DEVELOPMENT OF A STATE OF THE ART INTERNET OF THINGS (IoT) BASED LOCKOUT TAGOUT (LOTO) DEVICE FOR ACCIDENT PREVENTION IN HAZARDOUS INDUSTRIES

A thesis submitted to the
University of Petroleum and Energy Studies

For the Award of
Doctor of Philosophy
in
Engineering

BY
Sameer Kumar

December 2020

SUPERVISOR (s)

Dr. S. M. Tauseef
Dr. R. S. Saini

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Department of Health, Safety & Environment and Civil Engineering

School of Engineering

University of Petroleum and Energy Studies

Dehradun-248007, Uttarakhand, India

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Internal Supervisor
Dr. S. M. Tauseef
Professor and Assistant Dean (Research)
School of Engineering
University of Petroleum and Energy Studies

External Supervisor
Dr. R. S. Saini
Management Practitioner and Consultant
Green Economy Initiatives Pvt. Ltd., Chandigarh, India

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UNIVERSITY WITH A PURPOSE

Department of Health, Safety & Environment and Civil Engineering
School of Engineering
University of Petroleum and Energy Studies
Dehradun-248007, Uttarakhand, India

18- October-2021

DECLARATION

I declare that the thesis entitled "DEVELOPMENT OF A STATE OF THE ART INTERNET OF THINGS (IoT) BASED LOCKOUT TAGOUT (LOTO) DEVICE FOR ACCIDENT PREVENTION IN HAZARDOUS INDUSTRIES" has been prepared by me under the guidance of Dr. S. M. Tauseef, Professor and Assistant Dean (Research) of Department of Health, Safety & Environment and Civil Engineering, School of Engineering, University of Petroleum and Energy Studies. No part of this thesis has formed the basis for the award of any degree or fellowship previously.

Sameer Kumar

Department of Health, Safety & Environment and Civil Engineering

School of Engineering,

University of Petroleum and Energy Studies

Dehradun-248007, Uttarakhand, India

DATE: 18-October-2021

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CERTIFICATE

I certify that Sameer Kumar has prepared his thesis entitled "DEVELOPMENT OF A STATE OF THE ART INTERNET OF THINGS (IoT) BASED LOCKOUT TAGOUT (LOTO) DEVICE FOR ACCIDENT PREVENTION IN HAZARDOUS INDUSTRIES" for the award of PhD degree of the University of Petroleum and Energy Studies under my guidance. He has carried out the work at Department of Health, Safety & Environment and Civil Engineering, School of Engineering.

Internal Supervisor

(Dr. S.M. Tauseef)
Professor and Assistant Dean (Research)
Department of Health, Safety & Environment and Civil Engineering
School of Engineering,
University of Petroleum and Energy Studies
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Managing Director

Green Economy Initiatives Pvt. Ltd.

Chandigarh, India

DATE: 18-October-2021

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ABSTRACT

Despite all the technological advances, safety remains the biggest challenge in Industries. Each year, thousands of electrocutions and hundreds of machinery-related accidental deaths are happening. A number of these accidents involve inadequate, unauthorised or improper use of hazardous energy control procedures, also known as lockout/tagout (LOTO) procedures. Although the organizations like Occupational Safety and Health Administration (OSHA), USA, The National Institute for Occupational Safety and Health (NIOSH) and others have defined a very detailed LOTO procedure, however, these LOTO procedures have many manual activities. With the emergence of IoT (Internet of Things) these manual activities can be combined with automated activities thereby enhancing safety. IoT based devices can be implemented to ensure authorized access to hazardous areas around operating machinery, improve documentation and monitoring of service during repair and/or maintenance that requires shutdown of the machinery, and prevent unexpected, unauthorised start up, or movement during maintenance of machinery or related activities. Acknowledging the importance of IoT enabled safety devices NIOSH is also exploring the possibility of implementing IoT based technologies to provide intelligent machine monitoring as part of a comprehensive LOTO program. This work presents the development of an IoT based LOTO device, its implementation and effectiveness in improving safety and accident prevention.

Several tests have been performed on a developed test kit to find the effectiveness and limitations of the IoT based LOTO device. The results obtained from test kit are very encouraging as the person working on the hazardous energy is safe from the hazard and 100% adherence of LOTO has been found.

The test also shows the limitation of LOTO devices in case of weak network strength, fluctuation in voltage and assessing the life of the complete system.

These limitations can be overcome by ensuring right network strength and voltage level. In case of weak signal and voltage, display of signal strength and voltage value at device and user level so that conventional LOTO can be used.

The statistical analysis for effective operation of LOTO device, delay in on-off time and delay in SMS communication using different tests for indoor and remote location has been done.

The IoT based devices are real time, automatic, temper-proof and capable of adding extra safety to the person in controlling the hazardous energy. The developed device has proven its effectiveness by providing safety through reduction in number of accidents and safety incidents, it has also helped to reduce LOTO implementation time.

It is found that the IoT based LOTO device is effective in accident prevention by reducing number of incidents from 47 to 0 and its performance by reducing LOTO implementation time from 697 to 349 seconds.

Reduction in accidents and incidents gives safer work environment and lesser LOTO implementation time improves productivity

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List of Abbreviations

AC	Alternating Current
ASU	Arbitrary Strength Unit
CAGR	Compound Annual Growth Rate
CB	Circuit Breaker
CFR	Code of Federal Regulations
CNC	Computerised Numerical Control
dBm	Power Ratio in Decibels of Radio Power Per Milli-Watt
DC	Direct Current
DGFASLI	Directorate General Factory Advice and Labour Institutes
FRL	Filter Regulator Lubricator
GSM	Global System for Mobile Communications
IDE	Integrated Development Environment
IoT	Internet of Things
LOTO	Lockout Tagout
LPG	Liquefied Petroleum Gas
MCB	Miniature Circuit Breaker
mm	Millimeter
MSHA	Mine Safety and Health Administration
MSME	Micro, Small and Medium Enterprises
NCRB	National Crime Records Bureau
NIOSH	National Institute for Occupational Safety and Health
NSA	National Safety Award
OSHA	Occupational Safety and Health Administration
PLC	Programmable Logic Controller
PNG	Piped Natural Gas
s	Second
SIM	Subscriber Identification Module
SMS	Short Message Service
SOP	Standard Operating Procedure
V	Voltage
VRP	Vishwakarma Rashtriya Puraskar

CONTENTS

Chapter 1. Introduction

1.1 Chapter Overview

There are electrocution and machinery related deaths and injuries in industries due to non-adherence of the safety procedures. This chapter has details of introductory work like background and significance of different accidents, safety procedures, motivation and need of the research work, objectives and plan of the research work.

Manufacturing industries has many equipment which require maintenance, repair, and service [1] to be done by an individual or a group of competent personnel to make sure that no untoward incident happens during the operation of such equipment [2]. The competent person is required to follow a defined hazardous energy control program or LOTO procedure wherein they isolate the hazardous energy source and puts a lock so that no one accidentally energize the equipment while it is under repair or maintenance.

Different type of hazardous energy like electrical, pneumatics, hydraulics, chemical, potential etc. are used in machines in engineering industries. The person working with or near to the machine must use LOTO procedure to safeguard himself/herself from the risk [3], but there are many industrial accidents happening due to non-adherence to LOTO Procedures (Hazardous Energy Control Program).

The basis of this work is study of accidents with respect to LOTO adherence and study of various LOTO devices, benefits, and limitations.

1.2 Background and significance of the Study

There are well known global organisations like OSHA [4] , NIOSH [5] etc., who collect and publish accidental deaths related data [6]. In India, National Crime Record Bureau (NCRB) under Ministry of Home Affairs, Government of India [7] too has started collecting and publishing data from the year 1967. As per NCRB Data for the year 2019, India had 411,824 accidental deaths in 2018 and 421,104 in the year 2019[8]. There were 13,432 deaths due to electrocution and 1001 machinery-related accidental deaths in the year 2019 [9].

Similar analysis of accident data is available from the Mine Safety and Health Administration (MSHA) conducted by Ruff *et. al.* [10] from the National Institute for Occupational Safety and Health. Based on the analysis of the accident data Ruff *et. al.* (2011) concluded that one-third of these accidents involved improper LOTO procedures as a contributing factor [11]. The MSHA has acknowledged this problem in their report RIN 1219-AB 91 It is reported that 76% of the 17 fatalities [11] involved working near or around belt conveyors, where the miners become entangled in belt drives, belt rollers, and discharge points. Factors that were identified as responsible for these accidents were inadequate, insufficient or missing guards and number of crossovers in strategic locations, and/or inappropriate LOTO procedures. It was concluded in the report that interlock systems that ensure that machine guards are properly secured in place; and/or ensure machines are properly locked out and tagged out during maintenance would reduce fatalities [12]

In order to ensure proper implementation of LOTO a number of researchers have explored various solutions like worker-worn electric field sensor [13] potential application of IoT technologies based intelligent machine monitoring systems for improved worker safety and design of safety related parts of control systems in machines [14]. However, the solutions proposed by these researchers are limited to electric field sensors, machine monitoring systems and design of safety related parts of control systems in machines [15]. IoT based LOTO device is not in their scope.

This work is a practical work in an important emerging area relevant to the age of digitalization, IoT, Industry 4.0, and automation in general.

There may be critical issue of Industrial safety as we move to greater automation. The importance of industrial safety and Internet of things alone can be gauged from the fact that

a) Globally the market for Industrial safety alone is expected to go from $ 5.6 billion in 2020 to USD $7.7 billion by 2025 at a near 7% compound annual growth rate. Especially with an accelerated movement towards workplace safety standards linked to Industrial Internet of Things.

b) IoT is a huge emerging opportunity as there are already close to 45 billion devices connected to internet and about 8.7 billion were added just in 2020. The market is expected to be over $1 Trillion by 2030.

The scope for the work includes many customized innovations, adaptations to products and processes, standards, standardized functional block IPs, cyber security linked products and other automation areas. The current work forms a part of such an important emerging area. More importantly also offers huge scope for experimental work in the "Atm-Nirbhartha" and "Make in India" initiatives.

This work presents the design and development of an IoT based LOTO device to enhance safety of LOTO procedures. Data is collected and analysed to test device performance and its effectiveness in improving safety

1.2.1 Study of NCRB data on accidental deaths

- The major unnatural causes of accidental deaths (Table 1-1) were (i) Traffic accidents (53.4%), (ii). Drowning (9.4%), (iii) Accidental Fire (6.2%), (iv) Falls 4.9% and (v) Electrocution (3.0%)
- Electrocution related death cases were 9,606 in the year 2014.
- Year 2014 had 3% of electrocution related deaths which were 2.4% in the year 2011, 2.4% in the year 2012 and 2.7% in the year 2013.

Further Analysis of these 9,606 deaths shows that there were 1,267 deaths happened due to non-adherence of LOTO procedure also known as hazardous energy control program (

- Table 1-2).

- These 1,267 cases are 13.1% of the total electrocution related 9,606 deaths. and 0.4% of the total 3,16,628 un-natural deaths.

- As per recent report published by NCRB for the year 2019 (Table 1-1), Electrocution related deaths are 13,432 which is 3.3% of the total 412,959 un-natural accidental deaths [9].

Table 1-1 Accidental deaths in Year 2014 and 2019 due to un-natural causes

Category	Year-2014		Year-2019	
	No. of Deaths	%age	No. of Deaths	%age
Traffic	1,69,107	53.4%	1,81,113	43.9%
Drowning	29,903	9.4%	32,671	7.9%
Accidental Fire	19,513	6.2%	10,915	2.6%
Falls	15,399	4.9%	20,901	5.1%
Electrocution	9,606	3.0%	13,432	3.3%
Collapse of Structure	1,821	0.6%	1,929	0.5%
Accidental Explosion	1,194	0.4%	655	0.2%
Factory/Machine Accidents	797	0.3%	1,001	0.2%
Fire Arm	633	0.2%	320	0.1%
Mines or Quarry Disaster	210	0.1%	82	0.0%
Stampede	178	0.1%	12	0.0%
Air Crash	15	0.0%	20	0.0%
Ship Accidents	7	0.0%	-	0.0%
Other Causes	55,482	17.5%	16,666	4.0%
Causes not Known	12,963	4.1%	58,576	14.2%
Total	3,16,828	100.0%	4,12,959	100.0%

Table 1-2 Accidental deaths in Year 2014 due to non-adherence of LOTO

S. No.	Category	No of Deaths	% age
1	Non- Adherence of LOTO	1,267	13%
2	LOTO relationship not available	8,339	87%
	Total	9,606	100%

1.2.2 Study and Analysis of DGFASLI Data on Safety Incidents

DGFASLI (Director General Factory Advisory Services and Labour Institutes, Government of India) invites applications for National Safety Awards from all the industries including MSMEs, Ports etc... Many Industries apply for these awards and submit their safety related data with the application. There are 300-400 applications are received by DGFASLI every year. The researcher has analysed these data to understand the relationship between safety incidents and LOTO adherence.

These data were studied and analysed.

- Total 45 incidents were analysed from the year 2011-2014 of the National Safety Award received at DGFASLI.
- These 45 incidents were having 29 non-fatal,14 near-misses and 1 fatal incident
- In 29 non-fatal incidents 22 electrical energy related 6 thermals and 1 mechanical energy related
- In 22 Electrical Energy related non-fatal incidents, 20 incidents were having provision of conventional LOTO device, and 2 incidents were not having any provision of LOTO.
- In 20 incidents where LOTO provision were available, 19 incidents LOTO were applied but procedure was not followed and in 1 incident LOTO was bypassed.
- These 20 incidents out of 45 would have certainly been avoided if LOTO were applied and procedures were followed.
- LOTO related data for unorganised sector could not be find in the given data for the years from 2011 to 2014.

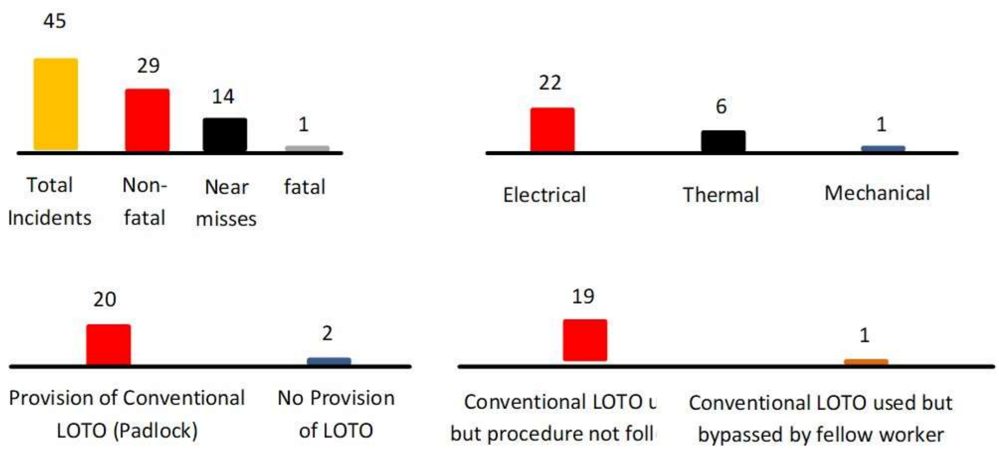


Figure 1-1 Incident Analysis due to non-adherence of LOTO from Year 2011-2014

1.2.3 Conclusion from NCRB and DGFASLI data

The researcher has analysed both the data and found that there are safety incidents and accidental deaths are happening due to non-adherence of LOTO procedure. Person working on hazardous energy is not following the LOTO procedure and meeting with an accident. These accidents can be prevented by following proper LOTO procedure and devices.

1.3 Motivation and Need for the Research:

The researcher has many equipment and processes [16] which have various hazardous energy like Electrical, Hydraulic, Thermal, Mechanical, Chemical and Gravitational etc. These energies are required to operate the equipment, tools and processes [17].

For Example, Electrical Energy of 230V AC is used in various household electrical appliances and lightings in India. The LOTO user needs to follow a right and safe procedure to replace a faulty electrical bulb so that no harm or injury or accident happens before, during or after the bulb replacement process [18].

In the same way, the LOTO user needs to work on the equipment having certain hazardous energy for operation, repair or service. This/These energy/energies need to be properly locked out, isolated and verified before starting of any operation, service or repair activity [19] for safe work and accident prevention [20].

OSHA and various other safety organizations [21] in the world have well defined LOTO Procedures. The person going to operate, repair or service of the equipment which has hazardous energy must follow these procedures.

The person may meet with an accident if the procedure is not followed [22].

