviation maintenance were found to pose ergonomics deficiencies including frequent awkward and restricted postures, working in hot and noisy environments, forceful exertions, and manual materials handling (Chervak and Drury, 1996). To address these latter exposures, Koli et al. (1998) developed an ergonomics audit as an approach to assess human-system mismatches in aviation maintenance.

During 1982–2006, NIOSH investigated 185 fatalities related to installation, maintenance, service or repair tasks on or near machines, equipment, processes or systems. Investigations were carried out in 20 states as part of the Fatality Assessment and Control Evaluation (FACE) Program. Failure to completely de-energize, block or dissipate the energy source was a factor in 142 (77 %) of the incidents; failure to lockout and tagout energy control devices and isolation points after de-energization was a factor in 31 (17 %). These fatalities represent only a portion of the U.S. workers who were killed by contact with uncontrolled hazardous energy. If machines start up during maintenance, repair, adjusting or servicing, workers can be caught in the machinery and suffer fractures, crushing injuries, amputations, or death. According to OSHA, approximately 39 million workers are protected by this rule. Occupational Safety and Health Administration (OSHA) estimates that compliance with the standard prevents about 122 fatalities, 28,400 lost workday injuries and 31,900 non-lost workday injuries each year. OSHA estimates that adherence to the requirements of this standard can eliminate nearly 2 percent of all workplace deaths in establishments affected by this rule and can have a significant impact on worker safety and health in the United States. Berry C, McNeely A, Beauregard, K (2011),

In USA LOTO started some 50 years ago with efforts by employers, unions, and trade associations, in conjunction with now well-known national consensus and safety organizations such as the National Safety Council (NSC), the American National Standards institute (ANSI), and the National Fire Protection Association (NFPA). These efforts led to the development of several consensus standards, which ultimately led to what today are the regulations enforced by federal and state agencies. OSHA's LOTO regulation was published in the Federal Register on Sept. 1, 1989. Although the LOTO regulation met with some resistance and court challenges by labor and industry organizations when first published, OSHA responded with final rule corrections and technical amendments that were published in the Sept. 20, 1990, Federal Register. While they call them something other than LOTO, many other countries also have promulgated regulations mandating the elimination of the unexpected start-up or release of hazardous energy that may cause injury or fatality. Lippert,B., Brown,R.E. (2004)

As published in the OSHA official web site (www.osha.gov/oshdoc/data_General_Facts/factsheet-lockout-tagout.pdf) OSHA identifies that this one standard can have a tremendous impact on the approximately 3 million workers who service equipment throughout the United States. Successful LOTO programs have been credited with saving hundreds of lives since the standard requiring such a program was promulgated by OSHA more than a decade ago. Not only do successful programs save lives; they have prevented approximately 50,000 injuries each year.

2. Problem Description

Several years ago studies in US indicated the failure to establish an effective LOTO program resulted in significant increases in employee exposure to hazardous energy, and in the resulting injuries and fatalities. OSHA and the National Institute for Occupational Safety and Health conducted the studies using data relating to injuries and fatalities from 1974-84. The seriousness of the problem was evident and the significant risk resulting from exposure to hazardous energy clearly affected the majority of general industry. Findings relating to the cause of the incidents gathered from these studies indicated most were completely preventable. OSHA used this information to develop the current LOTO standard that is designed to prevent future incidents. Lippert B, Brown Jr R.E. (2004)

Many industries as a whole has been successful in implementing LOTO program. Its success can be attributed, in part, to extensive operations personnel training and specific plant equipment access limitations. However, even with the proven successful safety history, the United States power generating industry still finds its LOTO violations on OSHA's top 10 most frequently cited list. This has caused many plant operations managers to re-evaluate their existing methods and investigate better ways of implementing their LOTO programs. They find that there have been significant advancements in LOTO devices and methods as well as enhanced interpretive provisions to the regulations. These factors have an impact on reducing implementation costs. Benda S, Kressin R (2008).

These findings suggest that LOTO standards even in developed countries are being frequently reviewed for their effectiveness during recent history. Although LOTO being a regulatory requirement in developed countries, the regulatory enforcement on LOTO in developing countries is limited. In most of the developing countries, manufacturing sector including the large scale exporters has either organizational specifics or local factory specific practices to accommodate the basics of LOTO. Many serious injuries even deaths occur each year as a result of employees performing maintenance on equipment with ineffective LOTO, including serious death cases reported in Sri Lanka during last 3 years.

In a world where automation is emerging as a manufacturing strategy very rapidly, many maintenance activities still remain extremely human intense as per the demands particularly in terms of trouble shooting. The findings on continuous improvement efforts made for LOTO standards directs to an opportunity to explore mismatches between the LOTO system components and human who uses the LOTO system. There is no literature available presently of the direct investigation on alignment of LOTO system components and human aspects. An Ergonomic review of LOTO implementation would enable to identify series of human aspects considerations to improve effectiveness of LOTO. Thus, the key problem investigation in this research is "How Ergonomic aspects should be incorporated in the LOTO implementation process"

3. Objectives

Overall goal being improving safety in maintenance sector through human factor intervention, LOTO system components were reviewed for the level of ergonomics use. Primary objective of this study is to provide recommendations for improving Ergonomics of LOTO system components in general manufacturing sector. To arrive at these recommendations below objectives are planned in this research.

