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Department of
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Master Degree Thesis

Risk for the Operation in Confined Space and IOT Solutions

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Abstract

Confined space operation has been the area of frequent occurrence of accidents, with the development and application of Internet of Things technology, many new technologies are the large-scale change of the global industry status, but also provides a new direction for confined space safety research, especially in the aspect of environmental monitoring and pre-warning system, so the Internet of things technology has very important significance and application value of research.

In this thesis, the automobile painting workshop is taken as an example to analyze the risk factors existing in the confined space, and basis of its existing safety measures, the relevant Internet of Things management scheme is designed, and the related safety degree improvement is evaluated and comparison.

At first, introduces the development status of confined space safety and Internet of Things technology, then analyzes the literature of other scholars, introduces the framework structure and application of Internet of Things technology, and selects the technology suitable for safety improvement of confined space. Then, taking an automobile painting workshop as an example, the safety level of existing safety measures and the safety level after the application of relevant Internet of things technology are evaluated by Dow's fire and explosion index analysis, and the safety impact brought by the Internet of Things technology is finally compared. Based on the existing technology, several management schemes are proposed to improve the safety status.

Key words: Internet of Things; confined space operation; Dow's fire and explosion index

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1 Introduction

1.1 Background

Due to the technology requirement increasing, more and more factory use the confined space to produce items, to achieve higher quality requirements. Manufacturing is an important industry in every country, if maximum the profit the factory must develop more excellent technology. While the safety problem is also a popular topic, in the confined space, many potential risks are threatening production. If there is a danger, it will cause a disaster to the workers' lives and the profit of the company will be damaged. In the project lifetime, the accident have four key factors, people, machine, environment and management, but the people always be the sufferers.

In recent years, the Internet of Things is more and more used, in base idea be shown in 《The rode ahead》 by Bill Gates. And at 2008, the IBM company raise the "smart earth" plan, apply in the medical, transport, energy power and physical distribution, it marks the arrival of a new era of global communication

1.2 Research status and signification

According to a survey (Xin,Yang&Jiang,2006) from 1989.06-2006.07, they research 122 complete confined space casualty accident. 122 accidents cause 321 people died, 344 people mild or severe injury. The most direct cause of death and injury was asphyxia in 63 cases, accounting for 63.5%.Poisoning was followed by 35 cases, accounting for 28.7%.7 cases of hypoxia (5.8%); Most of the accidents occurred in the petrochemical industry, accounting for 61.5 %, followed by construction work at 15.6 % and sewage treatment at 8.2 %. Two thirds of accidents because the operation environment changed in a dangerous situation, and 70% of these type accidents that the risk existed before the operator entered into the operation areas. According to the analysis and statistics of operation activities at the time of the accident, there were 56 cases of troubleshooting and equipment maintenance, accounting for 45.9%.45 cases, 36.9%, were directly attributable to emergency rescue; There were only 15 cases of normal production operations, accounting for only 12.3%.The statistical results indicate that the risk of casualty accident is higher when the equipment is overhauling and troubleshooting.

From the analysis of the direct causes of the accident (Xin et al.2006), there were 47 safety management reasons, accounting for 38.5%, such as mismanagement or violation of rules and regulations. There were 33 cases (27.1%) of accident casualties caused by blind rescue due to poor quality of workers and insufficient emergency response ability. 30 cases, accounting for 24.6%, were caused by workers' illegal operation, including labor protection equipment not being used or being used improperly. Only 12 deaths (9.8%) were caused directly by equipment failure

Through the results of this study, it can be found that the reasons for the confined space are mainly due to lax safety supervision, imperfect operation procedures and workers' lack of risk awareness. In order to improve these problems, we can use the Internet of Things related technologies to improve safety procedures and risk warnings, and at the same time issue risk warnings in a timely manner. In confined space operations, the three principles of permission, repetition and closure should be strictly

implemented to protect operators' safety and reduce risks in confined space to the greatest extent.

Improving management efficiency and operation safety are the important reason for introducing Internet of Things technology into confined space operations. Because above research, the human error is the most serious problem of accident, and the Internet of Things technology could solve part of problem of human error. Like the environmental monitoring, equipment management and risk early warning, they all have Internet of Things solutions that are actually available. In terms of the efficiency of the overall workflow, Internet of Things technology can also bring great convenience and save a lot of time. Therefore, the Internet of Things technology in confined space operation will be a promising research field and investment area.

1.3 Research contents

In my paper, it will introduce the background of confined space risk, explain the significance and the application of IOT technology. Summarize and analysis the previous research from expert. Through the analysis of the present situation of the safety management of the construction persons in the confined space, the problems existing in the safety management of the construction personnel are summarized, the main safety problems and types are summarized, the causes are analyzed, the existing safety management evaluation system is improved, and its effects are tested.

In the case study chapter, it will use an actual factory to analysis the problem in their safety management, and using the IOT technology to improve the risk management in the factory. Finally, compare the results to definite some effectively improvement measure, and choice the suitable device to improve production safety.