LOTO users can save many lives by various safety precautions and following hazardous energy control procedures.

There are hazardous energies is being used in Housing Complex, Shopping Malls and other areas is not under scope of this work however learning from this work can be evaluated and applied in future.

1.4 Study of accidents with respect to LOTO adherence

State of the art literature review to make an exhaustive list of accidents arising from Improper Implementation of LOTO.

1.5 Study of LOTO devices, Benefits and Limitations

There were various LOTO devices being used and study of these conventional LOTO devices had helped to understand their specifications, usage, benefits, complexities and limitations in controlling the hazardous energy.

1.6 Objectives:

The work is mainly focused on developing IoT based LOTO devices. These devices are important elements of hazardous energy control program. There were two objectives as listed below.

1.6.1 Development of IoT based LOTO device

Development of an IoT based LOTO complementing device to minimize accidents in Hazardous Industries. Different technologies related to IoT their usage, benefits, complexities, and limitations were considered in the development of IoT based LOTO device.

1.6.2 Trial and Validation of Developed Devices.

This work was planned with detailed literature review of various accidents arising from improper implementation of LOTO. These reviews help to understand different gaps in LOTO implementation. Detailed study of conventional LOTO devices to control various hazardous energies like electrical, hydraulics, pneumatics, thermal etc. helps to understand limitations of these conventional LOTO devices. The researcher planned to develop various LOTO devices (Objective-I) using electrical kit, electro-pneumatics kit, Programmable Logic Controllers (PLC) kit and IoT based LOTO device for accident prevention in Industries. The researcher also planned to take trial (Objective-II) of the developed device and collect real time data as these IoT based devices are network and signal strength depended. the researcher also planned to validate functioning of IoT based LOTO device at different location, different signal strength and different actuation voltage. These IoT devices may be useful in operation and controlling hazardous energies.

1.7 Structure of the Thesis Chapters

Chapter 1

Chapter 1 introduces the research problem and the objectives of the research work

Chapter 2

Chapter 2 describes the literatures (journals, texts, books, reports, and internet sites) reviewed in connection with the research work.

Chapter 3

Chapter 3 narrates the experiment, design, develop and trial of different LOTO devices.

Chapter 4

Chapter 4 narrates the data collection of the experimentation done for the research work. Data collected for different parameters and work conditions.

Chapter 5

Chapter 5 narrates the data collection of the experiment after a gap of 1 year to understand functioning, reliability and effectiveness of the developed IoT based LOTO device.

Chapter 6

Chapter 6 presents the analysis of collected data in the form of descriptive statistics, inference of the data with respect to device actuation time, location of the devices and network strengths. The chapter also presents the IoT based LOTO device and its effect on safety incidents.

Chapter 7

Chapter 7 presents the conclusions and limitations of this research work along with the scope exists for further research.

References

Journals, textbooks, reports, and internet sites referred in connection with this research work are given in this section.

1.8 Chapter Summary

Detailed study of the accidents motivated to define objective and scope of the further study and research. The researcher had defined 2 objectives as development of IoT based LOTO device, Trail and Validation of the developed device based on study of accidents, LOTO adherence,

A detailed literature review was conducted and described in the next chapter.

Chapter 2. Review of Literature

2.1 Chapter Overview

Detailed study of different LOTO devices, LOTO procedures and Hazardous energies are very important part of this research work. The findings of literature survey for getting clear understanding of the existing devices and the gaps noticed in the related knowledge are presented in this chapter.

2.2 Review of Literature and Problem Formulation

An exhaustive literature review was done to understand the theoretical significance of the concept and a detailed review of the various LOTO device and Program [23].

A review of the literature to understand the theoretical significance of the concept and holistic and quantitative method is urgent for a modified LOTO i.e., Hazardous Energy Control Program.

Few important components of LOTO were studied and briefed as below,

2.2.1 Hazardous Energy

Machines, Machinery Parts or equipment use energy or energy sources like mechanical, electrical, hydraulic, chemical, pneumatic, thermal, or any other sources. These energy sources can cause injuries or hazardous to the operators, and or workers who are working on the machine and involved in any kind maintenance, repair or servicing or tool setup. The unanticipated or unexpected energization or start up or release of stored energy or the hazardous energy can result in to safety incidents like serious injury or death to workers [24].

2.2.2 Hazardous Energy and Effect

The hazardous energy needs a proper control so that the person working on the machines or equipment is safe and no injury or fatality happens.[25].

Injuries may include electrocution, burns, crushing, cutting, lacerating, amputating, or fracturing body parts, and others.

- Internal wiring on a piece of factory equipment giving electrical shocks to the worker who is repairing the equipment. This may happen due to short-circuit.

- Pressurised pipeline on a hydraulic machine clamping unit giving finger injuries to the worker who is repairing the machine.

- Workers, who are working and repairing on a downstream steam pipeline may get burn injuries, if unexpected or unanticipated start up of the steam valve happens.

- A worker working on the jammed conveyor system gets injured or get crushed while repairing of the jammed conveyor.

2.2.3 OSHA Definitions LOTO Standards (29 CFR 1910.147)

2.2.3.1 Normal Production Operations

The utilization of a machine or equipment or machinery part to perform its intended production function.

2.2.3.2 Servicing and / or Maintenance

Workplace activities such as manufacturing, constructing, installing, adjusting, setting up, modifying, repairing, trouble shooting, inspecting, and maintaining and/or servicing machines or equipment [26].These activities include cleaning ,tightening, torquing, lubrication, or unjamming of machinery parts, machines or equipment and making setting-adjustments or tooling changes, where the employee may be exposed to the unexpected or unanticipated or sudden energization or start-up of the equipment or release of stored hazardous or residual energy.

2.2.3.3 Setting Up

Any work performed to prepare a machine or machinery part or equipment to perform its normal intended operation.

2.2.3.4 Affected Employee:

An employee whose job requires him or her to operate or run or use or take trial of a machine or machinery part or equipment while lockout or tagout is in effect, or whose job requires him or her to work in an area where such repair, servicing or maintenance is in effect.

2.2.3.5 Authorized employee:

An employee who follows LOTO procedure for putting locks and tags on the machine or equipment to carry out repair, servicing or maintenance on that machine or equipment. When an affected employee's duties involve repair, service or maintenance of the equipment, that employee becomes an authorized employee.

2.2.3.6 Energized

The machines or equipment needs energy to work and when these are connected to energy source, they are energized.

2.2.3.7 Energy Isolating device which are capable of being locked out

Machines or equipment needs to be locked out and need a place or attachment or a mechanism or a hasp, where the lock can be applied. The hazardous energy control procedure requires the machines or equipment must have energy isolating device which can be locked out. These device prevents workers from any kind of safety incident like injuries or death due to unanticipated on unexpected energization.

2.2.3.8 Device of Energy Isolation

A mechanical or physical device that physically prevents the transmission or release of energy, including but not limited to the following: A manually operated switch by which the conductors of a circuit can be disconnected from all the ungrounded supply conductors, a manually operated electrical circuit breaker; a switch to disconnect, and in addition, no pole of the electrical switch can be operated independently; a physical block; a butterfly valve; a gate valve; and any similar device used to isolate or block or disconnect energy. Selector switches, Push buttons, and other electrical control circuit type devices are not energy isolating devices.

2.2.3.9 Energy source

Any source of mechanical, electrical, pneumatic, hydraulic, thermal, chemical, or other energy

2.2.3.10 Hot Tap

Hot Tap is commonly used procedure to replace or add sections of pipeline without the interruption of service for air, gas, water, steam, and petrochemical distribution systems, in order to install connections or appurtenances. It is commonly used in the repair, maintenance and services activities which involves welding on a piece of equipment under pressure.

2.2.3.11 Lockout

The placement of a lockout device on an energy isolating device, in accordance with an established procedure or hazardous energy control procedure, ensuring that the energy isolating device and the equipment being controlled cannot be operated until the lockout device is removed [27].

2.2.3.12 Lockout Device

A device that utilizes a positive means such as a lock, either key or combination type, to hold an energy isolating device in the safe position and prevent the energizing of a machine or equipment [28].

2.2.3.13 Tagout

The placement of a tagout device on an energy isolating device, in accordance with an established hazardous energy control procedure, to indicate that the energy isolating device and the equipment being controlled may not be operated until the tagout device is removed.

2.2.3.14 Device for Tagout

An important warning device, such as a paper tag or card or sheet and a means of attachment, which can be securely fastened to an energy isolating device in accordance with an established procedure, to indicate that the energy isolating device and the equipment being controlled may not be operated until the tagout device is removed.

2.2.4 OSHA specified LOTO Procedure

OSHA has identified and defined LOTO procedures (Figure 2-1) for Operation and Maintenance Persons/ Workers servicing or maintaining machines or equipment.

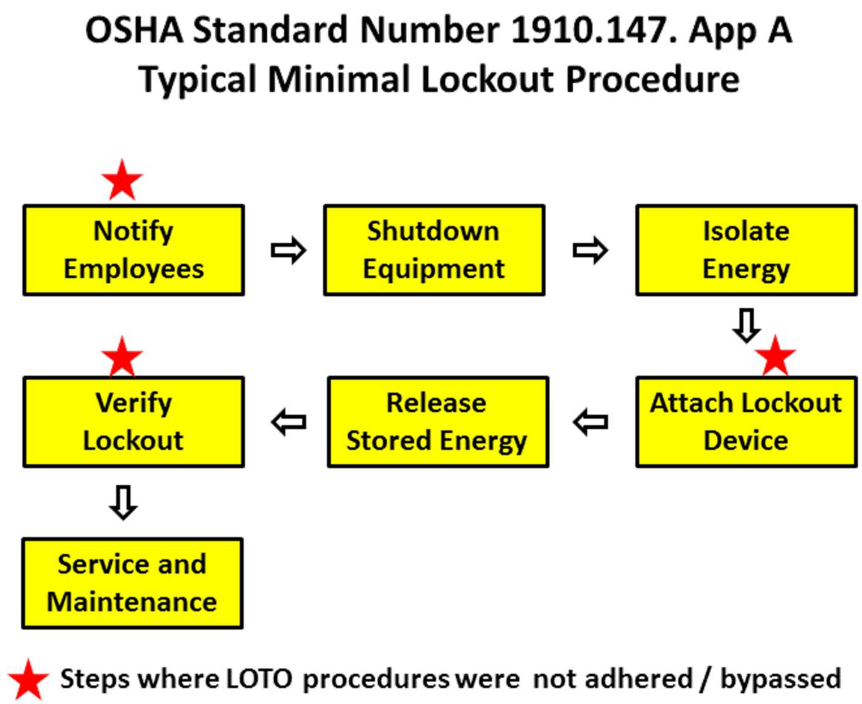


Figure 2-1 OSHA –Standard Number 1910.147 Typical LOTO Procedures

2.2.5 The Factory Act, 1948 and LOTO:

Indian Factory Act, 1948, Chapter IV, Safety, 24, 1*(3) [29] mentions about "When a device, which can inadvertently shift from "off" to "on" position, is provided in a factory to cut off power, arrangements shall be provided for locking the device in safe condition to prevent accidental starting of the transmission machinery or other machines to which the device is fitted [30]"

2.2.6 Basic elements of LOTO Program

LOTO program has many basic elements like type of energy sources, type of locks, process sequence, LOTO procedure etc... These Basic elements of

Lockout Safety Program are shown in (Figure 2-2) OSHA has also defined six steps of LOTO program (Figure 2-3).

1. DETERMINE WHAT ENERGY SOURCES WILL BE LOCKED OUT
2. CAN LOCKS BE APPLIED
3. DETERMINE SEQUENCE TO FOLLOW
4. DETERMINE WHO WILL APPLY LOCKS/TAGS
5. DETERMINE NUMBER OF MULTIPLE PERSONNEL MAY WORK
6. BE SURE ALL STORED ENERGY IS RELEASED OR BLOCKED
7. FOLLOW LOCKOUT TAGOUT PROCEDURE FOR PERFORMING SERVICING OR REPAIR OR MAINTENANCE AS APPLICALE
8. VERIFY BEFORE REMOVING LOCKS/TAGS
9. ONLY PERSON WHO APPLIED LOCK/TAGS REMOVES IT
10. FOLLOW THE DEFINED SEQUENCE OF REMOVING LOCKS/TAGS AND STARTING THE MACHINE
11. RECORD IN LOTO REGISTER
12. CONTINUE EMPLOYEE TRAINING AND EDUCATION.

Figure 2-2 Basic Elements of a Lockout Safety Program

1. **Notify Affected Employees that Machine or Equipment will be Shutdown and Locked Out**
2. **Shutdown the Machine or Equipment**
3. **Isolate Energy Sources with Energy Isolating Devices**
4. **Lockout Energy Isolating Device with assigned Lock/Tag**
5. **Release or Block Stored or Residual Energy**
6. **Verify/Test the Machine or Equipment that it can not startup.**

Figure 2-3 Six Steps LOTO Program

2.2.7 Study of LOTO devices used in Industries for controlling hazardous Energy

Study was conducted to identify different LOTO device (Table 2-1)being used in different industries for controlling various hazardous energies with their salient feature and limitations.

Table 2-1 LOTO device(s) used in Industries for control of hazardous energies

Sl. No.	Type of Hazardous Energy	LOTO Device(s)	Salient Features	Limitations
1	Electrical	Electrical Panel Lockout	• Higher Voltage 230V-440V AC • Transparent cover improves visibility	• Non-Standard • Fragile/Prone to Breakage • Panel needs modification to fit these devices
2	Electrical	Electrical Panel Handle Lockout	• Wide Voltage Range 0-440V AC and 0-24V DC • Easy fitment and visible	• Non-Standard • Arc Flash Hazard Prone Area • Fragile/Prone to Breakage • Panel needs modification to fit these devices
3	Electrical	Push Button Lockout	• Regular Range 0-230V AC and 0-24V DC • Customized for Emergency and Normal Control Push Buttons • Adjustable for oversize Push Buttons.	• Non-Standard • Fragile/Prone to Breakage • Mounting Surface needs modification to fit these devices
4	Electrical, Pneumatics, Hydraulics and Gravity	Cable Lockout	• Multiple energy sources can be lockout • Adjustable for many locations in single plane.	• Non-Standard • Lengthy, Difficult to hand carry • Damages other parts while lockout
5	Pressurized Water, Liquid, Oil, Gases, Compressed Air	Gate Valve Lockout	• Multiple energy sources can be lockout • Visible	• Can be broken or removed easily • Gets damaged in open areas

Sl. No.	Type of Hazardous Energy	LOTO Device(s)	Salient Features	Limitations
6	Pressurized Water, Liquid, Oil, Coolant Compressed Air (0-7 Bar)	Ball Valve Lockout	• Multiple energy sources can be lockout • Visible	• Can be broken or removed easily • Gets damaged if applied in open areas.
7	Pressurized Water, Liquid, Oil, Gases with High Flow >10LPM	Butterfly Valve Lockout	• Multiple energy sources can be lockout • Large in Sizes (> 150 mm Diameter)	• Can be broken or removed easily • Gets damaged if applied in open areas.
8	Gas stored and used through Gas Cylinders	Gas Cylinder Lockout	• Customized as per Cylinder Sizes • Easy to apply	• Non- Standard • Can be broken or removed Easily
9	Electrical	Electrical Plug Lockout	• Regular Range 230V AC,440V AC • Easy to Apply	• Non-Standard • Can be broken or removed easily
10	Compressed Air (0-7 Bar)	Air Service Unit (FRL) Lockout	• Customized as per FRL size(s) • Easy to Apply • Some devices are with quick release features.	• Non-Standard • Can be broken or removed easily
11	Compressed Air (0-7 Bar) and Gases	Pneumatic Lockout	• Customized as per tube size(s) • Tube(s) life gets reduced due to folding for applying lockout	• Non-Standard • Can be broken or removed easily
12	Electrical	Circuit Breaker (CB) Lockout	• Customized as per CB • Wide voltage Range0-440V	• Non-Standard • Difficult to apply and can be broken or removed easily

2.3 Scope, Study, Experiment and Trials

2.3.1 Scope

The researcher had defined the scope limited to study of widely used conventional Lockout devices on CNC Machine [31] which covered servicing, repair, and maintenance [32] of equipment, machines, fixtures and machinery parts in which unplanned start up or unexpected energization or release of stored energy could cause physical harm or injury to workers or persons working nearby.

2.3.2 Study of various Lockout devices.

There were different lockout device(s) for different energy isolating devices. Systematic study was carried out to study these devices, their usage, specifications, manufacturer, complexities etc.