- Identifying industrially accepted common list of system components in LOTO program and segment the components that needs most ergonomic focus.
- Identify the type of ergonomics disciplines that apply mostly on the LOTO system components.
- Develop a tool that assesses ergonomics of LOTO system components that can be applied generally in Industry.

4. Methodology

This research is a form of systematic inquiry, researcher involving the practical application of Human Work Science (Ergonomics) to explore improvement opportunities during implementing a LOTO program. The framework utilized for implementation of LOTO was studied in an apparel accessories manufacturing organization of which the head office is located in California, USA. The study of LOTO implementation covered three sites of the organization located in Colombo (Sri Lanka), Bangalore (India) and Dhaka (Bangladesh). These manufacturing sites comprise up to 5 different product lines using Offset printing, Flexography printing, Screen printing, Thermal printing and Weaving technologies. These technologies utilize different energy sources including Electrical and pneumatic. All three sites employ approximately 2,500 employees having capacity to manufacture 600 million labels to apparel industry a month.

Researcher was a team member of the LOTO implementation program. The team has been given with general written implementation guidelines and template procedures. Team members engaged in discussions providing their respective feedback on implementation plan. Discussions centered on common and prevalent concerns resulted in a focus of gaps in implementation.

To determining best known practices in LOTO implementation generally in Industry, written LOTO programs of some other industries were also reviewed. The industry, document and institute of the other LOTO programs reviewed are presented in Table 1.

The implementation phases determined during the discussion were then decomposed to generate series of elementary activities that require accomplishment of key phases. The elements identified during the literature review on other industries were also used in this decomposition exercise. Each of this elementary activates was evaluated for multiple ergonomic aspect using a detailed checklist that covers below ergonomics aspects.

- Physical Job Restrictiveness

- Physiological Work Postures and movements
- Psychological Stress
- Cognitive (Job Content, Difficulty in decision making, Repetitiveness of the work, Attentiveness, Worker Communication),
- Environmental (Noise, Heat, Light and vibration)

Efforts were then devoted to sharing and reviewing the ergonomic challenges and exploring and documenting methods to improve each LOTO component.

Industry/Sector	Document Name	Organization / Institute
General	SOP 2.9: Lock-Out/Tag-Out	Minnesota Pollution Control Agency-Teresa Gilbertson
General	Lockout/tagout compliance guide	Michigan Occupational Safety and Health Administration
General	Lockout / Tagout control of hazardous Energy Sources	Central Contra Costa Sanitary district
General	Guidelines for controlling Hazardous Energy during Maintenance and Services	NIOSH
General	A Guide to the Control of Hazardous Energy	N.C. Department of Labor
General	Implementing Energy Control Procedures Lockout/Tagout	Michigan Municipal Workers' Compensation Fund
Education	Lockout/Tagout Manual	Lowa States University
Electronics	Equipment Lockout/Tagout (LOTO) Capability Improvement	SEMATECH

Table 1: industry, document and institute of LOTO programs reviewed.

5. Results and Discussion

This chapter is organized to discuss the Key component in LOTO program, elementary tasks obtained by decomposition and relations with multiple ergonomic disciplines identified through link analysis against a standard ergonomic evaluation checklist.

5.1. Ergonomic Challenges in developing an equipment priority list

As the first step of LOTO implementation, it is required to define a list of priority equipment that has the greatest need for protection from hazarded energy sources. The basis for prioritization was identified as risk and multiplicity of hazards and sources of energy, difficulties and complexity of isolating energy and availability of equipment manufacturer to assist with the project.

Some of the machines that were assessed for priority possess multiple types of energy. In some cases, multiple feeds of the same type of energy were noted. For example, screen printing machine contains two electricity inputs, one for the printing section and another for the drying tunnel. Some equipment that has multiple energy feeds were utilizing those multiple feeds to operate different forms of actuators belong to different systems and locations of the machine. As an example, same electricity input is being used to operate an electric motor and group of solenoid valves. Utilization of multiple energy sources in different energy feeds to operate multiple actuators led a complex situation which is difficult to comprehend all potential hazards. Some of the sources and actuators got lack of attention so it was required to formulate a logical configuration of links between each energy input and actuator.

This is a situation where decision complexity occurs that refers to cognitive ergonomic challenge. As defined by International Ergonomics Association, Cognitive ergonomics is concerned with mental processes, such as perception, memory, reasoning, and motor response, as they affect interactions among humans and other elements of a system. Relevant topics include mental workload, decision-making, skilled performance, human-computer interaction, human reliability, work stress and training as these may relate to human-system design. (http://www.iea.cc/whats/index.html). In order to overcome this challenge and to finalize this phase with meaningful identification of priority equipment, it required to have a very systematic approach by figuring out three separate layers namely, energy source, input point and actuator.

5.2. Ergonomic challenges during identifying suitable LOTO methods for priority equipment

Once the list of priority equipment is identified, then it was required to identify suitable LOTO methods or improvement needs in the already used LOTO methods of the priority equipment. List below presents a device available as LOTO with ergonomic features unique to them.

