Development of an Internet of Things (IoT) based Lockout/Tagout (LOTO) device for Accident Prevention in Manufacturing Industries

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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 paper presents the development of an IoT based LOTO device, its implementation and effectiveness in improving safety and accident prevention. It is found that the IoT based LOTO device is effective in accident prevention (from 47 to 0 incidents) and its performance (from 697 to 349 Seconds) is reliable.

1. Introduction

Manufacturing industries has many equipment which require maintenance, repair and service to be done by an individual or a group of persons to make sure that no untoward incident happens during the operation of such equipment. These persons are trained to perform the job with safety and efficiently known as competent person. 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, hydraulics, chemical, pneumatic, potential etc. are used in machines in engineering industries.

1.1. Historical data on Accidental Deaths

Many agencies collect data for different type of accidents, worldwide. National Crime Record Bureau (NCRB) under Ministry of Home Affairs, Government of India 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 [1] and 421,104 in the year 2019 [2]. There were 13,432 deaths due to electrocution and 1001 machinery-related accidental deaths in the year 2019. Similar analysis of accident data available from the Mine Safety and Health Administration (MSHA) was conducted by Ruff et. al. [3] from the NIOSH. Based on the analysis of the accident data Ruff concluded that one-third of these accidents involved improper LOTO procedures as a contributing factor [4]. The MSHA has acknowledged this problem in
their report RIN 1219-AB 91. It is reported that 76% fatalities are involved working near or around belt conveyors, where the mining workers become entangled in belt drives, belt rollers, and discharge points. Factors that were identified as responsible for these accidents were insufficient, inadequate or missing guards and number of crossovers in different 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 [5].

In order to ensure proper implementation of LOTO a number of researchers have explored various solutions like worker-worn electric field sensor [6], 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 [7]. 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. IoT based LOTO device is not in their scope[8]. This paper 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.

2. Research Methodology for Development of IoT based LOTO device
The development of the IoT based LOTO device was done in 3 phases. Selection of the hazardous machines and hazardous energy were done in Phase-1, study of the existing conventional LOTO device and procedure were done in Phase-2 and device with different control technologies were developed in Phase-3. These trials and experiments were planned and carried out at JCB India Limited, Ballabgarh, India Plant.

2.1. Phase-1: Selection of machine and hazardous energy for IoT based LOTO
In this paper, data on safety incidents related to one of the Machine was collected. There were 30 Near Miss and 17 Minor Injury cases in the period of May 2011 to April 2018. Further analysis of these 47 incidents revealed that in 10 cases LOTO procedures were not implemented properly. This Computer Numerical Control (CNC) machine is used to do machining of Gear Box Parts and uses various hazardous energies [9]. In order to work a CNC machine, the machine operator loads the parts into a machine, starts the machine and unloads the parts after machining [10]. Machine operator calls maintenance person for any kind of support whenever the need arises. Maintenance and Service person also apply LOTO during scheduled preventive maintenance and repair work. There are 52 activities identified on this CNC Machine which requires LOTO implementation and procedure adherence. In these 52 activities 67% are electrical, 13% are Hydraulic, 4% Mechanical and 4% Pneumatics [11]. The machine has 16 different types of LOTO devices in which majority 6 are circuit breaker (CB) LOTO device. Out of these 6 CB LOTO devices, there are 4 Miniature Circuit Breakers (MCB) of different ratings, which requires 4 different types of MCB LOTO devices. The above study and data related to CNC Machine reveals complexity of different LOTO activities and devices. Furthermore, Specification and Type of MCB LOTO devices depend on specifications and type of MCBs [12]. Based on the safety incidents and type of hazardous energy, we have selected to develop an IoT based LOTO device for controlling electrical energy on CNC A-81 Makino machine.

2.2. Phase-2: Study and Analysis of conventional LOTO device and procedure for CNC machine
Operation and Maintenance Persons follows LOTO procedures identified and defined by OSHA [13] for maintenance, repair or servicing of machines or equipment [14] as shown in ‘Figure 1’. Data collected on CNC machines from May 2011-June 2018 reveals that LOTO procedures were not adhered mainly in steps of notifying the employees, attaching LOTO device and verifying LOTO.