2.3.2.1 Electrical Panel Lockout

Equipment has electrical panels with electrical supply 440V,230V,110V,24V,12V etc., these panels are fitted with various push buttons, emergency mushroom push buttons, switches, switches with lever etc. These needs to be lockout with correct Lockout (Figure 2-4) devices [33].

Figure 2-4 Electrical Panel Lockout Device (Make and Image Source -Bradyid)

2.3.2.2 Electrical Panel Handle Lockout

Electrical Panels has handles for changing the position to on/off the equipment. These handles require special handle lockout devices (Figure 2-5).

Figure 2-5 Electrical Panel Handle Lockout Device (Make and Image Source - Bradyid)

2.3.2.3 Push Button Lockout

Emergency Stop, Mushroom Push Buttons, Normal push buttons are used more frequently by operators for different functions of the equipment and processes. These push buttons require special lockout device (Figure 2-6).

Figure 2-6 Push Button Lockout Device (Make and Image Source –E Square)

2.3.2.4 Oversize Push Button Lockout

Some of the equipment is fitted with oversize Electrical Push Buttons on the electrical panels or on control stations. These requires special lockout device (Figure 2-7).

Figure 2-7 Oversize Push Button Lockout Device (Make and Image Source–E Square)

2.3.2.5 Lockout Pad Locks

These padlocks (Figure 2-8) are applied on lockout device to lock the device. These locks can be opened with respective dedicated keys only.

Figure 2-8 Lockout Pad Locks (Make and Image Source –E Square)

2.3.2.6 Lockout Hasps

There are times when many people need to work on the equipment or multiple energy needs to be lockout. Safety lockout hasps (Figure 2-9) are used when the LOTO user wish to use multiple padlocks to isolate one energy source. A hasp is placed through the isolating point and closed, allowing each authorized person to place their own padlock on it.

Figure 2-9 Hasps for Multiple Locks and Group Lockout (Make and Image Source –Bradyid)

2.3.2.7 Cable Lockout

These devices are used when different energy sources are at distance and coordinates (Figure 2-910). Cables are flexible and can be used in different applications.

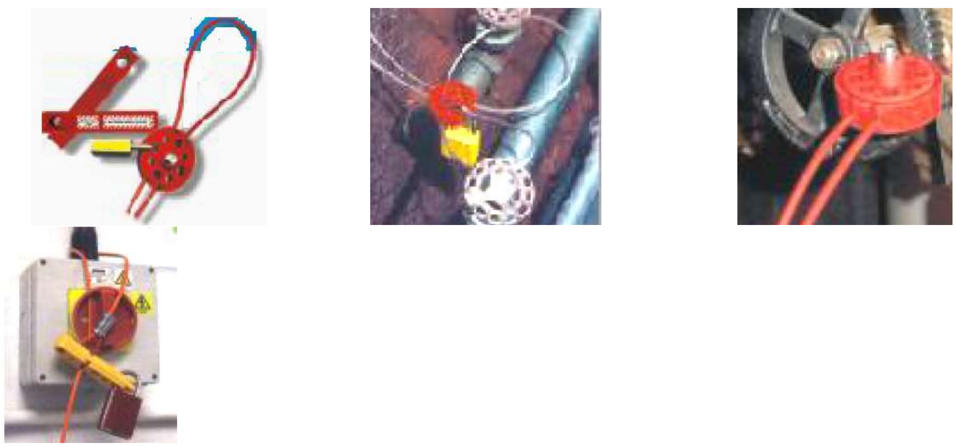


Figure 2-10 Cable Lockout Devices (Make and Image Source –E Square)

2.3.2.8 Gate Valve Lockout

Equipment needs fluids and gases like pressurized water, compressed air, hydraulic oil, coolant oil and gases which can be very harmful. There are Gate Valves which requires to control flow of these fluids and gases. The LOTO user need to lock out these gate valves with correct lockout devices (Figure 2-11).

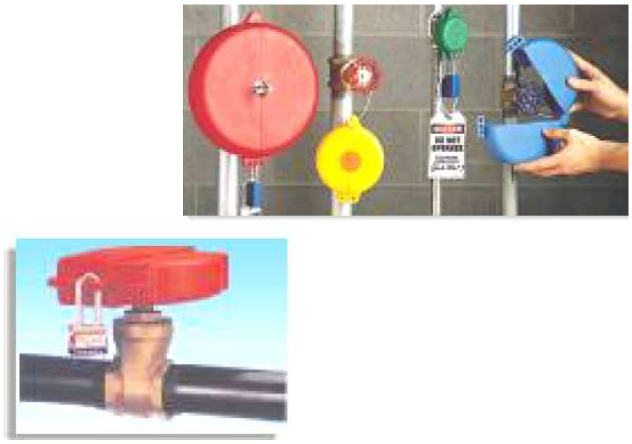


Figure 2-11 Gate Valve Lockout Devices (Make and Image Source –E Square)

2.3.2.9 Ball Valve Lockout

Equipment needs fluids and gases like pressurized water, compressed air, hydraulic oil, coolant oil and gases which can be very harmful. There are Ball Valves (Shut Off Valves) which requires to control flow of these fluids and gases. The LOTO user need to lock out these Ball Valves with correct lockout devices (Figure 2-12).

Figure 2-12 Ball Valve Lockout Device (Make and Image Source –LOTO)

2.3.2.10 Butterfly Valve Lockout

Equipment needs fluids and gases like pressurized water, compressed air, hydraulic oil, coolant oil and gases which can be very harmful. There are Butterfly Valves which require to control flow of these fluids and gases. The LOTO user need to lock out these Butterfly valves with correct lockout devices (Figure 2-13). Butterfly valves are generally bigger than gate valves and ball valves. They control larger flow rate.

Figure 2-13 Butterfly Valve Lockout (Make and Image Source –E Square)

2.3.2.11 Gas Cylinder Lockout

Equipment and processes need gases like Argon, Oxygen, Nitrogen LPG , PNG etc. These gases are pressurized and can be very harmful if not controlled. There are Gas Cylinder Lockout devices to apply lockout on cylinders (Figure 2-14).

Figure 2-14 Gas Cylinder Lockout Device (Make and Image Source –E Square)

2.3.2.12 Electrical Plug Lockout

Equipment and processes are fitted with electrical plugs. Many daily use appliances also have electrical plugs. The LOTO user need to lockout these plugs to be safe and avoid any harmful incident. Electrical Plug Lockout devices are used to lockout electrical plugs (Figure 2-15).

Figure 2-15 Electrical Plug Lockout Device (Make and Image Source –E Square)

2.3.2.13 Air Service (FRL) Unit Lockout

Some Equipment and processes need compressed air and fitted with FRL (Filter Regulator Lubricator) Unit. These units need to be lockout (Figure 2-16) to control hazardous energy.

Figure 2-16 Air Service Unit (FRL) Lockout Device (Make and Image Source –Festo)

2.3.2.14 Pneumatic Lockout

Some Equipment and processes need compressed air, which flows through different pneumatic tubes and hoses. These hazardous energy (1-12 Bar pneumatic pressure) needs to be controlled with correct pneumatic lockout devices (Figure 2-17).

Figure 2-17 Pneumatic Lockout Device (Make and Image Source –E Square)

2.3.2.15 Circuit Breaker Lockout

Most of the Equipment and processes requires electricity and fitted with Circuit Breakers to control the electricity. These Circuit Breakers comes in many varieties. Most widely used Circuit Breakers are known as MCB (Miniature Circuit Breakers). Many lockout devices (Figure 2-18) are available to lockout these circuit breakers.

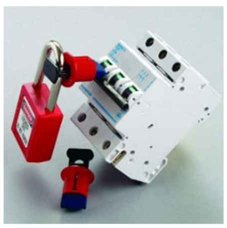


Figure 2-18 Circuit Breaker Lockout Device (Make and Image Source –Bradyid)

2.4 Data Collection and Analysis of LOTO application on a Machine

The researcher has observed the LOTO device related data from Makino CNC Machine (Model A81) for Gear Box Machining; This CNC Machine (Figure 2-19) uses various hazardous energies, lockout devices and activities. Total 52 Activities requires Lockout Tagout in which majority (67%) are electrical lockout followed by hydraulic lockout (13%).

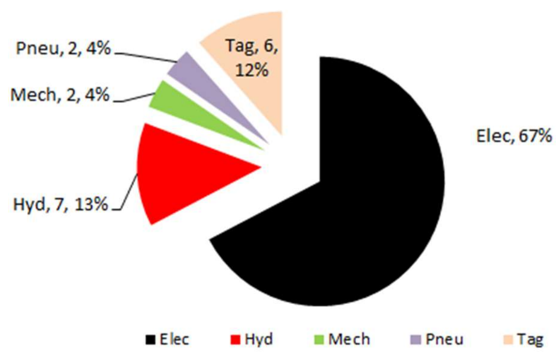


Figure 2-19 LOTO Activities on CNC Machine –Makino A81

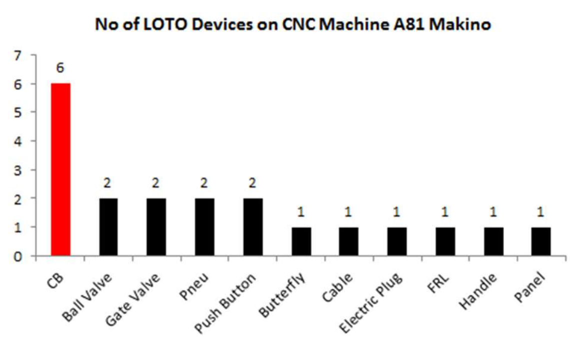


Figure 2-20 LOTO devices on CNC Machine –Makino A81

- The machine has 16 different type of Lockout devices (Figure 2-20) in which majorities are circuit breaker lockout device. Further Analysis of these 6 different CB (Circuit Breakers) has been done,

- There are 4 Miniature Circuit Breakers or MCB (Figure 2-21) of different ratings which requires 4 different type of MCB Lockout devices out of these 6 CB

- The above study and data reveals complexity of different lockout activities and devices. Specification and Type of MCB Lockout devices depend on specifications and type of MCBs.

Further data were collected for different MCB and respective LOTO devices as shown in Figure 2-22.

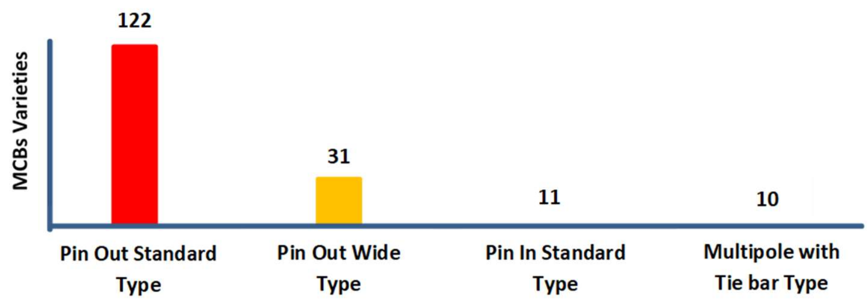


Figure 2-21 Bar Chart for Different MCB Lockout Devices and various MCBs (Source https://www.safetylock.net/circuit-breaker-lockout.html)

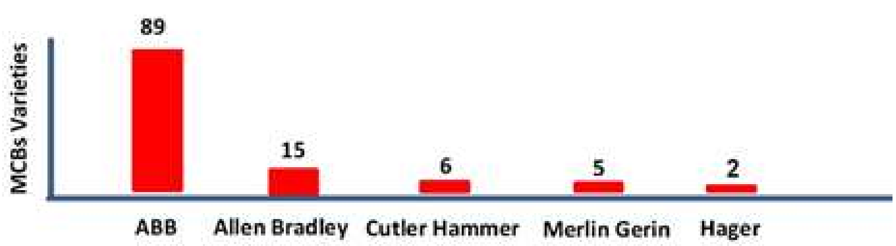


Figure 2-22 Manufacturer of Different Type of MCB Pin Out Standard Lockout Devices (Source https://www.safetylock.net/circuit-breaker-lockout.html)

2.5 Conclusion from Data Analysis and Study

Following conclusions can be made based on the data

- There are various energy sources and energy isolating devices
- There is variety of energy isolating devices in different specifications by different manufacturer

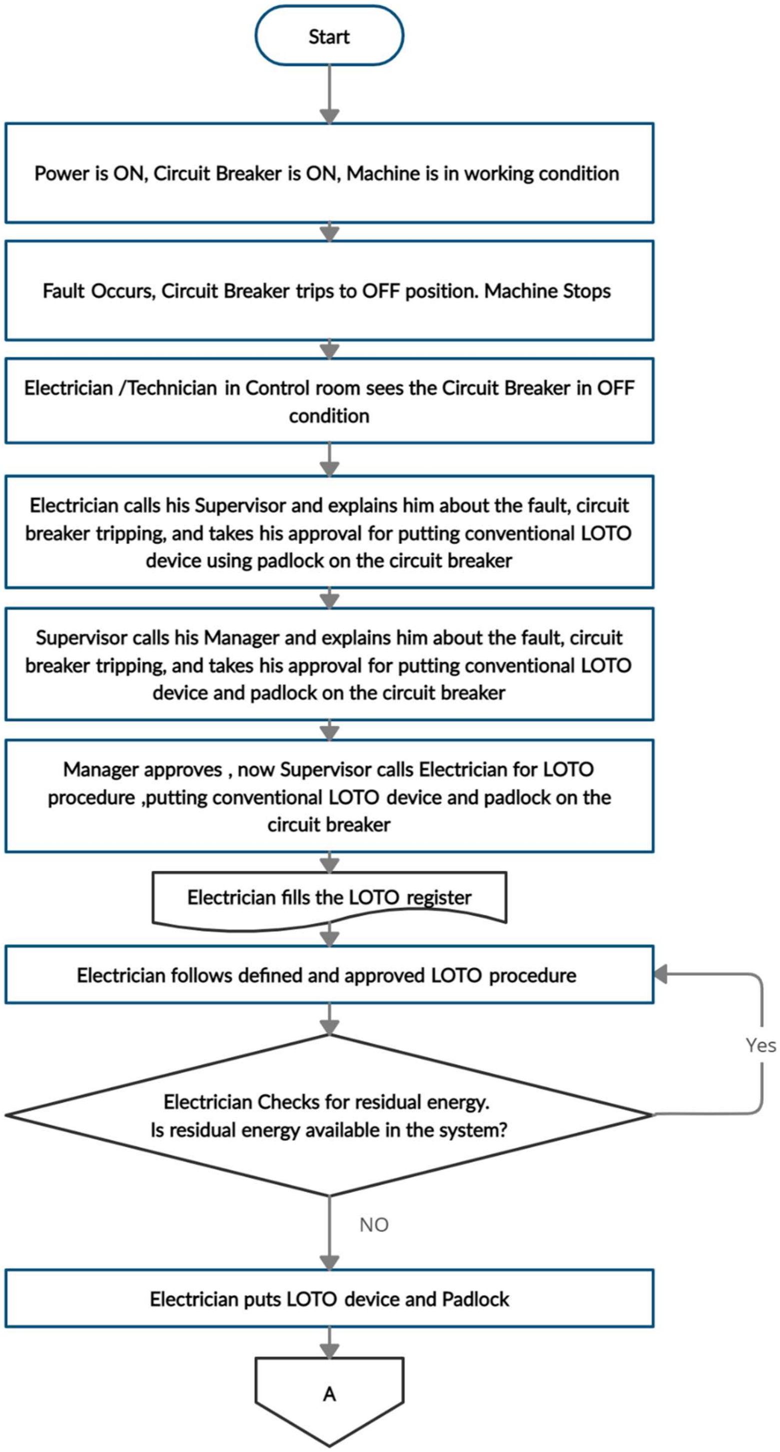
- Lockout devices do not have any specified standard, manufacturer makes customized devices (Figure 2-22).
- These devices do not have testing and endurance data which shows their life.
- The inspection of these devices is visual/manual and human error may happen [34].
- Sometimes these devices do not get right fitting on the energy source and can be removed easily.
- Some of these devices are bulky/heavy and cannot be hand carried.
- LOTO Procedure is standardized however the lockout devices are still custom made.

2.6 Recommendations and Future Scope

- Extensive theoretical and practical training required for each type of lockout device for respective energy isolating devices [35].
- The Lockout devices can be standardized for respective energy isolating device like electrical energy related LOTO for MCBs, pneumatic energy related LOTO devices for air service units (FRL Unit) etc.
- Further studies can be made for other lockout devices based on identified hazard.