5.2.1. LOTO Tags

There are two types of tags that can be used in lockout & tag out applications:

Individual Tag: A tag that is attached to LOTO lock when an authorized individual is actively working on the equipment that is under servicing or maintenance.

Transition Tag: A tag that is used to indicate that a machine, equipment, process or circuit is out of service or inoperable, and that no one is actively working on the system. Examples of when this tag can be used are: shift changes, week end shut downs, disabled or mothballed equipment, etc. No activity or operation of the machine, equipment, process and/or circuit may occur when a transition tag is in place.

When individual or transition tags are used, they must be attached to the lock and be completely filled out so that the nature of the work and the lock/tag owner are clearly identified. Tags used for lock out and tagout programs are to be standardized within each facility. The room allowed for local standardization can be utilized to make them more attentive by having the content in native language. The content has to be carefully identified to strengthen the message been communication and to have an easily understood job content. To ensure there will not be difficulties to decide that machine should not be used, the tags should not to be used for any other purposes.

5.2.2. Individual LOTO Lock

A type of key lock that is used for no other purpose in the facility, having one key, and for which master keys are not available. Such locks are individually assigned (personal lock) to authorized individuals or can be obtained from a central repository of LOTO devices, whereupon they become personal locks while in use by an individual. The basis of LOTO is that any individual has "total control" of the lockout of the machine, equipment, process or circuit that is being serviced and/or maintained. This concept assures the individual sole lockout responsibilities.

It was allowed for individual facility to designate color, type and size of individual LOTO lock to be used by authorized individual. Selection of color theme should carry a rational to alert the operator of the danger. While red and yellow colors convey sense of danger, green would imply a safe situation. When locks are bought with multiple keys, the remaining keys must be destroyed before using the lock in LOTO program. Destroying the additional keys also ensures the confidence over the maintenance person who would perform the job of his own safety.

5.2.3. Transition Locks

Keyed locks that are used on equipment or processes when they are not actively being serviced. Key control or access must be limited to a small, closely controlled group of authorized individuals, such as maintenance technicians, maintenance supervisors, etc. This lock must be used in combination with a Transition tag to indicate that it is unsafe to operate. Transition locks must not be used as an Individual LOTO Lock or on equipment that is being actively serviced. This lock is also used with a Transition tag for the transition of group LOTO when there is a gap between active work shifts.

5.2.4. Group LOTO Lock

Keyed locks that are used for large or complex lockouts that involve multiple lock out points and employees performing service or maintenance on the same piece of equipment or operating process, commonly referred to as a "Group Lockout". These locks have only one key (master keys are not available) and are intended to be used with a group "lock box" to minimize the number of locks and simplify the control process.

5.2.5. Group LOTO Box

For large or complex group LOTO applications, a "lock box" will be used as the control point for securing the lockout of the equipment or process. The keys for each group lock that has been placed on each of the energy isolation points will be placed into the lock box and secured in the closed position with an individual lock by each authorized employee that is working on the LOTO application. To accommodate a large number of locks, a multiple lock "hasp" can be used.

5.2.6. Lock Out Accessories/Devices

Lock out accessories or devices are used to secure energy isolation points in the "off or closed" positions so that the equipment or process can be brought to a zero energy state. These devices are attached to isolation points such as switches, breakers, valves, etc. and secured with a LOTO lock and tag to prevent normal energy usage that powers the equipment or process.

Some of the lockout devices applied on small breakers and plastic valves and some of the clamshells type lockout may block access to other neighboring controls once installed with LOTO. This can result in restricting reach for other controls. This is a physical ergonomic problem in nature and well thought of during selection of the suitable device.

Due to physical limitations of individuals and different individual perspectives, a group lockout program may get mixed acceptance by different individuals. Physical location of isolation points, time constraints in reaching them, ease of access and travel distances to isolation point can lead to different levels of interest in complying with the LOTO standard particularly when group lockouts are required. These situations that need additional physical effort to operate LOTO can lead to usage of lockable energy isolation devices (emergency switches mounted on the machine) which will not provide the safety of LOTO. These human factors need attention during selection of correct devices. Training of employees will also help gaining individual alignment that is discussed separately.

5.3. Ergonomic Challenges in developing a LOTO program

Once suitable devices are selected, a written lockout/tagout program should be developed. A standard written program would contain the scope, purpose, authorization, rules, techniques, procedures, responsibilities, training requirements and enforcement of the program.

Although an organization would develop a model LOTO program to be adopted by multiple sites, different sites of the same organization may use control documents or specifications to define LOTO performance requirements and activities within the individual company's operations. Often this customization towards individual site program that is modified from location to location is based upon variables such as regulatory requirements, nature of the operation, and depth of implementation. Due to these variables, no single program document would be accepted by all sites and companies, thus a program document template would be drafted for member companies to adapt and use or to evaluate existing site-level programs. Though the content would be different, use of a template program would ensure that the key elements of LOTO program are covered including training requirements. Such program would also contain a section on

Ergonomic evaluation of the program to ensure human factors are seriously considered.