- Notifying employees: In this step employees working on the machine and or near to the machine was not notified of the operation/maintenance person and safety incident had happened as the persons were not known about the hazardous machines available on the machine.
• Attaching the lockout device: In this step the conventional LOTO devices like padlock were not attached as per procedure and maintenance person was working on the machine thinking that the work will take less time and he will do it without applying LOTO.
• Verifying lockout: In this step maintenance person forgets to verify the lockout for isolation of hazardous energy[15].

![OSHA Standard Number 1910.147 Typical LOTO Procedures](image)

Figure 1. OSHA –Standard Number 1910.147 Typical LOTO Procedures

2.2.1 Limitations and Challenges of Conventional LOTO device and Procedure
- A maintenance / service person has sole responsibility and decision making of putting LOTO device and physical padlock, he/she can bypass and lock or unlock the LOTO device and padlock[16].
- Manager and Supervisor need to visit, see and verify the physical condition of actual padlock at the circuit breaker.
- LOTO procedure takes time (697 seconds as per data collected) and delays the actual trouble shooting and fault-finding process.

2.2.2 Leveraging IoT based LOTO device and procedure to overcome challenges
IoT based devices are being used in industries[17] and IoT based LOTO device can be helpful to Operation and Maintenance Persons in adherence of LOTO procedures identified and defined by OSHA.

2.2.3 Proposed Benefits and advantages of IoT based LOTO Device and Procedure
- The IoT based LOTO device will improve LOTO procedure adherence and reduction in safety incidents.
- It may help to reduce LOTO implementation time and improves productivity.
- Person cannot bypass the LOTO procedure as any action by him will send an automatic text message to his supervisor and manager.
- Any person other than authorized cannot lock/unlock the device or break the IoT based LOTO device, as any action by him/her will send a text message automatically to concerned manager, supervisor and electrician.

2.3. Phase-3 Development of IoT based LOTO device for CNC machine
The proposed device consists of Arduino Mega 2560, Global System for Mobile Communications (GSM) Module, Relay, Transistors, Liquid Crystal Displays (LCD), Transformers, Servo Motor and Mechanical device for carrying out IoT based LOTO Procedure in case of an electrical fault occurs or
need arises[18] as shown in ‘Figure 2’. IoT based communication has also been set up between different
person like electrician, supervisor and managers based on their roles, responsibilities and approval
hierarchy. As soon the fault occurs, complete system consisting of hazardous energy (in our case
electrical energy is hazardous energy) gets locked and real-time message reaches the supervisor and
manager. Since system is locked, it becomes safe to carry out repair work. After completion of the work,
electrician makes a request to his supervisor to unlock the system from his IoT based device (in our case
mobile phone), supervisor unlocks the IoT based LOTO and now electrician can physically switch on
the hazardous energy. Focusing on standardization, ease of understanding and implementation, the
localization of the IoT based device is done by using standard devices like Arduino and GSM modules
which has advantage of being low cost, easily available and widely used over other industrial device
like Programmable Logic Controllers (PLC). The device uses the state-of-the-art technique in IoT based
ON-OFF switching for LOTO.

![Schematic Block Diagram for developing IoT based LOTO device](image)

Figure 2. Schematic Block Diagram for developing IoT based LOTO device

3. Trial of IoT based LOTO Device for Performance, Reliability and Effectiveness
Several tests were performed on the developed IoT based LOTO device as shown in ‘Figure 3’ to find
the effectiveness, performance, and to understand its effect on improving safety and accident prevention.

![IoT based LOTO device](image)

Figure 3. IoT based LOTO device

3.1 Plan for Experiment and Data Collection for IoT based device performance
The most important factor of the IoT based LOTO device is actuation time. The SMS must reach within
standard/defined time and actuation must happen within standard/defined time
- Location of IoT based LOTO device
- Network Operators


- Network Signal Strength (as shown in table 1) - Being IoT based device, network strength is a very important factor [19].
- The signal is usually measured in dBm which is the power ratio in decibels of the radio power per milli-watt, a signal of -60dBm is nearly perfect and at -112dBm the call drops. Above -87dBm android mobile phone shows full 4 bars of signal.
- Arbitrary Strength Unit (ASU) is maps to (ASU - 141) ≤ dBm < (ASU - 140) [20] and ASU is an integer value proportional to the received signal strength measured by the mobile phone.
- Voltage Level
- Actuation Time - The time was noted down as start time and finish time and later difference were calculated

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

### 3.2 Data Collection and Analysis of IoT based LOTO device

Data collection was done in April 2018 for IoT based LOTO device on various parameters.