2.7 Process Flow Study of LOTO implementation with Conventional LOTO Device and Padlock

This Flow Diagram (Figure 2-23) shows an electrical fault happening at one of the electrical supplies to the equipment and subsequent communication between electrician, technician, supervisor, engineers and managers, fault identification, conventional LOTO adherence, troubleshooting, authorisation and data recording.


Start
Power is ON, Circuit Breaker is ON, Machine is in working condition
Fault Occurs, Circuit Breaker trips to OFF position. Machine Stops
Electrician /Technician in Control room sees the Circuit Breaker in OFF condition
Electrician calls his Supervisor and explains him about the fault, circuit breaker tripping, and takes his approval for putting conventional LOTO device using padlock on the circuit breaker
Supervisor calls his Manager and explains him about the fault, circuit breaker tripping, and takes his approval for putting conventional LOTO device and padlock on the circuit breaker
Manager approves , now Supervisor calls Electrician for LOTO procedure ,putting conventional LOTO device and padlock on the circuit breaker
Electrician fills the LOTO register
Electrician follows defined and approved LOTO procedure
Electrician Checks for residual energy.
Is residual energy available in the system?
Yes
NO
Electrician puts LOTO device and Padlock
A

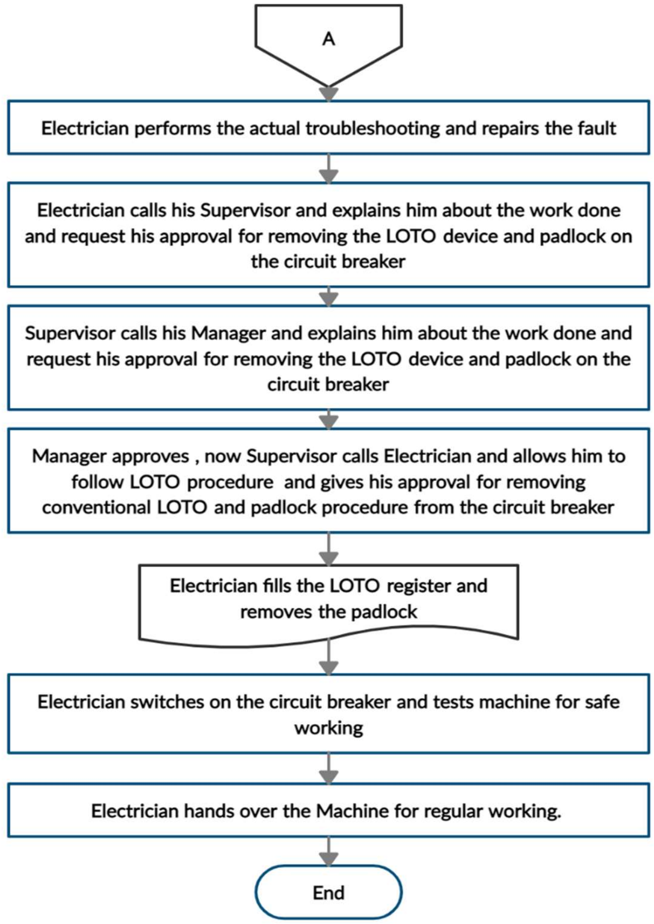


Figure 2-23 Conventional LOTO Program

2.8 Limitations and Challenges of Conventional LOTO Procedure

- Electrician has sole responsibility and decision making of Putting LOTO device and physical pad lock, Electrician can bypass and lock or unlock the LOTO device and padlock.
- Any other unauthorized person can lock/unlock the device or break the lock and only personal vigil can avoid these mischiefs.
- Supervisor and Manager need to visit, see and verify physical condition of actual padlock at circuit breaker.
- LOTO procedure takes time and delays the actual trouble shooting and fault-finding process.

- Record Keeping is manual.
- Mode of communication is phone call or physical discussion.

2.9 Section Summary

There were limitations in conventional LOTO devices and accidents were happening due to non-adherence of LOTO. Emerging technologies like IoT were studied and described in the next section.

2.10 Study of IoT based devices

Conventional LOTO devices and procedure has many gaps. IoT based device [11] could be of helpful in getting over limitations. This chapter explains the Internet of Things, IoT devices, specific properties of IoT devices, and its application in LOTO adherence.

2.11 Internet of Things (IoT)

An Internet of things (IoT) is a development of the Internet in which everyday objects have network connectivity, allowing them to send and receive data

In simple words, The Internet of Things (IoT) is the concept of linking or connecting any device having an on/off switch to the Internet (and/or to each other). The devices like cell phones, computers, wearable devices [36], vending machine, washing machines, headphones, lightings, and virtually everything else we can think of fall into this concept. The IoT is a very large network of connected "things". These connected things also include people. The relationship will be between people-people, people-things, and things-things [37].

As explained before, the IoT can encompass many communication networks in which the devices can interact with each other via the Internet.

Examples of these devices are Arduino, Raspberry Pi, Radio Frequency Identification (RFID) tags, Cubie Board and Beagle Board. These development boards include microcontrollers, which contain a processor, a Read Only

Memory, a Random-Access Memory and a number of both digital and analog general purpose input/output pins. Arduino Mega 2560 has been used in developing IoT based LOTO device as it is easily available and widely used in IoT devices.

Evaluation of IoT based devices [38]

IoT based devices are leveraged for Cyber Security, Energy Efficiency, data reliability and built-in redundancy to ensure a fool proof system.

2.12 Specific Properties of IoT Device

The IoT device possess specific properties which are described further below.

2.12.1 Communication

Communication with users and objects refers to the interconnection methods which are utilized in order to communicate the objects with the users or with other objects. Trial of different Network Strength has been completed for communication time and actuation time.

2.12.2 Identification

IoT based LOTO device possess an identity as an Internet Protocol address in order to communicate with other objects in the device like Servo Motors and Sensors.

2.12.3 Computation Methods

Computation Methods: The computation methods are used to process the information of sending message, actuation, switching of the devices etc. which is obtained from the objects like sensors, GSM-SIM Module.

2.12.4 Services

Services refer to the functions which are provided by the objects like sensors [39] to the users in accordance with the information which they receive from the physical environment of machine breakdown or failure.

2.12.5 Semantics or ability to take and process right information

Semantics implies that the objects like sensors, servo motors, input devices, output devices etc. in the IoT have the ability to take the right information from an environment and provide this information as services at the appropriate time.

2.12.6 Sensors and Sensing Methods

The sensing methods using different sensors employed to obtain information from the physical environment.

2.12.7 Wiring, Real Time Operating System and Other Properties

The IoT based LOTO device include various sensors, which has been hardwired in the Arduino microprocessor controller unit for local processing, responsive actuation of Servo Motors, Relays.

The IoT devices required a Real-Time Operating System for the information processing, memory management as well as utility services supporting messages and other communications.

2.13 IoT based device for LOTO

For LOTO, the researcher developed an IoT enabled device (Figure 2-24) which communicated to different devices, actuated different switches, which further made the actuator work [40]. The researcher did lock/unlock of the IoT enabled LOTO device from remote/many locations like shop floor, outdoor, indoor and had the SMS/text message(digital) about the condition of LOTO (Lock/Unlock/Tempered/Broken) and performed the pre-defined action.

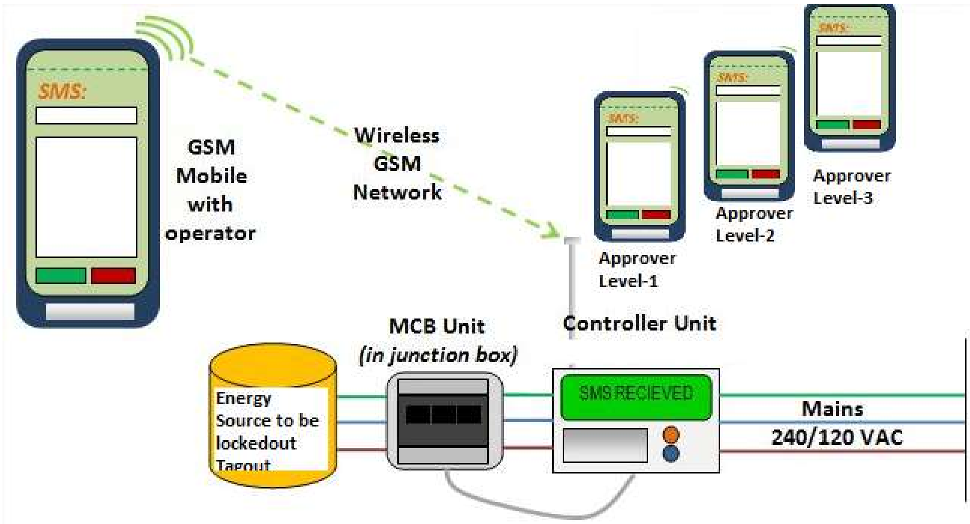


Figure 2-24 IoT enabled Communication System (Image Source https://www.researchgate.net/figure/SMS-contrlled-Irrigation-Via-Arduino_fig1_335973028)

2.14 Chapter Summary

IoT based devices were emerging. The IoT device had specific properties like communication, identification, computation method, sensors, real time operating systems, hard wiring, actuators etc, These IoT devices were efficient and useful.

There were many choices among the microprocessors like Arduino, Raspberry Pi etc. and their selection required right environments like network strength, actuation method, actuation time, actuation speed, accuracies etc. based on different LOTO locations like shop floor, basement, and outdoor locations.

The researcher had decided to develop different IoT based device and described in the next chapter.

Chapter 3. Development and Trial of IoT based LOTO device

3.1 Chapter Overview

IoT based LOTO devices required many automations related technologies like programmable logic controllers, pneumatics, electro-pneumatics, mechatronics, microprocessors like Arduino, sensors etc. This chapter explains the IoT based device, its trial in LOTO adherence. Researcher has planned a considered different design principles [41]–[44]and design steps for development of IoT based LOTO device.

3.2 Design Principle and steps

The researcher has used principles of design or guidelines [41] that are organised and structured to assist the designer in lowering the cost and difficulty of manufacturing an item. The following rules were followed

i. Reduce the total number of parts
ii. Develop a modular design
iii. Use of standard components
iv. Design for ease of fabrication
v. Avoid separate fasteners
vi. Minimize assembly directions
vii. Maximize compliance
viii. Minimize handling

3.3 Design steps

The researcher has adapted product design steps[45] like synthesis, sketching, analysis, selection of parts, programming, simulation, prototype, and trial.

3.3.1 Synthesis

Try to develop different alternatives using pneumatics, relay logic, Arduino based device and programable logic controllers

3.3.2 Sketching

Sketches in exact scale for different alternatives were drawn.

3.3.3 Analysis

Analysis of different alternatives were done with respect to operability, maintainability, inspection, assembling and dismantling issues, cost parameters, assembly and manufacturing methods.

3.3.4 Selection

The researcher selected the best alternative of using Arduino based IoT LOTO device.

3.3.5 Basic Engineering and design

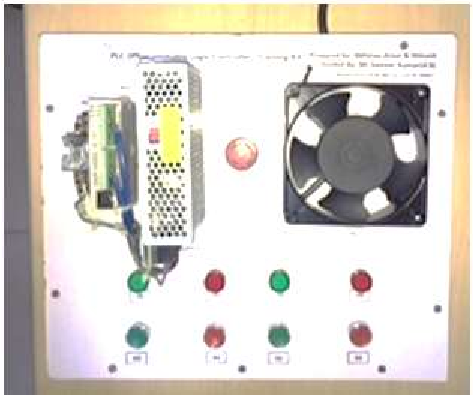
The block diagram and layout was prepared in exact scale considering size, shape, strength, specifications of different components and cost effective material.

3.3.6 Prototype

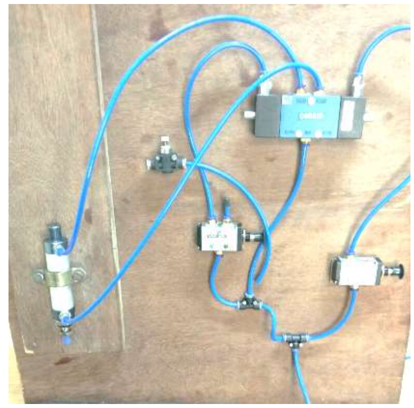
The researcher developed a prototype of IoT based LOTO device to be used with selected machine and tested the device.

3.4 Synthesis: Development of different Experimental kits

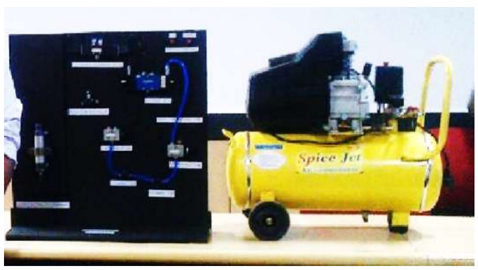
Different experiment kits (Figure 3-1) like Programmable Logic Control Kit, Pneumatic Kit, Electro-Pneumatic Kit, Arduino Kit, GSM Kit etc. have been developed for experimenting different LOTO conditions and different locations. Some of the trial kit developed for trial and experimentation are as below.



(A)Programmable Logic Controller Kit



(B)Pneumatic Kit



(C) Electro-pneumatics and Automation Kit

(D) Arduino Board

(E) GSM Module

Figure 3-1 IoT based LOTO device Experimentation Kits

(A) Programmable Logic Controller Kit (Figure 3-1) was used in developing different logics of switching on/off the switch. PLC was programmed to test various logics.

(B) Pneumatic Kit was used in experimenting different pneumatic actuator which provided mechanical motions.

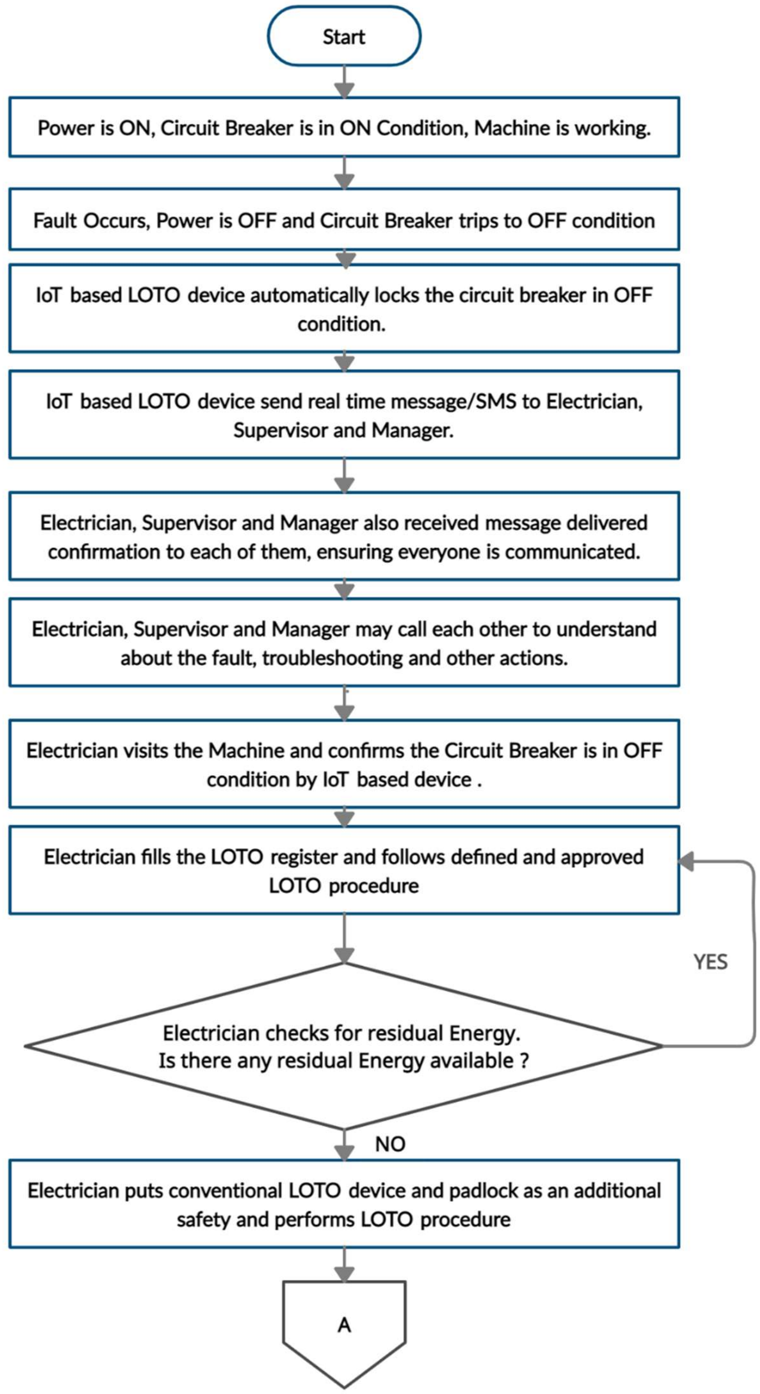
(C) Electro-pneumatics and Automation Kit were also used for experimenting actuation with electrical and pneumatic mediums.