5.4. Ergonomic Challenges in Developing documented LOTO procedures

Documented LOTO procedures contain steps required to follow LOTO at their point of application. Complexity of procedures and the need for equipment-specific procedures vs. generic procedures are the important factors to consider ensuring job content is clearly communicated.

LOTO procedures are typically prepared in one of three formats described below. Their advantages and disadvantages in an ergonomic perspective are also discussed.

Generic procedures give a set of instructions that include general steps for the isolation and securing (LOTO) of hazardous energy. Generic procedures offer the simplest approach and require little effort to prepare. These procedures may be sufficient in some regulatory environments and with some simple equipment where energy sources are limited. These procedures however require more judgmental decisions made by the operator based on his knowledge on energy sources and experience with the usage and installation of their equipment.

More detailed and standalone procedures define actual hazardous energy sources relevant to a machine or installation. This would give specific steps for how and where to isolate or secure energy and other specific measures to ensure work is performed safely. Detailed standalone procedures offer a higher level of detail than generic procedures. These procedures may define the exact types of hazardous energy, their impact, how and where to isolate, how to secure, types of LOTO devices to use, and other measures to take for a specific machine and or installation. These procedures are less subjective than generic procedures, leaving less for judgmental decision by field personnel. These procedures do not require maintenance workers to have much specific knowledge on energy sources. Alternatively, much of the judgment required to work safety is made by knowledgeable personnel in advance of the work and is documented in the procedure. One major challenge is the number of actual procedures required for each situation. In certain instances where multiple energy sources and actuators are present, the maintenance workers require to work on a maintenance procedure and separate LOTO procedure simultaneously. Working on multiple procedures that were developed for specific purposes separately, can create complications if the documents do not complement each other.

Integrated procedure involves a set of steps similar to the standalone procedure except that the steps are integrated into maintenance and service procedures and become an integral part of maintenance instructions. This may be done by the equipment manufacturer when preparing a maintenance manual. One limitation involves the installation configuration and modifications with the equipment. An equipment manufacturer designing an integrated procedure cannot always comprehend these variables at the time of delivery and subsequent changes and re-installations over the life of the product. In a human aspect's perspective, enforcing such universal procedures would gain limited attraction at site level where individuals have never been involved in understanding risk factors of their own equipment. Individuals may perceive it only as creating restrictions to their regular activities by the measures demanded by LOTO.

The ideal method of formulating integrated documents would be the original equipment manufacturer comprehending the need for LOTO, designing LOTO features into the equipment, and preparing clear and precise LOTO procedures having some flexibility for adaptation based upon the end-use environment. Having no flexibility in procedures but allowances given for alternations would lead difficulties in decision making while executing the procedure as it is, knowing or unknowing the alternations been done on the equipment. If alternations are allowed, it would also require the end-user to be knowledgeable, capable, and resourced to customize the procedures for the particular installation.

5.5. Ergonomic Challenges in developing a template procedure

Defining a standard format for an integrated LOTO procedure is challenging because the content may vary widely depending upon the design and format of original equipment manufacturer's maintenance manuals. However, a template for the development of detailed standalone LOTO procedures would have multiple benefits in terms of ensuring the essentials are covered in each procedure adopted from the template. Further, a standard template may also be useful for equipment manufacturers who want a better understanding of the format of LOTO procedures that their customers expect.

While equipment manufacturers usually provide LOTO procedures when equipment is delivered, individuals sites sometimes must develop equipment LOTO procedures from "scratch" when equipment has been heavily modified, when procedures have been supplied by third-party sources, or when procedures are inadequate or in other languages, etc.

A format which is pictorial, providing a quick reference to maintenance personnel to determine what hazards are present, where to locate energy isolation points, how to isolate energy, how to secure sources, what hardware is required, how to dissipate residual energy, how to test for zero energy states, what personnel protective equipment is required, what waste disposal is required, and what is meant by the "hazard zone" will ease the understanding of the content of the task. The template procedure would also contain a quick reference checklist to ensure essential steps are followed so workers attentiveness on covering each element is improved.

It is important that each LOTO Energy Isolation Devices (EID) can be uniquely and consistently identified on the system, drawings, schematics, procedures, …etc, to reduce confusion. These graphical aids should facilitate locating an individual EID, differentiate LOTO EIDsfrom other operating devices or control devices that might be confused with a LOTO EID. A consistent manner of color coding the graphical energy source locators used in pictures and diagrams will help readily identify hazards.

Language used in such procedures are of prime importance to ensure employees understand the content, thus the site level program would be developed in native language while respecting the format of the template.

5.6. Ergonomic challenges in executing installation of equipment LOTO

Installation of LOTO typically involves seven steps. Dudgeon, M. (2013).

1. **Prepare for shutdown**

The Authorized Employee shall evaluate the equipment to be serviced and identify all sources of hazardous energies and the methods necessary to control them. Particularly when multiple energy sources are present in multiple forms, this evaluation would be a difficult decision making. This detail is usually presented in a specific or an integrated procedure making this evaluation much easier.