#### 3.2.1 Parameters recorded

- 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 terms of the Number of Bars displayed on the phone screen

#### 3.2.2 Descriptive Statistics of actuation time

Table 2 shows the Actuation time in Seconds (difference of start and finish time) for 1080 readings.

| Descriptive Statistics | Op- A_Loc-SF | Op- A_Loc-OD | Op- B_Loc-SF | Op- B_Loc-OD | Op- C_Loc-SF | Op- C_Loc-OD | Op- C_Loc-Base |
|------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| Condition              | Conditi n-1 | Conditi n-2 | Conditi n-3 | Conditi n-4 | Conditi n-5 | Conditi n-6 | Conditi n-7 |
| Mean                   | 22.60       | 22.44       | 25.86       | 24.18       | 23.23       | 23.46       | 23.40       |
| Standard Error         | 0.06        | 0.05        | 0.04        | 0.07        | 0.09        | 0.11        | 0.09        |
| Median                 | 22.50       | 22.00       | 26.00       | 24.00       | 23.00       | 23.00       | 22.00       |
| Mode                   | 22.00       | 22.00       | 26.00       | 24.00       | 23.00       | 23.00       | 22.00       |
| Standard Deviation     | 0.67        | 0.58        | 0.45        | 0.72        | 1.03        | 1.15        | 1.02        |
| Sample Variance        | 0.44        | 0.33        | 0.21        | 0.52        | 1.07        | 1.33        | 1.05        |
| Kurtosis               | -0.60       | 1.86        | 4.35        | 8.43        | 4.96        | 3.04        | 6.48        |
| Skewness               | 0.67        | 1.17        | -0.02       | 2.64        | 2.15        | 1.72        | 2.66        |
### 3.2.3 Regression Analysis of Trial Data

Regression Analysis were done for all the trials in different test conditions and depicted in table 3. Actuation time \((y)\) of IoT based LOTO device has a strong positive correlation with the signal strength \((x)\).

#### Table 3. Regression Analysis

| Trial Condition               | Location of IoT device | Network Operator | Regression Equation          | \(R^2\)   |
|------------------------------|------------------------|------------------|------------------------------|----------|
| 1                            | Shop-floor or Indoor   | A                | \(y = -1.4034x + 29.412\)   | 0.2918   |
| 2                            | Outdoor                | A                | \(y = -1.4034x + 29.412\)   | 0.2918   |
| 3                            | Basement               | A                | \(y = -0.9462x + 29.777\)   | 0.6769   |
| 4                            | Shop-floor or Indoor   | B                | \(y = -1.2414x + 28.902\)   | 0.7687   |
| 5                            | Outdoor                | B                | \(y = -1.8415x + 32.103\)   | 0.8504   |
| 6                            | Basement               | B                | \(y = -0.6933x + 26.208\)   | 0.3346   |
| 7                            | Shop-floor or Indoor   | C                | \(y = -1.5813x + 30.017\)   | 0.8008   |
| 8                            | Outdoor                | C                | \(y = -0.2999x + 24.451\)   | 0.0896   |
| 9                            | Basement               | C                | \(y = -1.0402x + 29.201\)   | 0.874    |

#### 4. Analysis of Safety Incidents on a Machine before and after implementation of IoT based LOTO device

Data on various safety incidents and machine stoppages was collected from May 2011 to April 2018 on a Makino CNC Machine. In May 2018, we applied IoT based LOTO device on this machine and collected data again from May 2018 to April 2019 to gauge the effectiveness of IoT based LOTO devices in enhancing safety.

#### 4.1 Time Period of data collection
- May 2011 to April 2018 the machine was secured for maintenance and other related activities with the Conventional LOTO device.
- May 2018 to April 2019 the machine was secured for maintenance and other related activities with the IoT based LOTO device.