(D) Arduino Board [46] was used for experimenting different programmes and logics for switching on/off with the help of phone or text message or through PC/Laptop.

(E) GSM module was used for experimenting different communication condition with actuator, controller and Kits [47].

3.5 IoT based LOTO device implementation (pictorial illustration)

Figure 3-2 shows the flow diagram for the proposed IoT based LOTO device giving pictorial presentation of step-by-step process.


Start
Power is ON, Circuit Breaker is in ON Condition, Machine is working.
Fault Occurs, Power is OFF and Circuit Breaker trips to OFF condition
IoT based LOTO device automatically locks the circuit breaker in OFF condition.
IoT based LOTO device send real time message/SMS to Electrician, Supervisor and Manager.
Electrician, Supervisor and Manager also received message delivered confirmation to each of them, ensuring everyone is communicated.
Electrician, Supervisor and Manager may call each other to understand about the fault, troubleshooting and other actions.
Electrician visits the Machine and confirms the Circuit Breaker is in OFF condition by IoT based device .
Electrician fills the LOTO register and follows defined and approved LOTO procedure
YES
Electrician checks for residual Energy.
Is there any residual Energy available ?
NO
Electrician puts conventional LOTO device and padlock as an additional safety and performs LOTO procedure
A

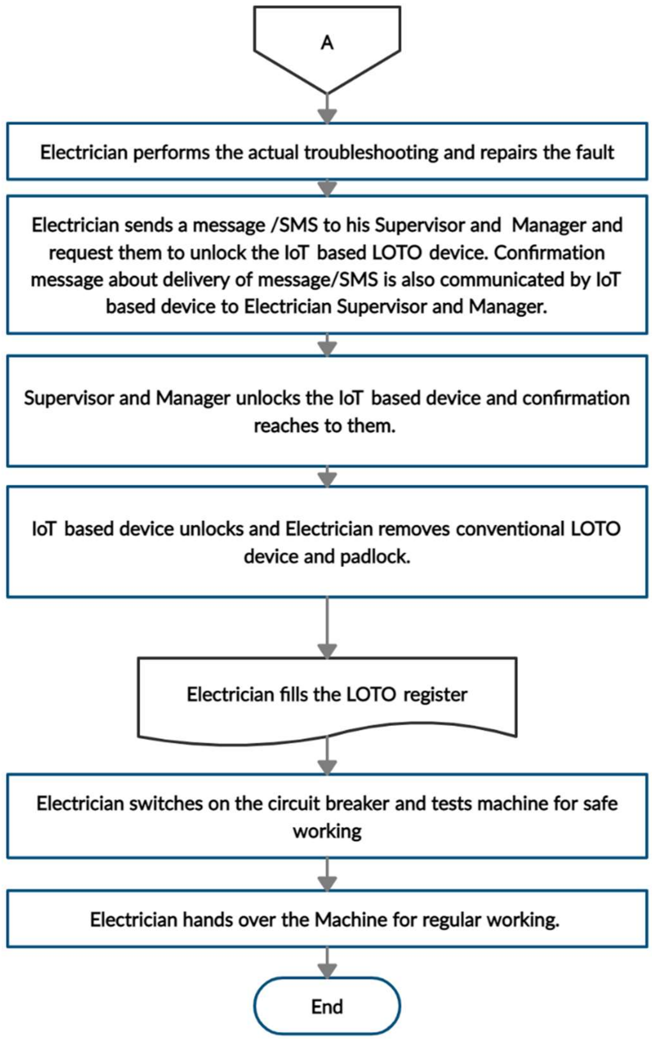


Figure 3-2- LOTO procedure with IoT based device.

3.6 IoT based LOTO Device (Prototype) – Construction & Assembly

3.6.1 Components Used

- Arduino Mega 2560
- 6V EM Relay
- BC (547) Transistor

- Resistance
- 16x2 LCD
- 3Phase LED Indicator
- Servo Motor
- 10A MCB
- SIM 900 GSM Module
- Transformer 6-0-0
- Cabinets for LOTO device
- Wires and Cables

3.6.2 Schematic Block Diagram

IoT based LOTO device has been developed (Figure 3-3) using standard components like Arduino Mega 2560, GSM SIM Module, Servo Motors, LCD Display, MCBs etc. A schematic block diagram (Figure 3-4) have been made for assembly of these components of IoT based LOTO device.

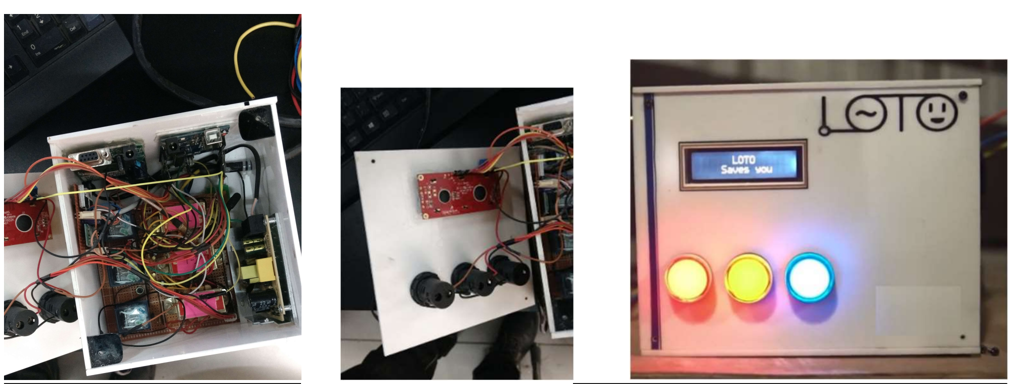


Figure 3-3 IoT based LOTO Device (Prototype)

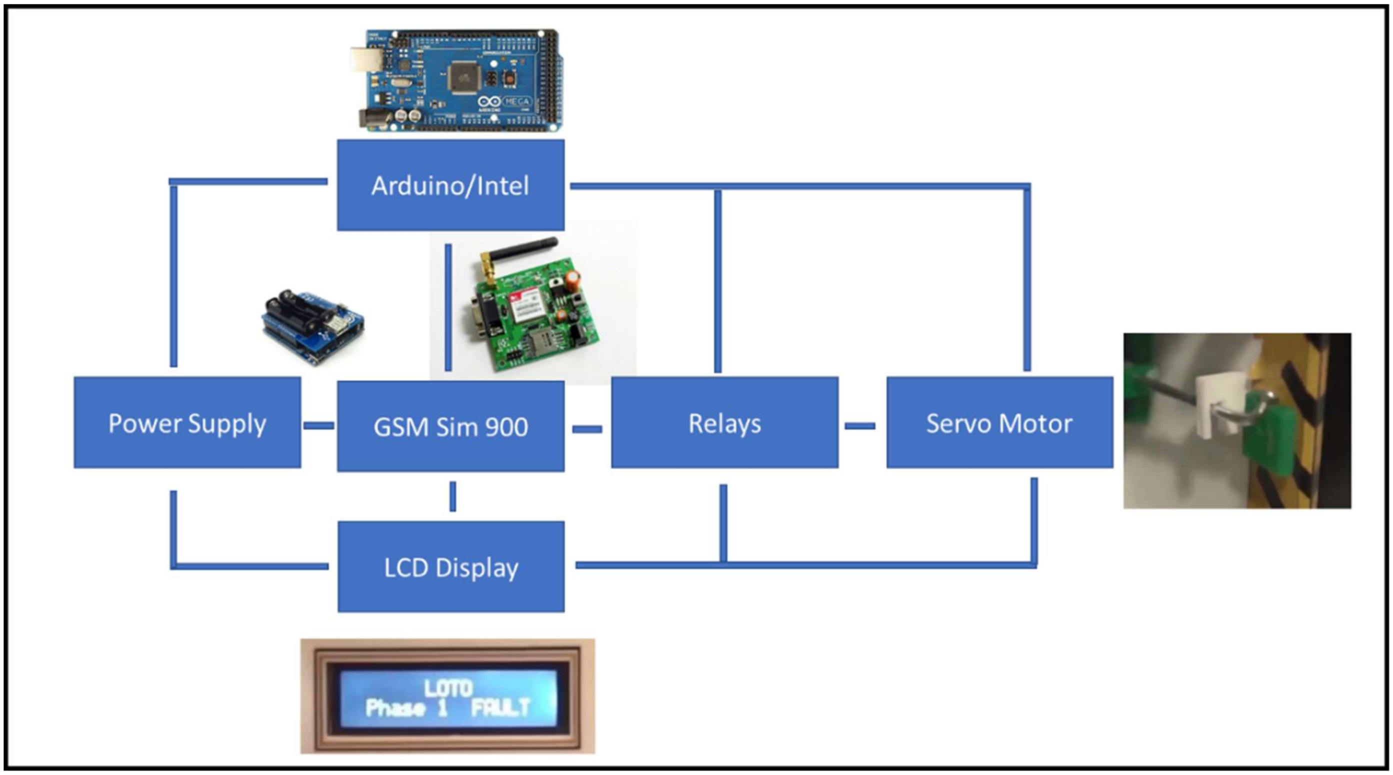


Figure 3-4 Schematic Block Diagram of IoT based LOTO Device (Prototype)

3.6.3 Programming using Arduino

/*

IoT based LOTO Device

The LOTO device is used for controlling the hazardous energies and based on the workflow (Figure 3-2) the device isolates energy, lock out the device and sends messages to electrician, supervisor, and manager. The IoT based lock gets only after approval of the manager and supervisor.

This program is written for custom designed product for testing LOTO enabled by IoT for this study.

```
 Circuit:

 * GSM shield

 * SIM card that can send SMS

 created 25 Apr 2018

 by Sameer Kumar

 */

// Include the GSM library

#include <GSM.h>

#define PINNUMBER ""


// initialize the library instance

GSM gsmAccess;

GSM_SMS sms;


void setup() {

  // initialize serial communications and wait for port to open:

  Serial.begin(9600);

  while (!Serial) {

    ; // wait for serial port to connect. Needed for native USB port only
```

```
  }

  Serial.println("IoT based LOTO Device");

  // connection state
  boolean notConnected = true;
  // Start GSM shield
  // If your SIM has PIN, pass it as a parameter of begin() in quotes
  while (notConnected) {
    if (gsmAccess.begin(PINNUMBER) == GSM_READY) {
      notConnected = false;
    } else {
      Serial.println("Not connected");
      delay(1000);
    }
  }
  Serial.println("GSM initialized");
}
void loop() {
```

```
  Serial.print("8527232406 ");
  char remoteNum[20];  // telephone number to send sms
  readSerial(remoteNum);
  Serial.println(remoteNum);


  // sms text
  Serial.print("This device has been locked out, please perform defined LOTO Process ");
  char txtMsg[200];
  readSerial(txtMsg);
  Serial.println("SENDING");
  Serial.println();
  Serial.println("Message:");
  Serial.println(txtMsg);
  // send the message
  sms.beginSMS(remoteNum);
  sms.print(txtMsg);
  sms.endSMS();
  Serial.println("\nCOMPLETE!\n");
}
```

```
/*
  Read input serial
 */
int readSerial(char result[]) {
  int i = 0;
  while (1) {
    while (Serial.available() > 0) {
      char inChar = Serial.read();
      if (inChar == '\n') {
        result[i] = '\0';
        Serial.flush();
        return 0;
      }
      if (inChar != '\r') {
        result[i] = inChar;
        i++;
      }
    }
  }
```

}

/*

IoT based LOTO Device

Programming Code from Sidney Dekkar [34] has been used as a reference, for the Arduino GSM shield, sends an SMS message for the developed IoT device.

*/

3.6.4 Locking and Unlocking with IoT based LOTO device

IoT based LOTO device has one Servo Motor which is fitted with a locking wedge. This locking wedge is fixed on servo motor shaft and normally in unlocked condition. Once getting instruction from Arduino controller the shaft of the servo motor rotates 90^0 clockwise and locking wedge reaches to lock position (Figure 3-5).

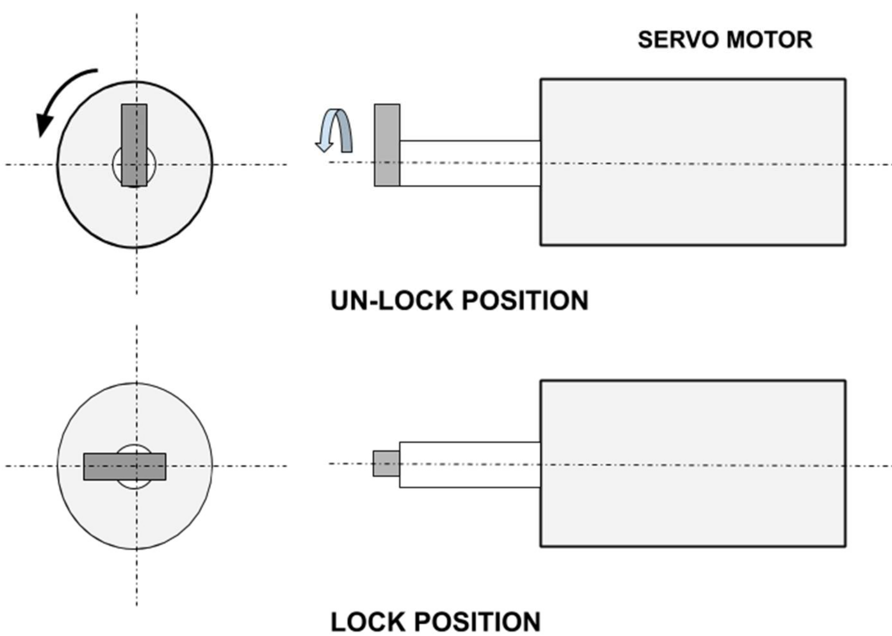


Figure 3-5 Schematic of the Locking and Unlocking process of IoT based LOTO device system.

3.7 Chapter Summary

IoT based LOTO device was developed using design principle and steps with standard components like Arduino, GSM and other components for 230V AC electrical energy. The trial of this device was planned, and data was collected as described in the next chapter.

Chapter 4. Analysis of Experimental Data (Case Study-1)

4.1 Chapter Overview

IoT based devices works with internet network. Experiments were conducted of the developed IoT based device at different conditions. These conditions and data collected and analysed are explained in this chapter.

4.2 Plan for Experiment and Data Collection

Data Collection were planned in 2 phases. Phase 1 were planned in April-2018 and Phase-2 were planned in August-2019. These phases were considered as Case Study-1 and Case Study-2.

Most important factor of IoT based LOTO device is actuation time. The SMS must reach within standard/defined time and actuation must happen within standard/defined time.

a) Place of Experiment- Makino Machine, Transmission Line

b) Duration of Experiment for data collection

- 02-Apr-2018, 120 readings
- 03-Apr-2018, 120 readings
- 04-Apr-2018, 120 readings
- 05-Apr-2018, 120 readings
- 09-Apr-2018, 120 readings
- 16-Apr-2018, 120 readings
- 17-Apr-2018, 120 readings
- 18-Apr-2018, 120 readings

C) Location of IoT based LOTO device

- Indoor or Shop Floor-The indoor area has many other communication devices, equipment, machineries, power tools, press machines & working personnel. Most of the LOTO devices are used in this area.

- Basement- The basement is 12 feet below ground i.e., underground level to check the functioning of IoT based device. Some critical machines and equipment are used in the area which has LOTO device.

- Outdoor- The outdoor is open to sky area with no roofs. The area may have LOTO device based on the application.

D) Network Operators- Being IoT based device the network is one of the important factors. (There are 3 leading telecom network operators, who has been considered and their SIM has been used on the LOTO device)

- Operator No. A-This network operator has good presence and good service support

- Operator No. B- This network operator has good presence.

- Operator No. C- This network operator is upcoming and low cost.