2. Notify all Affected Employees

The Authorized Employee turning off the power shall notify Affected Employees in the work area that power will be shut off, the reason for the shut-down and that the equipment will be locked/tagged out. Mode of this communication is an important human factor predominantly with remote locked/tagged where rest of the employees would not simply see the power has been disconnected.

3. Shut down equipment

The equipment/machine shall be shut down by the normal stopping procedure. When appropriate, a "DO NOT OPERATE" tag shall be affixed to the power switch. The appropriateness of tagging the equipment is an important worker communication factor particularly with remote LOTO device disconnects the energy to instrument.

4. Isolate equipment

The equipment/machine shall be de-energized, secured and isolated from hazardous energy sources. An orderly shutdown must be utilized to avoid any increased or additional hazard(s) to employees.

5. Apply LOTO

The Authorized Employee shall place locks and/or tags in the appropriate energy isolating locations. Sometimes procedures and hardware for LOTO are not compatible for equipment manufacturer personnel and device manufacturer personnel leading to confusion or erroneous application at point of use. Better coordination between all parties is necessary to anticipate these differences before installation. This problem often impacts employee training requirements on how to use the devices as well.

Person performing maintenance must travel to and from energy isolation points, because regulations and good practice mandate that maintenance individuals must apply their own locking mechanisms to isolated energy sources, maintain control of those mechanisms, and eventually remove those mechanisms. Physical location of isolation points, time constraints, ease of access and travel distances are associating with practical difficulties in physical and physiological demands that refer to posture and movements of the human who conducts them. Achieving more localized point of energy isolation will require developing more methods and hardware for use on downstream energy paths at the subsystem level located within the machine rather than solely at the main energy source located remotely. These improvements should be however complying with regulatory requirements and acceptable to local authorities.

6. Release stored energy

After lockout devices have been placed on the equipment, all stored electrical, gravitational, mechanical and/or thermal energy must be disconnected and drained to a zero-energy state or otherwise made safe by the blocking or repositioning of equipment. This can be accomplished by:

• Releasing pressured lines such as hydraulic, air, steam, gas and water.

• Releasing spring-loaded equipment.

• Blocking mechanical equipment with moving, rotating or elevated parts.

7. Verify isolation

Before performing maintenance on the machine, the Authorized Employee should verify the system is isolated. This is generally accomplished by first establishing that no personnel are exposed and then turning the machine switch to the ON position using the normal operating controls. Verification of isolation must be continued if there is a chance of the re accumulation of stored energy during the service/maintenance activity. Repetition of a sequential activity in higher frequency can lead to both physical and psychological strain depending on the force and posture requirement and the complexity of task context.

5.7. Ergonomic challenges in executing release of equipment LOTO

When maintenance or repair is complete, powering up equipment calls for several steps to ensure worker safety and prevent equipment damage. Below tasks should be performed before any LOTO devices are removed.

1. Authorized employees must replace machine guards, and remove tools and nonessential items from the work area. Block devices that were inserted also need to be removed, although in some cases the machine may need to be restarted first. Conduct tests and visual inspections, as necessary, to check that employees have removed all tools, electrical jumpers, shorts, grounds, and similar devices so that the circuits and equipment can be safely energized. In order to avoid any tool left within the machine unnoticed, the tools storage would be

made allocating demarcated location for each individual tool, so blank space would represent a missing tool.

2. Work area has to be made clear and workers should be in safe place away from the machines or equipment. Once those steps are complete, LOTO release can be continued.

3. Removal of LOTO devices. This task should only be performed by the employee who applied the devices.

4. Before re starting any machine or equipment, all affected employees should be notified that the LOTO devices have been removed.

5. Restore energy to the machine. As noted, this step may require cautiously reenergizing some machines to remove blocking devices. Additional authorized employee assistance may be needed to reenergize certain sections or parts of the equipment in order to avoid a single worker taking hazarded reach to take out the block while switching on the machine.

5.8. Ergonomic Challengers with design of Energy Isolation Devices enabling LOTO

Energy Isolation Devices (EID)are defined by SEMI S20-0303, Safety Guideline for Identification and Documentation of Energy Isolation Devices for Hazardous Energy Control, as “a mechanical device that physically prevents the transmission or release of energy, including but not limited to the following: a manually operated electrical circuit breaker; a disconnect switch; a manually operated switch by which the conductors of a circuit can be disconnected from all ungrounded supply conductors, and, in addition, no pole can be operated independently; a line valve; a block; and any similar device used to block or isolate energy. Push buttons, selector switches, and other control devices are not considered to be energy isolation devices per OSHA 29 CFR 1910.147.” Williams, C (2003)

Best practices for LOTO demand that EIDs be designed and installed so that they readily accept approved locks and tags for securing the EID in a safe position and in a manner that prevent energy flow. EIDs may be integral to manufacturing or other equipment as well as facilities infrastructure systems (i.e., electrical distribution systems, chemical delivery systems, etc.). When this is not achievable or was not employed with older systems and installations, supplemental devices may be necessary to interface with locks and tags with isolation devices that cannot be locked directly.