#### 4.2 Nature of Accident or Safety Incident
• Minor injuries are injuries which do not involve medical treatment and requires only first aid treatment [21].
• Major injuries are non-fatal but severe injuries. They are defined by: Part of the body injured, Nature of injury, Incident type and Duration of medical leave. Examples include: Blindness, Amputation, Crushing, Deafness, Paralysis, fractures and dislocations: hand, head, back, abdomen and chest, neck, hip and pelvis, Exposure to electric current, drowning, Hypothermia etc.
• Near Miss- a person is just saved from the accident.

4.3 Descriptions of the Problems like Breakdown, Maintenance or repair work on the Machine and LOTO process adherence.
• Descriptions of the problems where LOTO applied and processes were adhered
• Descriptions of the problems where LOTO processes were not adhered

4.4 Descriptions of the Hazardous Energies and 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 standardized operating procedure.

4.5 Details of the Accidents or Safety Incidents
All the safety incidents, whether minor injuries, major injuries, near-misses and accidents were recorded and analysed for their possible root causes. Corrective and Preventive actions are also taken based on the incident analysis[21].

4.6 Details of the hazardous energies to be controlled on the machine for various repair, service and or maintenance work
The machine has many hazardous energies. LOTO needs to be applied to control these hazardous energies. The t data collected on the machine from May 2011-April 2019 with various hazardous energies like Electrical -98, Pneumatics-55, Hydraulics-41, Gravity and Mechanical -16 were observed with the service/repair problem.

4.7 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 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 LOTO were applied. The data were also taken in the cases where LOTO were not applied. Table 4 shows the data collection sheet of safety incidents. Table 5 shows the summary of safety incidents.

| Parameter No. | Description of Parameters in data collection sheet | Details filled in the data collection sheet |
|---------------|---------------------------------------------------|--------------------------------------------|
| 1             | Serial Number                                      | 1                                          |
| 2             | Date                                              | 23 May 2011                                |
| 3             | Month                                             | 01 May 2011                                |
| 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
7. No of times Conventional LOTO applied
8. No of Times IoT based LOTO applied
9. No of Times LOTO not adhered
10. Time Taken in LOTO Implementation (Minutes)
11. No. of Safety Incidents (Injuries, Near-Miss & Accidents)
12. Description of Safety Incident-1
13. Possible Causes of Safety Incident-1
14. Corrective and Preventive Action for Safety Incident-1

Table 5. Summary 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                                        |

5. Results and Discussion

5.1 Interpretation of data analysis

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

5.1.2 Location of the LOTO device and network strength
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.
5.2 Result of experiment on IoT based LOTO device
These results are very encouraging and shows reliability of the developed IoT based LOTO device. We could not find any malfunction in 1080 readings and IoT based LOTO device works best when network signal strength is good (-51 to -100 dBm).

5.3 Reduction in number of safety accidents or incidents on machine before and after IoT based LOTO device implementation.
The data collected (table 6, ‘Figure 4’) clearly shows that the number of safety incidents reduced from “47” to “0”. The IoT based device is also able to reduce (table 7) finger (from 10 to 0), hand (from 5 to 0) and arm (from 2 to 0) related minor injuries.

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

Table 6. Types of Safety Incidents occurs

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

Table 7. Body parts injured (minor)

Figure 4. Number of safety incidents before and after implementation of IoT based LOTO device.

5.4 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 8) clearly
shows that average LOTO implementation time (seconds) is reduced by almost 50% from 697 to 349 on the machine. Lesser LOTO implementation time improves the availability of the machine for more productive work.

Table 8. Reduction in LOTO implementation time

| 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. 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 a 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 auto locked (based on the pre-programmed flow) and sends text messages to concerned 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/her will send an automatic text messages to his/her 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 tampering with the device.

- The IoT based LOTO device is 99.7 % faster than the conventional LOTO device with an average implementation time of 349 seconds compared to 697 seconds of conventional LOTO device. It helps electrician in troubleshooting, repair, maintenance or servicing work. It also helps in digital record keeping as data from microcontrollers/sensors can be recorded and verified.
- The IoT based LOTO device has resulted into reduction in the number of accidents and safety incidents from 7 to 0 incidents per year, it also helped to reduce LOTO implementation time from 697 seconds to 349 seconds.
- Reduction in accidents and incidents gives safer work environment and lesser LOTO implementation time improves productivity.
- 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 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. A mobile app (an application) can also be developed for Android/iOS/other systems. The researcher is planning to apply for patenting the IoT based LOTO device.
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