(E) Network Signal Strength (Figure 4-1)-Being IoT based device, network strength is very important factor. Signal is usually measured in dBm [48],

- dBm is the power ratio in decibels of the radio power per milli-watt, a signal of -60dBm is nearly perfect and -112dBm is call dropping badly. Above -87dBm android mobile phone shows full 4 bars of signal[49]

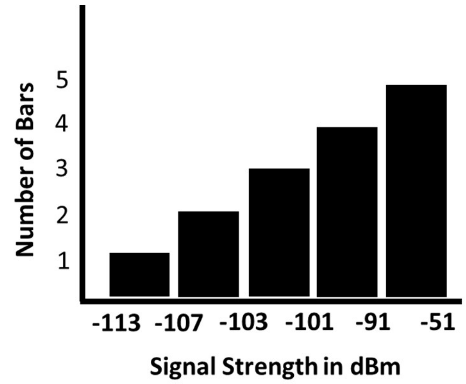


Figure 4-1 Signal Strength Mapping with No. of Bars

- Arbitrary Strength Unit (ASU) is an integer value proportional to the received signal strength measured by the mobile phone (Table 4-1).

- ASU maps to (ASU - 141) ≤ dBm < (ASU - 140).

Table 4-1 Various factors of an experiment of an IoT based LOTO device

Network Strength-Number of Tower	Network Strength-dBm	Network Strength – ASU	Practical Impact on Communication
1	-107 to -113	27 to 33	Very Poor- Call Drop
2	-103 to -106	34 to 37	Poor
3	-101 to -102	38 to 39	Average
4	-91 to -100	40 to 49	Good
5	-51 to -90	50 to 89	Excellent

(F) Voltage Level- The developed IoT based device needs power supply for actuation. The voltage has been measured from 220-240V AC.

(G) Actuation Time- The time was noted down as start time and finish time and later difference were calculated

- Start Time- When LOTO user authorise by press/touch button on phone to send message

- Finish Time- When the actuation “physically” happens at the IoT based LOTO device.

- Actuation Time- This is difference between start and finish time measured in seconds.

4.3 Data Collection and Analysis of IoT based LOTO device.

The researcher has collected data in April 2018 for IoT based LOTO device on various parameters

4.4 Data Collection Parameters

- Location
- Date
- Start Time
- Finish Time
- Total Actuation Time in Seconds
- Voltage Level in Volts
- Name of Network Operator
- Signal Strength in dBm
- Signal Strength in ASU
- Signal Strength in number of Tower Bar

4.5 Data Analysis for Descriptive Statistics

Collected data were analysed for IoT device actuation time and descriptive statistics (Table 4-2)

- Actuation time in Seconds (difference of start and finish time)
- Minimum
- Maximum
- Sum
- Count
- Mean or Arithmetic Mean or Average
- Median
- Mode
- Standard Deviation (Measures of Dispersion)
- Sample Variance (Measures of Dispersion)
- Kurtosis and Skewness (Measures of Dispersion)
- Range (Measures of Dispersion)
- Confidence Level (95%)
- R-Square Value
- Regression Equation

Table 4-2 Data Collection in tabular form for actuation time of an IoT based LOTO device

Sl. No.	*Date*	*Start Time*	*Finish Time*	*Input Voltage (V)*	*Network Operato r*	*Network Signal dBm*	*Network Signal ASU*	*Network Signal No. of Bar*	*Total Time (Sec)*	*Location*
1	02 April 2018	10.02	10.02.23	230	A	-60	80	5	23	SF (Shop Floor)
2	02 April 2018	10.04	10.04.22	231	A	-60	80	5	22	SF(Shop Floor)
3	02 April 2018	10.06	10.06.23	230	A	-60	80	5	23	SF(Shop Floor)
4	02 April 2018	10.08	10.08.22	230	A	-60	80	5	22	SF(Shop Floor)
5	02 April 2018	10.10	10.10.22	230	A	-60	80	5	22	SF(Shop Floor)

Sl. No.	*Date*	*Start Time*	*Finish Time*	*Input Voltage (V)*	*Network Operator*	*Network Signal dBm*	*Network Signal ASU*	*Network Signal No. of Bar*	*Total Time (Sec)*	*Location*
6	02 April 2018	10.12	10.12.22	230	A	-58	82	5	22	SF(Shop Floor)
7	02 April 2018	10.14	10.14.22	230	A	-91	49	4	22	SF(Shop Floor)
8	02 April 2018	10.16	10.16.23	230	A	-60	80	5	23	SF(Shop Floor)
9	02 April 2018	10.18	10.18.24	230	A	-60	80	5	24	SF(Shop Floor)
10	02 April 2018	10.20	10.20.22	230	A	-60	80	5	22	SF(Shop Floor)
11	02 April 2018	10.22	10.22.22	230	A	-60	80	5	22	SF(Shop Floor)
12	02 April 2018	10.24	10.24.22	230	A	-60	80	5	22	SF(Shop Floor)
13	02 April 2018	10.26	10.26.22	230	A	-60	80	5	22	SF(Shop Floor)
14	02 April 2018	10.28	10.28.22	230	A	-60	80	5	22	SF(Shop Floor)
15	02 April 2018	10.30	10.30.22	230	A	-60	80	5	22	SF(Shop Floor)
16	02 April 2018	10.32	10.32.22	230	A	-60	80	5	22	SF(Shop Floor)
17	02 April 2018	10.34	10.34.22	232	A	-60	80	5	22	SF(Shop Floor)
18	02 April 2018	10.36	10.36.23	231	A	-91	49	4	23	SF(Shop Floor)
19	02 April 2018	10.38	10.38.22	230	A	-60	80	5	22	SF(Shop Floor)
20	02 April 2018	10.40	10.40.22	230	A	-60	80	5	22	SF(Shop Floor)

Sl. No.	Date	Start Time	Finish Time	Input Voltage (V)	Network Operator	Network Signal dBm	Network Signal ASU	Network Signal No. of Bar	Total Time (Sec)	Location
21	02 April 2018	10.42	10.42.22	230	A	-60	80	5	22	SF(Shop Floor)
22	02 April 2018	10.44	10.44.22	230	A	-60	80	5	22	SF(Shop Floor)
23	02 April 2018	10.46	10.46.22	231	A	-60	80	5	22	SF(Shop Floor)
24	02 April 2018	10.48	10.48.22	230	A	-60	80	5	22	SF(Shop Floor)
25	02 April 2018	10.50	10.50.22	232	A	-60	80	5	22	SF(Shop Floor)
26	02 April 2018	10.52	10.52.23	230	A	-60	80	5	23	SF(Shop Floor)
27	02 April 2018	10.54	10.54.22	230	A	-60	80	5	22	SF(Shop Floor)
28	02 April 2018	10.56	10.56.22	230	A	-55	85	5	22	SF(Shop Floor)
29	02 April 2018	10.58	10.58.22	233	A	-60	80	5	22	SF(Shop Floor)
30	02 April 2018	11.30	11.30.22	233	A	-60	80	5	22	SF(Shop Floor)

4.6 Descriptive Statistics for different conditions

Condition-1 Network Operator-A and Location –Shop Floor or Indoor (Table 4-3)

Condition-2 Network Operator-A and Location –Outdoor (Table 4-3)

Condition-3 Network Operator-A and Location –Basement (Table 4-3)

Table 4-3 Descriptive statistics for Network Operator-A at Condition 1, 2 and 3(Left to Right)

Description	Value
Mean	22.60
Standard Error	0.06
Median	22.50
Mode	22.00
Standard Deviation	0.67
Sample Variance	0.44
Kurtosis	-0.60
Skewness	0.67
Range	2.00
Minimum	22.00
Maximum	24.00
Sum	2712.00
Count	120.00
Confidence Level(95.0%)	0.12

Description	Value
Mean	22.44
Standard Error	0.05
Median	22.00
Mode	22.00
Standard Deviation	0.58
Sample Variance	0.33
Kurtosis	1.86
Skewness	1.17
Range	3.00
Minimum	22.00
Maximum	25.00
Sum	2693.00
Count	120.00
Confidence Level(95.0%)	0.10

Description	Value
Mean	25.86
Standard Error	0.04
Median	26.00
Mode	26.00
Standard Deviation	0.45
Sample Variance	0.21
Kurtosis	4.35
Skewness	-0.02
Range	3.00
Minimum	25.00
Maximum	28.00
Sum	3103.00
Count	120.00
Confidence Level(95.0%)	0.08

- Condition-4 Network Operator-B and Location –Shop Floor or Indoor (Table 4-4)
- Condition-5 Network Operator-B and Location –Outdoor (Table 4-4)
- Condition-6 Network Operator-B and Location –Basement (Table 4-4)

Table 4-4 Descriptive statistics for Network Operator-B at Condition 4, 5 and 6(Left to Right)

Description	Value
Mean	24.18
Standard Error	0.07
Median	24.00
Mode	24.00
Standard Deviation	0.72
Sample Variance	0.52
Kurtosis	8.43
Skewness	2.64
Range	4.00
Minimum	23.00
Maximum	27.00
Sum	2901.00
Count	120.00
Confidence Level(95.0%)	0.13

Description	Value
Mean	23.23
Standard Error	0.09
Median	23.00
Mode	23.00
Standard Deviation	1.03
Sample Variance	1.07
Kurtosis	4.96
Skewness	2.15
Range	5.00
Minimum	22.00
Maximum	27.00
Sum	2788.00
Count	120.00
Confidence Level(95.0%)	0.19

Description	Value
Mean	23.46
Standard Error	0.11
Median	23.00
Mode	23.00
Standard Deviation	1.15
Sample Variance	1.33
Kurtosis	3.04
Skewness	1.72
Range	6.00
Minimum	22.00
Maximum	28.00
Sum	2815.00
Count	120.00
Confidence Level(95.0%)	0.21

- Condition-7 Network Operator-C and Location –Shop Floor or Indoor (Table 4-5)
- Condition-8 Network Operator-C and Location –Outdoor (Table 4-5)
- Condition-9 Network Operator-C and Location –Basement (Table 4-5)

Table 4-5 Descriptive Statistics for Network Operator-C at Condition 7, 8 and 9 (Left to Right)

Description	Value
Mean	22.40
Standard Error	0.09
Median	22.00
Mode	22.00
Standard Deviation	1.02
Sample Variance	1.05
Kurtosis	6.48
Skewness	2.66
Range	5.00
Minimum	22.00
Maximum	27.00
Sum	2688.00
Count	120.00
Confidence Level(95.0%)	0.19

Description	Value
Mean	22.98
Standard Error	0.03
Median	23.00
Mode	23.00
Standard Deviation	0.34
Sample Variance	0.12
Kurtosis	13.79
Skewness	1.00
Range	3.00
Minimum	22.00
Maximum	25.00
Sum	2758.00
Count	120.00
Confidence Level(95.0%)	0.06

Description	Value
Mean	24.23
Standard Error	0.06
Median	24.00
Mode	24.00
Standard Deviation	0.68
Sample Variance	0.46
Kurtosis	5.55
Skewness	2.30
Range	4.00
Minimum	23.00
Maximum	27.00
Sum	2907.00
Count	120.00
Confidence Level(95.0%)	0.12

All these descriptive statistics observations for different conditions has been summarised in a tabular form (Table 4-6)

Table 4-6 Descriptive Statistics for various conditions

Descriptive Statistics	*Op-A_Loc-SF*	*Op-A_Loc-OD*	*Op-A_Loc-Base*	*Op-B_Loc-SF*	*Op-B_Loc-OD*	*Op-B_Loc-Base*	*Op-C_Loc-SF*	*Op-C_Loc-OD*	*Op-C_Loc-Base*
	Condition-1	*Condition-2*	*Condition-3*	*Condition-4*	*Condition-5*	*Condition-6*	*Condition-7*	*Condition-8*	*Condition-9*
Minimum	22.00	22.00	25.00	23.00	22.00	22.00	22.00	22.00	23.00
Maximum	24.00	25.00	28.00	27.00	27.00	28.00	27.00	25.00	27.00
Sum	2712.00	2693.00	3103.00	2901.00	2788.00	2815.00	2688.00	2758.00	2907.00
Count	120	120	120	120	120	120	120	120	120
Arithmetic Mean	22.60	22.44	25.86	24.18	23.23	23.46	22.40	22.98	24.23
Median	22.50	22.00	26.00	24.00	23.00	23.00	22.00	23.00	24.00
Mode	22.00	22.00	26.00	24.00	23.00	23.00	22.00	23.00	24.00

Descriptive Statistics	*Op-A_Loc-SF*	*Op-A_Loc-OD*	*Op-A_Loc-Base*	*Op-B_Loc-SF*	*Op-B_Loc-OD*	*Op-B_Loc-Base*	*Op-C_Loc-SF*	*Op-C_Loc-OD*	*Op-C_Loc-Base*
	Condition-1	*Condition-2*	*Condition-3*	*Condition-4*	*Condition-5*	*Condition-6*	*Condition-7*	*Condition-8*	*Condition-9*
Standard Error	0.06	0.05	0.04	0.07	0.09	0.11	0.09	0.03	0.06
Standard Deviation	0.67	0.58	0.45	0.72	1.03	1.15	1.02	0.34	0.68
Sample Variance	0.44	0.33	0.21	0.52	1.07	1.33	1.05	0.12	0.46
Kurtosis	-0.60	1.86	4.35	8.43	4.96	3.04	6.48	13.79	5.55
Skewness	0.67	1.17	-0.02	2.64	2.15	1.72	2.66	1.00	2.30
Range	2.00	3.00	3.00	4.00	5.00	6.00	5.00	3.00	4.00
Confidence Level(95.0%)	0.12	0.10	0.08	0.13	0.19	0.21	0.19	0.06	0.12

4.7 Relationship between Actuation Time and Network Signal Strength for different conditions.

IoT based LOTO device had an actuator, the actuator does lock and unlock of the device and takes time in this actuation termed as actuation time. This actuation time may vary based on the network signal strength. Correlation analysis between actuation time and network signal strength was done for various locations and with different network operators. The analysis shown in the (Table 4-7) explains that the better network strength gives a quicker actuation.

Table 4-7 Regression Analysis at Different Condition

Trial Condition	Location of IoT device	Network Operator	Regression Equation
1	Shopfloor or Indoor	A	$y = -1.4034x + 29.412$ $R^2 = 0.2918$
2	Outdoor	A	$y = -1.4034x + 29.412$ $R^2 = 0.2918$
3	Basement	A	$y = -0.9462x + 29.777$ $R^2 = 0.6769$
4	Shop-floor or Indoor	B	$y = -1.2414x + 28.902$ $R^2 = 0.7687$

Trial Condition	Location of IoT device	Network Operator	Regression Equation
5	Outdoor	B	y = -1.8415x + 32.103 R^2 = 0.8504
6	Basement	B	y = -0.6933x + 26.208 R^2 = 0.3346
7	Shopfloor or Indoor	C	y = -1.5813x + 30.017 R^2 = 0.8008
8	Outdoor	C	y = -0.299x + 24.451 R^2 = 0.0896
9	Basement	C	y = -1.0402x + 29.201 R^2 = 0.874

4.8 Data Collection and Analysis of Safety Incidents on a Machine before and after implementation of IoT based LOTO device.

The researcher has collected data of various safety incidents and machine stoppages from May 2011 to April 2018 on Makino CNC Machine (Model A81) for Gear Box Machining; In May 2018, the researcher applied IoT based LOTO device on this machine and collected data again from May 2018 to April 2019 to understand the effectiveness of IoT based LOTO devices on the system.

4.8.1.1 Time Period

- Before Period May 2011- April 2018 Machine was with Conventional LOTO device.
- After Period May 2018- April 2019 Machine was with IoT based LOTO device.

4.8.1.2 Nature of Accident or Safety Incident

- Minor injuries [50] requiring only first aid treatment and which do not involve medical treatment, loss of consciousness, restriction of work or motion, or transfer to another job.
- Major injuries or Severe Injuries are non-fatal but severe injuries. They are defined by: Nature of injury, Part of the body injured, Incident type &

Duration of medical leave. Examples include Amputation, Blindness, Deafness, Paralysis, Crushing, fractures and dislocations: head, back, chest and abdomen, neck, hip and pelvis, Exposure to electric current, Asphyxia or drowning, Hypothermia etc.

- Near Miss- a person is just saved from the accident.

4.8.1.3 Descriptions of the Problem where LOTO Process adherence

- Descriptions of the problems where LOTO applied, and processes were adhered

- Descriptions of the problems where LOTO processes were not adhered

4.8.1.4 Descriptions of the Hazardous Energies where LOTO Process adherence

- There are many hazardous energies available on the machine in case of any problem the person needs to perform LOTO based on the nature of the problem and applicable hazardous energies. The person needs to perform his work based on the identified standardized operating procedure.

- Hazardous Energy-1, This is the primary energy where LOTO is applied.

- Hazardous Energy-2, This is the secondary energy where LOTO is applied.