Gang locking provides some advantages such as multiple locks but also poses some drawbacks such as obscuring adjacent breakers and isolation points, making it difficult the physical reach. Because of their bulkiness, the add-on devices sometimes obstruct verification of energy states due to restrictions in visual reach by obscuring the view around the EIDs. Many EIDs are installed in small enclosures and when add-on devices are used for LOTO, the enclosure covers may not be fully closed. Keeping the enclosures opened is not desirable in a safety perspective and can lead to further limitations in both visual and physical reach to neighboring equipment and controls. As secondary effect, keeping the enclosures open can lead to create a disturbing environment to operator by emission of both noise and heat that is usually been insulated at the enclosure door. To overcome this, energy isolation points must be made more accommodating for multiple locks and equipment manufacturers should install EIDs that have integrated LOTO hardware to reduce the need for add-on devices.

5.9. Ergonomic Challenges in using only tag outs.

If using a lock is not practicable or if the employer can demonstrate that tagging procedures will provide safety equivalent to a lock, a tag may be used without a lock. However, Tag outs should provide at least as much protection for employees as lockouts. Tagout only is prohibited unless a risk assessment documents the inability to lockout, and approved alternative methods are developed. If an energy-isolating device is not capable of being locked out or modified to accept lockout, a tag out program shall be used as defined by the risk assessment for the equipment or process.

The tag should comply with all the following requirements.

The tag should be of a distinctive employer design and clearly prohibit unauthorized energizing of circuits and removal of the tag. In order to gain more attention this would be distinguished from the tag outs that is used with lock outs.

Not be used without an additional safety measure such as the removal of an isolating circuit element, the blocking of a controlling switch, or the opening of an extra disconnecting device. In order to gain more confidence that the switch would not be used it can go to further extent of extra measures such as blocking a controlling switch from inadvertent activation, opening an extra disconnecting device or Removal of a valve handle.

The tagout device must be applied in the area where a Lockout Device would be applied and must provide an equivalent level of protection to that of a Lockout application. All Authorized and Affected Employees must be informed that a tagout operation is being conducted.

5.10. Ergonomic Challenges in determining alternative methods

Because of the sensitivity of certain manufacturing processes, total equipment shutdown and isolation is not a readily feasible approach. In some instances, this may be achieved safely while working with hazardous energies by administrative controls, personnel protective equipment (PPE), and carefully developed procedures. With the need for use PPEs, series of ergonomics issues unique to them will come to concern. Otherwise, equipment manufacturers should attempt providing equipment that allows for localized Isolation of subsystems and energy sources.

When activities other than servicing and/or maintenance are performed on a machine, a piece of equipment, a process, or a circuit, and these activities are routine, repetitive and integral to the process, alternative methods of energy control may be developed and used.

Alternative methods are also developed for situations where power is required or where traditional LOTO is not feasible because it prohibits the completion of the given task(s). The alternative methods are based on risk assessment, and provide effective personal protection. Such alternative methods are documented with a level of detail similar to energy control procedure. In order to avoid any confusion of absence of LOTO procedure, an inventory can be developed of the tasks deemed to be routine, repetitive and integral to the process. Each task on this inventory should have a documented procedure that clearly describes how employees performing the task are to protect themselves by means other than LOTO. The results of risk assessment should include awareness of hazards related to the task to be performed, familiarity with the task or process, availability of reference documents, and identification of personal protective equipment for use during task performance. It is important that such alternative methods do not create restrictions to other operations either in technical terms or human aspect perspective.

5.11. Ergonomic aspects of Training of Employees for LOTO

The training should cover the purpose of the program, methods of energy control and the proper use of LOTO procedures. Authorized employee must undergo class room training and practical demonstration of LOTO initially and refresher annually covering class room as well as practical demonstration. Typical LOTO training program would contain,

- A review of the aspects of this program.
- How to recognize hazardous energy sources.
- The types and magnitude of energy within the facility.
- Proper means to control and isolate energy prior to commencing repairs.
- Location of energy control procedures (equipment specific LOTO procedures).
- Location of the department/facility lockout boards and the protocol for obtaining and returning equipment.
- Affected and Other Employees.
- An explanation of the program purpose and use.

A demonstration during the training of personal lock, LOTO tag, Group LOTO lock & Tag, Transition lock & tag with an explanation of the significance of the hardware with emphasis upon the danger of anyone attempting to remove or bypass the equipment while it has been locked out will help cultivating a firm compliance with the LOTO program.

Ergonomic focus points determined during each LOTO program component are tabulated below in table 2.

No	LOTO Program Component	Ergonomics Considérations	Respective Ergonomic Discipline
1	Planning	A systematic criterion such as checklist or relationship diagram is used to identify multiple energy sources and feeds, multiple actuators and connections between each energy feed and actuator during prioritization of equipment.	Cognitive
2	Design	Tags are designed to understand the content easily (Presented in native language)	Cognitive
3	Design	Color theme used for tags and locks are suitable to convey the possible danger. (Red, Yellow preferable, green is not recommended)	Cognitive
4	Design	Physical location of isolation points present in the downstream energy paths at the subsystem level located within the machine area to ease reach requiring less travel distance.	Physical
5	Design	Energy isolation points are made accommodating for multiple locks or have integrated LOTO hardware to reduce bulkiness to ensure door of enclosure is closed while being used.	Environme ntal
6	Design	If tag out only is used, it is distinguishable from the tag outs that is used with lock outs.	Cognitive
7	Documenta tion	Use of generic procedures is limited to situations with simple and single energy sources.	Cognitive
8	Documenta tion	Specific procedures are reviewed for their content not to contradict with the steps written in other specific procedures when they need to be applied simultaneously.	Cognitive
9	Documenta tion	Operators are involved in preparing the generic and specific procedures so they become aware of the risk factors.	Cognitive
10	Documenta tion	Operators are educated of all hazarded energy factors when using all types of procedures generic, specific and integral.	Cognitive
11	Documenta tion	Integrated procedures contain a flexibility to accommodate local alternations that is limited by the OEM themself.	Cognitive
12	Documenta tion	If alternations are allowed in the original equipment and allowances provided in the integrated procedures, the OEM has listed down the training and competency requirements needed to carry out such alternations.	Cognitive
13	Documenta tion	Site uses a revised version of the integrated procedure of the OEM or procedure developed from scratch if the equipment is heavily modified, supplied by third-party sources, or when procedures are inadequate or in other language that is not understood.	Cognitive
14	Documenta tion	Procedures are written in native language or key points are presented in native language to ease understanding.	Cognitive

15	Documentation	Procedure contain visuals of what hazards are present, where to locate energy isolation points, how to isolate energy, how to secure sources, what hardware is required, how to dissipate residual energy, how to test for zero energy states, what personnel protective equipment is required, what waste disposal is required, and what is meant by the "hazard zone".	Cognitive
16	Documentation	LOTO Energy Isolation Devices (EID) can be uniquely and consistently identified on the system, drawings, schematics, procedures, etc in a consistent manner of color coding and graphic.	Cognitive
17	Documentation	The template procedure contains a quick reference checklist to ensure essential steps are followed and the check list is developed for each procedure.	Cognitive
18	Documentation	Procedural action is documented to communicate all employees of the affected area when the energy source is disconnected.	Cognitive
19	Documentation	Procedural action is documented to display a "DO NOT OPERATE" tag on the machine when remote LOTO has been used.	Cognitive
20	Documentation	All alternative methods of LOTO are listed in an inventory and alternative methods are documented in order to avoid any confusion due to absence of LOTO procedure.	Cognitive
21	Device Selection	LOTO devices are selected to ensure that physical strength needed to operate them is minimum.	Physiological
22	Device Selection	Hardware for LOTO are reviewed for the compatibility with the equipment to avoid any excessive force requirement	Physical
23	Device Selection	Procedure and Hardware for LOTO are reviewed for the compatibility with the equipment to avoid any confusion in instruction.	Cognitive
24	Application	Tags are not used for any other purpose that would lead to confusion of its use.	Cognitive
25	Application	Additional keys of individual locks are destroyed and Transition locks and tags are restricted to use as individual locks that can lead to lack of confidence of the LOTO.	Psychological
26	Application	Lockout devices are selected such that they will not restrict the access to neighboring controls once mounted on a control that needs to be locked.	Physical
27	Application	Steps required to verify isolation of energy do not contain physical tasks that need excessive force and uncomfortable postures that repeats multiple times.	Physiological
28	Application	Steps required to verification of isolation of energy are designed to have least number of repetitions of sequential tasks.	Psychological

29	Application	A method such as demarcated tool storage is available to ensure operator is alerted of any tool left in the machine before startup.	Cognitive
30	Application	Additional assistant is allocated and used to take out blocks to avoid operator taking hazarded posture while switching on the machine.	Physiological
31	Application	If PPE is required as an alternative, they are evaluated for human fit.	Physical
32	Application	Extra measures such as blocking a controlling switch from inadvertent activation, opening an extra disconnecting device or removal of a valve handle is taken when using only tag outs.	Cognitive
33	Application	Alternative methods are identified followed by a risk assessment and alternatives do not create job restriction on other functions.	Cognitive
34	Training	LOTO training program includes demonstration of personal lock, LOTO tag, Group LOTO lock & Tag, Transition lock & tag with emphasis upon the danger of anyone attempting to remove or bypass the equipment.	Cognitive

Table 2: Ergonomic focus points determined during each LOTO program component

Chart 2 graphically presents the interrelationship of number of ergonomic aspects with each LOTO system component segmented to different ergonomic discipline.

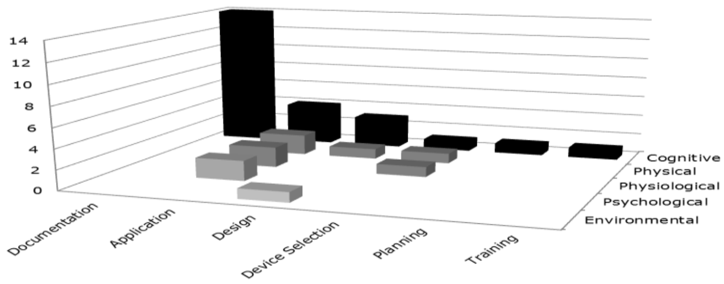


Chart 2: Number of ergonomic aspects identified under each discipline at each LOTO component

6. Conclusions and future work

Six key components of LOTO implementation were studied namely planning, design, documentation, device selection, application and training. There were 34 ergonomic points of interest were identified throughout all the phases. These ergonomics aspects fall under 4 ergonomic disciplines Cognitive, Physiological, Physical, Psychological and environmental. The findings lead to below conclusion with respective to the objective of this research.