4.8.2 Details of the Accidents or Safety Incidents

All the safety incidents whether minor injuries, major injuries, near-misses, and accidents has been noted down (Table 4-8) and analysed for their possible root causes. Corrective and Preventive actions are also taken based on the incident analysis [51]. These safety incidents were analysed for the period May 2011 to April 2019 to understand effect of IoT based LOTO device implementation on safety incidents.

Table 4-8 Data Collection Sheet for Safety Incidence from May 2011-April 2019

Parameter No.	*Description of Parameters in data collection sheet*	*Details filled in the data collection sheet*
1	Serial Number	1
2	Date Started	23 May 2011
3	Duration	May 2011- April 2019
4	Description of Machine Problem where Service, Repair, Maintenance required	Door Opening Problem-Improper, Jerks are observed at ends.
5	Type of Hazardous Energy-1 to be controlled	Electrical
6	Type of Hazardous Energy-2 to be controlled	Gravity
7	No of times Conventional LOTO applied	1
8	No of Times IoT based LOTO applied	0
9	No of Times LOTO not adhered	1
10	Time Taken in LOTO Implementation (Minutes)	12
11	No. of Safety Incidents (Injuries, Near-Miss & Accidents)	1
12	Description of Safety Incident-1	Near Miss- Finger Pinching Right Hand First Finger
13	Possible Causes of Safety Incident-1	1.Pnuematic LOTO Not followed, 2. Trapped air in the system was not released, LOTO procedure were not followed.
14	Corrective and Preventive Action for Safety Incident-1	1. LOTO Adherence Audit 2.LOTO Retraining

4.8.3 Details of the hazardous energies to be controlled on the machine for various repair, service and or maintenance work.

Machine had many hazardous energies like Electrical, Pneumatics, Hydraulics and Gravity. LOTO device to be applied to control these hazardous energies whenever any service and or repair related problem occurred on the machine or even during preventive maintenance [52]. Data Collected (Table 4-9) on the machine from May 2011-April 2019 and various hazardous energies associated with the service/repair problem. Machine was having conventional LOTO device during May 2011-April 2018. IoT based LOTO device was implemented in May 2018.

Table 4-9 Number of service/repair problems on the machine between May 2011-April 2019.

Sl. No.	Type of Hazardous Energy to Control	No. of Repair/Service Problems for LOTO application
1	Electrical	98
2	Pneumatics	55
3	Hydraulics	41
4	Gravity	16

4.8.4 Details of the Safety Incidents and LOTO procedure adherence

LOTO must be applied on the machine while working for service, repair, or maintenance. There were safety incidents (Table 4-10) on the machine-like minor injuries, major injuries and near-misses during repair, maintenance, or service of the machine. Data were collected from May 2011-April 2019 for all the cases where LOTO procedures were followed and conventional LOTO were applied. The data were also taken for the cases where LOTO were not applied.

Table 4-10 Summary Table of Safety Incidents from May 2011-April-2019

Time Period of the incident	*No. of Safety Incident*	*No of Times Conventional LOTO applied*	*No of Times LOTO procedure not adhered*	*Time taken in LOTO Implementation (Minutes)*
May 2011-April 2012	8	29	8	346
May 2012-April 2013	9	27	3	308
May 2013-April 2014	7	29	3	346
May 2014-April 2015	6	25	4	301
May 2015-April 2016	5	28	2	315
May 2016-April 2017	7	21	2	229
May 2017-April 2018	5	21	3	246
May 2018-April 2019	0	23	0	134

4.9 Chapter Summary

The data was collected from the trial and experiment of the developed device and analysed for their dependence on the network strength, safety incident with conventional LOTO device and IoT based device. IoT based LOTO device was useful in safety enhancement and reduction in LOTO time. The developed IoT device were kept in trial for 1 year and data were collected again in August 2019 for sustainability and reliability of the device. Detailed Analysis of data collected has been described in the next chapter.

Chapter 5. Analysis of Experimental Data (Case Study-2)

5.1 Chapter Overview

IoT based LOTO device was applied in April 2018 and data were collected again in August 2019 to understand and analyse functioning of IoT based device and its usefulness over conventional LOTO device. Experiments were conducted of the developed IoT based device at different conditions. These conditions and data collected and analysed are explained in this chapter.

5.2 Plan for Experiment and Data Collection for Case Study-2

IoT based LOTO device was implemented in May 2018. The researcher has performed one more study and collected data in the month of August 2019 to check the effectiveness of the IoT based LOTO device.

Data were collected with the same conditions to maintain the similarity. Most important factor of IoT based LOTO device is actuation time. The SMS must reach within standard/defined time and actuation must happen within standard/defined time.

a) Duration of Experiment for data collection

- 14-August-2019, 16 Months after IoT based LOTO device implementation

b) Location of IoT based LOTO device

- Indoor or Shop Floor
- Basement
- Outdoor

c) Network Operators

d) Network Signal Strength (Figure 4-1) Being IoT based device, network strength is very important factor. Signal is usually measured in dBm,

5.3 Data Collection and Analysis of IoT based LOTO device for Case Study-2

The researcher has collected data again in August 2019 for IoT based LOTO device on various parameters.

5.4 Data Collection Parameters

- Location
- Date
- Start Time
- Finish Time
- Total Actuation Time in Seconds
- Voltage Level in Volts
- Name of Network Operator
- Signal Strength in dBm
- Signal Strength in ASU
- Signal Strength in number of Tower Bar

5.5 Data Analysis for Descriptive Statistics

Collected data were analysed for IoT device actuation time and descriptive statistics (Table 5-1)

- Actuation time in Seconds (difference of start and finish time)
- Minimum
- Maximum
- Sum
- Count
- Mean or Arithmetic Mean or Average (Measure of Central Tendency)
- Median
- Mode
- Standard Deviation
- Sample Variance (Measures of Dispersion)
- Kurtosis (Measures of Dispersion)
- Skewness (Measures of Dispersion)
- Range (Measures of Dispersion)
- Confidence Level (95%)
- R-Square Value
- Regression Equation

Table 5-1 Data Collected after Implementation of IoT based LOTO device

Sl. No.	Date	Start Time	Finish Time	Input Voltage (V)	Network Operator	Network Signal dBm	Network Signal ASU	Network Signal No. of Bar	Total Time (Sec)	Location
1	14 August 2019	08.10.00	08.10.22	231	A	-60	80	5	22	SF(Shop Floor)
2	14 August 2019	08.12.02	08.12.22	231	A	-60	80	5	22	SF(Shop Floor)
3	14 August 2019	08.14.00	08.14.22	230	A	-60	80	5	22	SF(Shop Floor)
4	14 August 2019	08.16.00	08.16.22	230	A	-60	80	5	22	SF(Shop Floor)
5	14 August 2019	08.18.00	08.18.22	230	A	-60	80	5	22	SF(Shop Floor)
6	14 August 2019	08.21.00	08.21.22	230	A	-60	80	5	22	SF(Shop Floor)
7	14 August 2019	08.23.00	08.23.22	230	A	-60	80	5	22	SF(Shop Floor)
8	14 August 2019	08.26.00	08.26.22	230	A	-60	80	5	22	SF(Shop Floor)
9	14 August 2019	08.28.00	08.28.22	230	A	-60	80	5	22	SF(Shop Floor)
10	14 August 2019	08.31.00	08.31.23	230	A	-91	49	4	23	SF(Shop Floor)
11	14 August 2019	08.35.00	08.35.22	230	A	-60	80	5	22	SF(Shop Floor)
12	14 August 2019	08.37.00	08.37.22	230	A	-60	80	5	22	SF(Shop Floor)
13	14 August 2019	08.40.00	08.40.23	230	A	-60	80	5	23	SF(Shop Floor)
14	14 August 2019	08.42.00	08.42.22	230	A	-60	80	5	22	SF(Shop Floor)
15	14 August 2019	08.44.00	08.44.22	230	A	-55	85	5	22	SF(Shop Floor)
16	14 August 2019	08.46.00	08.46.22	230	A	-60	80	5	22	SF(Shop Floor)
17	14 August 2019	08.48.00	08.48.22	231	A	-60	80	5	22	SF(Shop Floor)
18	14 August 2019	08.51.04	08.51.23	231	A	-60	80	5	23	SF(Shop Floor)
19	14 August 2019	08.54.00	08.54.22	230	A	-60	80	5	22	SF(Shop Floor)
20	14 August 2019	08.56.00	08.56.23	230	A	-60	80	5	23	SF(Shop Floor)
21	14 August 2019	09.01.00	09.01.22	230	A	-60	80	5	22	SF(Shop Floor)
22	14 August 2019	09.04.00	09.04.22	230	A	-60	80	5	22	SF(Shop Floor)
23	14 August 2019	09.06.00	09.06.22	230	A	-60	80	5	22	SF(Shop Floor)
24	14 August 2019	09.06.00	09.06.23	230	A	-60	80	5	22	SF(Shop Floor)
25	14 August 2019	09.08.00	09.08.22	232	A	-60	80	5	22	SF(Shop Floor)
26	14 August 2019	09.10.00	09.10.22	230	A	-58	82	5	22	SF(Shop Floor)
27	14 August 2019	09.12.00	09.12.22	230	A	-91	49	4	22	SF(Shop Floor)
28	14 August 2019	09.14.00	09.14.23	230	A	-60	80	5	23	SF(Shop Floor)
29	14 August 2019	09.16.00	09.16.24	232	A	-60	80	5	24	SF(Shop Floor)
30	14 August 2019	09.18.00	09.18.22	231	A	-60	80	5	22	SF(Shop Floor)

A snapshot of the data collected in a tabular form after a year of IoT based LOTO implementation shown and were further analysed for different conditions using voltage, network operator, signal strength and locations.

5.6 Descriptive Statistics for different conditions

- Condition-1 Network Operator-A and Location –Shop Floor or Indoor (Table 5-2)
- Condition-2 Network Operator-A and Location –Outdoor (Table 5-2)
- Condition-3 Network Operator-A and Location –Basement (Table 5-2)

Table 5-2 Descriptive Statistics for Network Operator-A at Condition 1, 2 and 3 (Left to Right)

Description	Value
Mean	22.23
Standard Error	0.09
Median	22.00
Mode	22.00
Standard Deviation	0.50
Sample Variance	0.25
Kurtosis	4.25
Skewness	2.15
Range	2.00
Minimum	22.00
Maximum	24.00
Sum	667.00
Count	30.00
Confidence Level(95.0%)	0.19

Description	Value
Mean	22.20
Standard Error	0.09
Median	22.00
Mode	22.00
Standard Deviation	0.48
Sample Variance	0.23
Kurtosis	6.06
Skewness	2.50
Range	2.00
Minimum	22.00
Maximum	24.00
Sum	666.00
Count	30.00
Confidence Level(95.0%)	0.18

Description	Value
Mean	26.03
Standard Error	0.08
Median	26.00
Mode	26.00
Standard Deviation	0.41
Sample Variance	0.17
Kurtosis	19.95
Skewness	3.39
Range	3.00
Minimum	25.00
Maximum	28.00
Sum	781.00
Count	30.00
Confidence Level(95.0%)	0.15

- Condition-4 Network Operator-B and Location –Shop Floor or Indoor (Table 5-3)
- Condition-5 Network Operator-B and Location –Outdoor (Table 5-3)
- Condition-6 Network Operator-B and Location –Basement (Table 5-3)

Table 5-3 Descriptive statistics for Network Operator-B at Condition 4, 5 and 6(Left to Right)

Description	Value
Mean	24.13
Standard Error	0.10
Median	24.00
Mode	24.00
Standard Deviation	0.57
Sample Variance	0.33
Kurtosis	23.77
Skewness	4.78
Range	3.00
Minimum	24.00
Maximum	27.00
Sum	724.00
Count	30.00
Confidence Level(95.0%)	0.21

Description	Value
Mean	23.20
Standard Error	0.15
Median	23.00
Mode	23.00
Standard Deviation	0.81
Sample Variance	0.65
Kurtosis	18.77
Skewness	4.28
Range	4.00
Minimum	23.00
Maximum	27.00
Sum	696.00
Count	30.00
Confidence Level(95.0%)	0.30

Description	Value
Mean	23.47
Standard Error	0.16
Median	23.00
Mode	23.00
Standard Deviation	0.90
Sample Variance	0.81
Kurtosis	7.57
Skewness	2.54
Range	4.00
Minimum	23.00
Maximum	27.00
Sum	704.00
Count	30.00
Confidence Level(95.0%)	0.34

- Condition-7 Network Operator-C and Location –Shop Floor or Indoor (Table 5-4)
- Condition-8 Network Operator-C and Location –Outdoor (Table 5-4)
- Condition-9 Network Operator-C and Location –Basement (Table 5-4)

Table 5-4 Descriptive Statistics for Network Operator-C at Condition 7, 8 and 9(Left to Right)

Description	Value
Mean	22.70
Standard Error	0.25
Median	22.00
Mode	22.00
Standard Deviation	1.37
Sample Variance	1.87
Kurtosis	3.04
Skewness	1.97
Range	5.00
Minimum	22.00
Maximum	27.00
Sum	681.00
Count	30.00
Confidence Level(95.0%)	0.51

Description	Value
Mean	23.07
Standard Error	0.08
Median	23.00
Mode	23.00
Standard Deviation	0.45
Sample Variance	0.20
Kurtosis	13.27
Skewness	2.77
Range	3.00
Minimum	22.00
Maximum	25.00
Sum	692.00
Count	30.00
Confidence Level(95.0%)	0.17

Description	Value
Mean	24.77
Standard Error	0.20
Median	24.00
Mode	24.00
Standard Deviation	1.07
Sample Variance	1.15
Kurtosis	1.52
Skewness	1.40
Range	4.00
Minimum	24.00
Maximum	28.00
Sum	743.00
Count	30.00
Confidence Level(95.0%)	0.40

All these descriptive statistics observations for different conditions have been summarized in a tabular form (Table 5-5).

Table 5-5 Summary of Descriptive Statistics for various conditions Case Study-2

Descriptive Statistics	Condition-1	Condition-2	Condition-3	Condition-4	Condition-5	Condition-6	Condition-7	Condition-8	Condition-9
	Network Operator A	Network Operator A	Network Operator A	Network Operator B	Network Operator B	Network Operator B	Network Operator C	Network Operator C	Network Operator C
	Shop Floor	Outdoor	Basement	Shop Floor	Outdoor	Basement	Shop Floor	Outdoor	Basement
Arithmetic Mean	22.23	22.20	26.03	24.13	23.20	23.47	22.70	23.07	24.77
Standard Error	0.09	0.09	0.04	0.07	0.09	0.11	0.09	0.03	0.20
Median	22.00	22.00	26.00	24.00	23.00	23.00	22.00	23.00	24.00
Mode	22.00	22.00	26.00	24.00	23.00	23.00	22.00	23.00	24.00
Standard Deviation	0.50	0.48	0.41	0.57	0.81	0.90	1.37	0.45	1.07
Sample Variance	0.25	0.23	0.17	0.33	0.65	0.81	1.87	0.20	1.15
Kurtosis	4.25	6.06	19.95	23.77	18.77	7.57	3.04	13.27	1.52
Skewness	2.15	2.50	3.39	4.78	4.28	2.54	1.97	2.77	1.40
Range	2.00	2.00	3.00	3.00	4.00	4.00	5.00	3.00	4.00
Minimum	22.00	22.00	25.00	24.00	23.00	23.00	22.00	22.00	24.00
Maximum	24.00	24.00	28.00	27.00	27.00	27.00	27.00	25.00	28.00
Sum	667.00	666.00	781.00	724.00	696.00	704.00	681.00	692.00	743.00
Count	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
Confidence Level(95.0%)	0.19	0.18	0.15	0.21	0.30	0.34	0.51	0.17	0.40

A snapshot of the analysis of collected data in a tabular form after a year of IoT based LOTO implementation shown with descriptive statistics for different conditions using voltage, network operator, signal strength and locations.

5.7 Relationship between Actuation Time and Network Signal Strength for different conditions

IoT based LOTO device had an actuator, the actuator does lock and unlock of the device and takes time in this actuation termed as actuation time. This actuation time may vary based on the network signal strength. Correlation analysis between actuation time and network signal strength was done for various locations and with different network operators. The correlation analysis confirmed the functioning of IoT based LOTO device.

The analysis shows reliability of the developed IoT based LOTO device. The researcher could not find any malfunction in 1080 readings (Case Study-1), 270 readings (Case Study-2) and IoT based LOTO device works best when network signal strength is good.