1. Out of the 6 LOTO program elements documentation phase involves 14 ergonomics aspects. All 14 points relates to cognitive aspects. Documentation phase has been identified as needing most ergonomic focus.

2. Out of the 34 ergonomics aspects identified 24 are related to cognitive aspects. 4 of them are of physical nature and the rest comprises of 3 physiological aspects, 2 psychological aspects and 1 environmental aspect. This finding concludes that cognitive ergonomic aspect needs most attention during LOTO implementation.

3. The content presented in the table 2 would be applied as a tool to evaluate ergonomics of a LOTO program. To make the results more quantitative each alignment would be rated for level of compliance at each point evaluated, that would generate an overall rating that represent the extent of ergonomic consideration in implementation.

Different practices, traditions, and regulations around the world result in different products and approaches to LOTO. These are however will be used in human intense environment so evaluation of human aspects is of prime importance. The evaluation tool presented in this research would be important as an applied tool to evaluate the ergonomic fit. This study was based on an applied approach to improve ergonomics of LOTO program during its implementation, as future work evaluation of the results of these incorporations thorough a different research design is recommended.

References

1. Arlington, VA. Unger, R.L. and Conway, K. (1994), "Impact of maintainability design on injury rates and Maintenance costs for underground mining equipment", in Peters, R.H. (Ed.), Improving Safety at Small Underground Mines, Bureau of Mines SP 18-94, United States Department Of the Interior, Washington, DC, pp. 140-167.
2. Benda S, Kressin R(2008), " The Move Toward Initiating Best Practices" power engineering august, 2008
3. Berry C, McNeely A, Beauregard, K (2011), "A Guide to the Control of Hazardous Energy (Lockout/Tagout)", Education, Training and Technical Assistance Bureau, N.C. Department of Labor
4. Cawley, J.C. (2003), "Electrical accidents in the mining industry, 1990-1999", IEEE Trans IndAppl, Vol. 39 No. 6, pp. 1570-1577.
5. Chervak, S.G. and Drury, C.G. (1996), "Human factors audit program for maintenance",In Shepherd, W.T. (Ed.), Human Factors in Aviation Maintenance – Phase five Progress Report, National Technical Information System, Springfield, VA, pp. 93-126.
6. Department of Labor Ministry of Labor and Labor Relations, Sri Lanka (2013), Labour Statistics Sri Lanka 2012, ISBN No. 978-955-8817-24-7.
7. Dhillon, B.S. and Liu, Y. (2006), "Human error in maintenance: a review", Journal of Quality in Maintenance Engineering, Vol. 12 No. 1, pp. 21-36.
8. Dudgeon, M. (2013) Worker Safety, Professional Safety September 2013, www.asse.org
9. Harring, M.G. and Greenman, L.R. (1965), "Maintainability engineering", prepared under Contract No. DA-31-124-ARO-D-100-34, Martin-Marietta Corporation and Duke University, Durham, NC.
10. ILO (2009), ", World Day for Safety and Health at Work 2009 FACTS ON safety and health at work" , International Labor Organization
11. Koli, S., Chervak, S. And Drury, C.G. (1998), "Human factors audit programs for non repetitive tasks", Human Factors and Ergonomics in Manufacturing, Vol. 8 No. 3, pp. 215-231.
12. Lind, S. (2008), "Types and sources of fatal and severe non-fatal accidents in industrial Maintenance", International Journal of Industrial Ergonomics,

Vol. 38 Nos 11-12, Pp. 927-933.
13. Lind, S. And Nenonen, S. (2008), "Occupational risks in industrial maintenance", Journal of Quality in Maintenance Engineering, Vol. 14 No. 2, pp. 194-204.
14. Lind, S., Nenonen, S. And Kivisto¨-Rahnasto, J. (2008), "Safety risk assessment in industrial Maintenance", Journal of Quality in Maintenance Engineering, Vol. 14 No. 2, pp. 205-217.
15. Lippert B, Brown Jr R.E. (2004), A Ten Step Lockout/Tagout Program, OH&S Magazine OSAHA (2002), OSHA Fact Sheet –Lockout / Tagout, U.S. Department of Labor
16. Mason, S. (1990), "Improving plant and machinery maintenance", Applied Ergonomics, Vol. 21 No. 1, pp. 15-24.
17. Shahnavaza, H (2010), "Workplace injuries in the developing countries", Ergonomics, Volume 30, Issue 2, pages 397-404
18. Williams, C (2003), "Equipment Lockout/Tagout (LOTO) Capability Improvement", International SEMATECH, Inc,
19. Wireman, T. (1990), Total Productive Maintenance – An American Approach, Industrial Press Inc., New York, NY.