5.8 Chapter Summary

The data was collected from both the trials (April 2018 and August 2019) of developed device and were analysed for their dependence on the network strength, safety incident with conventional LOTO device and IoT based device. The developed IoT based device was useful in safety enhancement and reduction in LOTO time. The results have been described in the next chapter.

Chapter 6. Results and Analysis

6.1 Chapter Overview

This chapter explains about results achieved trial of IoT based LOTO devices, its relationship with network strength, LOTO implementation time and prevention of safety incidents.

6.2 Results from Trial and Experiment

Trials of IoT based LOTO device developed by us for electrical energy and on Circuit Breakers has been conducted on many network conditions, strengths and locations (Table 6-1 and Table 6-2).

Two Case Studies, Case Study-1 in April 2018 and Case Study-2 in August 2019 were conducted on

- Different network operator
- Different locations like indoor or manufacturing shop floor, outdoor and basement
- Different network strength dBm, ASU and on No. of Tower 1-5 (1 weakest and 5 strongest signal)
- Different input voltage condition (220-240V ac)
- 1080 readings were taken to understand reliability of LOTO actuation in Case Study-1.
- 270 readings were taken to understand reliability of LOTO actuation in Case Study-2.

Table 6-1 Descriptive Statistics and R^2 Value of observed data for Case Study No.1

Desc Statistics	Op-A_Loc-SF	Op-A_Loc-OD	Op-A_Loc-Base	Op-B_Loc-SF	Op-B_Loc-OD	Op-B_Loc-Base	Op-C_Loc-SF	Op-C_Loc-OD	Op-C_Loc-Base
Mean	22.60	22.44	25.86	24.18	23.23	23.46	22.40	22.98	24.23
Standard Error	0.06	0.05	0.04	0.07	0.09	0.11	0.09	0.03	0.06
Median	22.50	22.00	26.00	24.00	23.00	23.00	22.00	23.00	24.00
Mode	22.00	22.00	26.00	24.00	23.00	23.00	22.00	23.00	24.00
Standard Deviation	0.67	0.58	0.45	0.72	1.03	1.15	1.02	0.34	0.68
Sample Variance	0.44	0.33	0.21	0.52	1.07	1.33	1.05	0.12	0.46
Kurtosis	-0.60	1.86	4.35	8.43	4.96	3.04	6.48	13.79	5.55
Skewness	0.67	1.17	-0.02	2.64	2.15	1.72	2.66	1.00	2.30
Range	2.00	3.00	3.00	4.00	5.00	6.00	5.00	3.00	4.00
Minimum	22.00	22.00	25.00	23.00	22.00	22.00	22.00	22.00	23.00
Maximum	24.00	25.00	28.00	27.00	27.00	28.00	27.00	25.00	27.00
Sum	2712.00	2693.00	3103.00	2901.00	2788.00	2815.00	2688.00	2758.00	2907.00
Count	120.00	120.00	120.00	120.00	120.00	120.00	120.00	120.00	120.00
Confidence Level(95.0%)	0.12	0.10	0.08	0.13	0.19	0.21	0.19	0.06	0.12
R^2	0.001	0.292	0.677	0.769	0.850	0.335	0.801	0.090	0.874

Table 6-2 Descriptive Statistics and R^2 Value of observed data for Case Study No.2

Desc Statistics	Op-A_Loc-SF	Op-A_Loc-OD	Op-A_Loc-Base	Op-B_Loc-SF	Op-B_Loc-OD	Op-B_Loc-Base	Op-C_Loc-SF	Op-C_Loc-OD	Op-C_Loc-Base
Mean	22.23	22.20	26.03	24.13	23.20	23.47	22.70	23.07	24.77
Standard Error	0.09	0.09	0.08	0.10	0.15	0.16	0.25	0.08	0.20
Median	22.00	22.00	26.00	24.00	23.00	23.00	22.00	23.00	24.00
Mode	22.00	22.00	26.00	24.00	23.00	23.00	22.00	23.00	24.00
Standard Deviation	0.50	0.48	0.41	0.57	0.81	0.90	1.37	0.45	1.07
Sample Variance	0.25	0.23	0.17	0.33	0.65	0.81	1.87	0.20	1.15
Kurtosis	4.25	6.06	19.95	23.77	18.77	7.57	3.04	13.27	1.52
Skewness	2.15	2.50	3.39	4.78	4.28	2.54	1.97	2.77	1.40
Range	2.00	2.00	3.00	3.00	4.00	4.00	5.00	3.00	4.00
Minimum	22.00	22.00	25.00	24.00	23.00	23.00	22.00	22.00	24.00
Maximum	24.00	24.00	28.00	27.00	27.00	27.00	27.00	25.00	28.00
Sum	667.00	666.00	781.00	724.00	696.00	704.00	681.00	692.00	743.00
Count	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
Confidence Level(95.0%)	0.19	0.18	0.15	0.21	0.30	0.34	0.51	0.17	0.40
R^2	0.021	0.493	0.222	0.979	1.000	0.671	0.868	0.750	0.631

6.3 Inference from Data Analysis

6.3.1 Mean Actuation Time (Case Study-1)

Mean Actuation time for all the 9 test conditions was 23.49 Seconds. It means that a LOTO device can be designed considering mean actuation time of 23.49 seconds. This actuation time should be considered while making SOP (Standard Operating Procedure) of LOTO Program.

6.3.2 Mean Actuation Time (Case Study-2)

Mean Actuation time for all the 9 test conditions was 23.53 Seconds. It means that a LOTO device can be designed considering mean actuation time of 23.53 seconds. This actuation time should be considered while making SOP (Standard Operating Procedure) of LOTO Program.

6.3.3 Location of the LOTO device and Network Strength (Case Study-1)

For Network Operator A, it was found that the developed LOTO device has less actuation time & standard deviation at the Shop floor (mean 22.60 seconds and std. dev. 0.67 seconds) and Basement locations (mean 25.86 seconds and std. dev. 0.45 seconds). It means that Operator A can be used for the IoT based LOTO devices for equipment at Shop floor and Basement Location. Operator C can be used for outdoor locations. Network booster can be used to boost the network strength for operator B and C for improved signal strength.

6.3.4 Location of the LOTO device and Network Strength (Case Study-2)

For Network Operator A, it was found that the developed LOTO device has less actuation time & standard deviation at the Shop floor (mean 22.23 seconds and std. dev. 0.50 seconds) and Basement locations (mean 26.03 seconds and std. dev. 0.41 seconds). It means that Operator A can be used for the IoT based LOTO devices for equipment at Shop floor and Basement Location. Operator C can be used for outdoor locations. Network booster can be used to boost the network strength for operator B and C for improved signal strength.

6.4 Result of Experiment on IoT based LOTO device

These results are very encouraging and shows reliability of the developed IoT based LOTO device. The researcher could not find any malfunction in 1080 readings (Case Study-1), 270 readings (Case Study-2) and IoT based LOTO device works best when network signal strength is good.

6.4.1 Reduction in Number Safety Accidents or incidents on machine before and after IoT based LOTO device implementation.

The data collected from the machine before (May 2011-April 2018) and after (May 2018-April 2019) implementation of IoT based LOTO device on Machine with various hazardous energy (Table 6-3) clearly shows that the safety incidents are reduced from “47” numbers to “0” on the machine. The IoT based device is also able to reduce different injuries (Table 6-4) finger (from 10 to 0), hand (from 5 to 0) and arm (from 2 to 0) related minor injuries.

Table 6-3 Number of Safety Incidents Before and After implementation of IoT based LOTO device.

Type of Safety Incident	*Before IoT based LOTO*	*After IoT based LOTO*
	No. of Incidents from May 2011-April 2018	*No. of Incidents from May 2018-April 2019*
Near Miss	30	0
Minor Injury	17	0

Table 6-4 Body parts injured(minor) Before and After implementation of IoT based LOTO device

Type of Safety Incident	*Before IoT based LOTO*	*After IoT based LOTO*
	No. of Incidents from May 2011-April 2018	*No. of Incidents from May 2018-April 2019*
Fingers	10	0
Hand	5	0
Arm	2	0

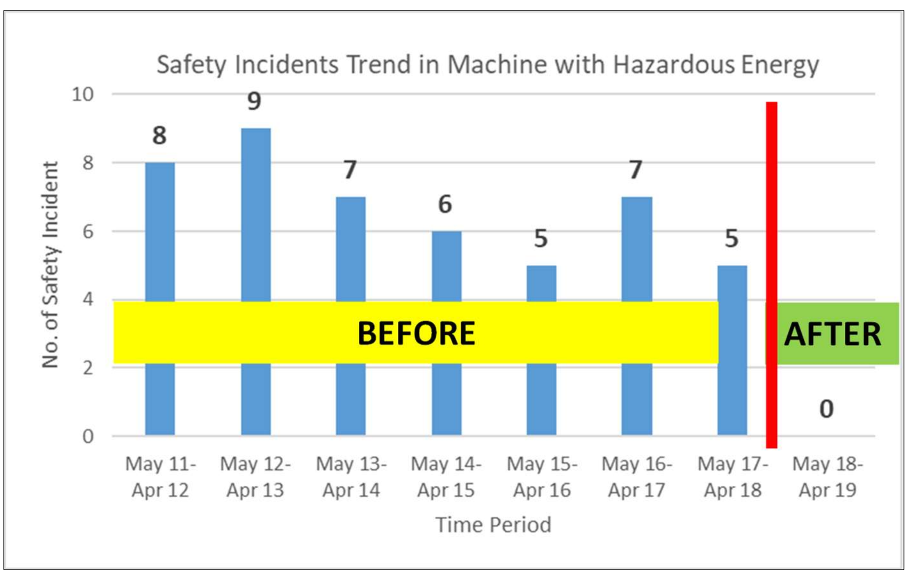


Figure 6-1 Number of safety incidents before and after implementation of IoT based LOTO device.

6.4.2 Reduction in LOTO implementation time on machine before and after IoT based LOTO device implementation.

The data collected from the machine before (May 2011-April 2018) and after (May 2018-April 2019) implementation of IoT based LOTO device on Machine with various hazardous energy (Table 6-5) clearly shows that average LOTO implementation time(seconds) are reduced from 697 to 349 on the machine. Lesser LOTO implementation time improves availability of the machine for more productive work.

Table 6-5 Reduction in LOTO implementation time Before and After implementation of IoT based LOTO device

LOTO Implementation Time	*Before IoT based LOTO*	*After IoT based LOTO*
	Data Collected from May 2011-April 2018	*Data Collected from May 2018-April 2019*
Number of Times LOTO Applied	180 Times	23 Times
Total Time Taken in LOTO Implementation (Minutes)	2091 Minutes	134 Minutes
Average Time Taken in LOTO Implementation (Minutes)	11.6 Minutes	5.8 Minutes
Average Time Taken in LOTO Implementation (Seconds)	697 Seconds	349 Seconds

6.5 Certification from JCB India Limited, Ballabgarh, India after successful trial of IoT based LOTO device

JCB INDIA LIMITED

JCB/HR&IR/AVP/8/19
19th August 2019

TO WHOM SO EVER IT MAY CONCERN

This is to certify that Mr. Sameer Kumar, EIN - 87973, worked with JCB India Ltd from 9th May 2011 to 30th June 2018. He was working as a DGM in Manufacturing Department of the organization.

Mr Sameer Kumar has developed an IOT based LOTO device for control of hazardous energy and improving safety. He has also conducted many trials and results are satisfactory.

This Certificate is not valid in the court of law and has been specifically issued on his request to fulfil the initial requirement of applying for Research work.

The Company shall not be responsible for any claim or liabilities etc. which would arise from or in connection with this certificate in future.

FOR JCB INDIA LIMITED

Subhasish Dasgupta
AVP - Human Resource

JCB India Headquarters/Plant : 23/7, Mathura Road Ballabgarh - 121004 Haryana, India Tel : + 91 129 4299000 Fax : +91 129 4299750 Website: www.jcb.com
Registered Office : B - 1/I - 1, 2nd Floor, Mohan Co-operative Industrial Estate, Mathura Road, New Delhi - 110 044, India, CIN - U74899DL1979PLC009431

Figure 6-2 Authentic Statement Letter from Company JCB India Ltd for data, trial and result.

6.6 Chapter Summary

The developed IoT based device was useful in safety enhancement and reduction in LOTO time. Detailed conclusion and future scope have been described in the next chapter.

Chapter 7. Conclusion and Future Scope

A reliable and robust IoT based LOTO device has been developed for automating the LOTO procedure for 230 V AC electrical devices. The device mainly consists of Power Supply, Microcontroller, GSM SIM Module, Relays, Servo Motors and Switches. The device can be programmed using open source like Arduino IDE. The device gives additional safety to the person as this device gets locked its own (based on the pre-programmed flow) and send text messages to defined person (based on the pre-programmed approval authority) for example- LOTO device gets locked and relevant electrician, supervisor and manager gets automated text message. It is different in a way that the electrician cannot bypass the LOTO procedure as any unauthorized action by him will send an automatic text message to his supervisor and manager. It also makes sure only authorized person can perform LOTO. It also communicates to every authorized person in case of weak network signal or any tempering with the device.

IoT based LOTO device is fast with average response time of 23.48 seconds. It helps electrician in trouble shooting, repair, maintenance or servicing work. It also helps in digital record keeping as data from microcontrollers/sensors can be recorded and verified.

IoT based LOTO device has resulted into reduction in number of accidents and safety incidents, it also helped to reduce LOTO implementation time.

Reduction in accidents and incidents gives safer work environment and lesser LOTO implementation time improves productivity [53].

IoT based LOTO device developed by us is simple, real time, digital, tested for functioning and endurance and verified with respect to present conventional LOTO devices which are customized, non-standard, un-reliable [54] and manual.

The present device has been made mainly for controlling the 230V AC hazardous energy at circuit breakers. Further improvements can be made on the device for other hazardous energies, faster actuation speed and better performance under low network strength conditions [55]. A mobile app(application) can also be developed for Android/iOS/other systems.

IoT enabled M2M Protocols [56] needs to be followed for future work, this work is a proof of concept and any specific M2M protocols were not followed.

There is a possible international work in the area of IoT linked study or mitigation of manufacturing or industrial hazards, this work focuses mainly in Indian context for IoT based LOTO devices.

The researcher is planning to apply for patenting the IoT based LOTO device.

7.1 Benefits and advantages of IoT based LOTO Devices and Procedure.

IoT based LOTO device helps to reduce number of accidents and safety incidents on the machine/equipment.

- IoT based LOTO device helps to reduce LOTO implementation time and improves productivity.
- IoT based LOTO device gets locked on its own (based on the pre-programmed flow) and send text messages to defined person (based on the pre-programmed approval authority) for example- LOTO device gets locked and electrician, supervisor and Manager gets text message.
- Electrician cannot bypass the LOTO procedure as any action by him will send an automatic text message to his supervisor and manager.

- Any other unauthorized person cannot lock/unlock the device or break the IoT based LOTO device, as any action by him/her will send an automatic text message to concerned electrician, supervisor, and manager.
- IoT based LOTO procedure in fast/instant and does not take much time and this fastens the actual trouble shooting, fault finding process.
- Record Keeping is digital/electronic.
- Mode of communication is phone call, SMS based and physical discussion.

7.2 List of Publications

1. Sameer Kumar and Syed Mohammad Tauseef, Development of an Internet of Things (IoT) based Lockout/Tagout (LOTO) device for Accident Prevention in Manufacturing Industries, IOP CONFERENCE SERIES: MATERIALS SCIENCE AND ENGINEERING" (SCOPUS) through iCADMA 2020.

2. Sameer Kumar and Syed Mohammad Tauseef, Analysis of Various Lockout Tagout (LOTO) devices used in Industrial Safety International Journal of Engineering and Technology (IJET), 7, (3,12), (2018),1329-1335 https://www.sciencepubco.com/index.php/ijet/article/view/19894

   Website www.sciencepubco.com/index.php/IJET

3. Sameer Kumar and Syed Mohammad Tauseef, Role of Internet of Things (IOT) based Lockout Tagout (LOTO) Safety Devices in Industrial Safety, International Journal of Computer Engineering and Applications (IJCEA), Volume XII, Special Issue, August 2018, www.ijcea.com ISSN 2321-3469.

4. Sameer Kumar and Syed Mohammad Tauseef, Effectiveness of Conventional LOTO v/s IoT based LOTO in Industrial Safety International Journal of Advance Research in Science and Engineering (IJARSE) ,Volume no 06,Issue No 09,September 2017, ISSN(O) 2319-5354, ISSN(P) 2319-8346, Pages 1370-1376.

www.ijarse.com › images › fullpdf › 1506228642_IETECH4092

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