The research methods is that refer to the related thesis and analytical investigation. The specific steps are below:

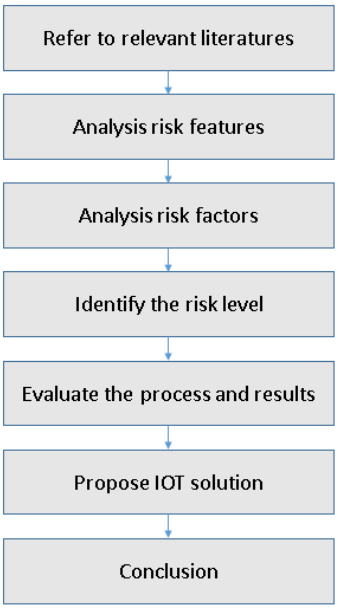

Figure 1-1 technology method

2 Relevant theoretical basis

2.1 Confined space

2.1.1 Introduction of the confined space

Confined space is a well-known term, but it has a more precise definition in industrial manufacture. The definitions have different explain in different institutions, for example, according to Occupational Safety and Health Administration (OSHA), an agency of the United States Department of Labor.

A confined space is a space that meets these criteria (Safe work in confined work, third edition,2014):

(1) Being large enough for an employee to enter and perform work;

(2) Has limited or restricted means for entry or exit;

(3) Is not designed for continuous occupancy.

What we usually think of as a confined space, like chamber, tank, vat, silo, pit, trench, pipe, sewer, flue and other similar space, they all have the same characteristics above, even some caves and coal mines in nature.

This describe is from a space definition, the space is must large enough for a worker to enter in or out, and this worker can do relevant work in this space. Whatever it was designed by a human or nature, the worker are temporary in the confined space, because confined space often has a substantial risk or potential risk. Prevention and forecast to these risks is a key point of our goals.

Compare with the Health and Safety Executive (HSE), a UK government agency responsible for the encouragement, regulation and enforcement of workplace health, safety and welfare, and for research into occupational risks in Great Britain.

Their Definition of confined space:

(1) It must be a space which is substantially (though not always entirely) enclosed;

(2) One or more of the specified risks must be present or reasonably foreseeable.

Their definition emphasizes the risk in the confined space, it is humanistic and let people pay more attention to the safety problem in confined space. They also mentioned the scene of many fires and chemical leaks, although there is no confined in the space, the working staff still have the same working environment as the workers in the confined space. We should provide them with the same risk prediction and response.

To sum up these two definition, I think the definition of confined environment should be defined not only from the actual space, but also from the situation of the worker, it will be more benefit for staff and industrial safety, reducing the possibility of risk occurrence.

2.1.2 Risk in the confined space

Because the confined nature of the place and potential environmental conditions combine together, it could increase the risk to safety and health. The risk could be the environment exist something or lack something, next we will list some common hazard

considered in confined space (Safe work in confined work, third edition,2014).

(1) Flammable substances and oxygen enrichment

When the environment exist flammable substance or oxygen in the atmosphere, it will arise the risk of explosion or fire. Meanwhile, presence of chemicals that can combust or spark, or the airborne flammable contaminants, such as flour dust, they also increase the risk of fire and explosion.

(2) Excessive heat

Hot work condition cause the dangerous in human body and the situation worse when the worker wear the personal protective equipment (PPE). This condition will reduce the available working time but increase the working stress. If it is serious, heat stroke and unconsciousness can result. Excessive heat occur in next situation: work is being done in heat conditions; work environment exist heat source; equipment has been steam cleaned to remove hydrocarbons; hot work is being carried out. The working clothes, or PPE, it will sum of the slower heat in the body, because of the enclosure of the confined space.

(3) Toxic gas, fume or vapor

Toxic gas, fume or vapor exist could make the worker asphyxia or unconsciousness. These gas could be from the previous processing or storage, sludge and deposits, not been effectively isolated from adjoining plant or from exhausts of equipment being used. Some work can also produce these gas, like welding, flame cutting and etc. Equipment failure, nature produce, actions out of the space also lead to hazardous substance.

(4) Oxygen deficiency

The confined space usually lack the oxygen, the reason for it is: purging the confined space with an inert gas to remove flammable or toxic gas, fume, vapor or aerosols; naturally occurring biological or chemical processes consuming oxygen; making the tank completely closed or poorly ventilated during a long time; Due to working operating, increasing levels of carbon dioxide or decreasing levels of oxygen; displacement of air during pipe freezing; A long time work, it consumes oxygen; and the last one is, in order to avoid the occurrence of fire, people reduce the concentration of oxygen. The dangers of oxygen deficiency are common, may lead to asphyxia or unconsciousness for human.

(5) The ingress or presence of liquids

If the work in sewers or other similar situation, we should consider the liquid. The level of the risk depend on which the liquid, if it is the water even the small depth, it could occur the drowning. If the liquid have corrosively or toxicity, it cause the serious injury.

(6) Solid materials which can flow

Solid materials flow could cause the physical injury on the body. When the materials is tiny it cause the breathing problems. In particular this hazard in confined space, the worker do not have enough space to action.

(7) Other hazards

It exist have many hazards not mention, like electricity, noise and equipment problems, they will be evaluated when they need to do or work in the confined space.

2.2 The Internet of Things

2.2.1 The Internet of Things introduction

IOT is the shortened form of The Internet of Things, it base on the internet, by connecting the digital machines provided with unique identifiers (UIDs), to make the information transfer from device to device or device to human. This process would use many kind of information sensor, radio frequency identification technology (RFID), Global Positioning System (GPS), infrared sensor and other information technology.

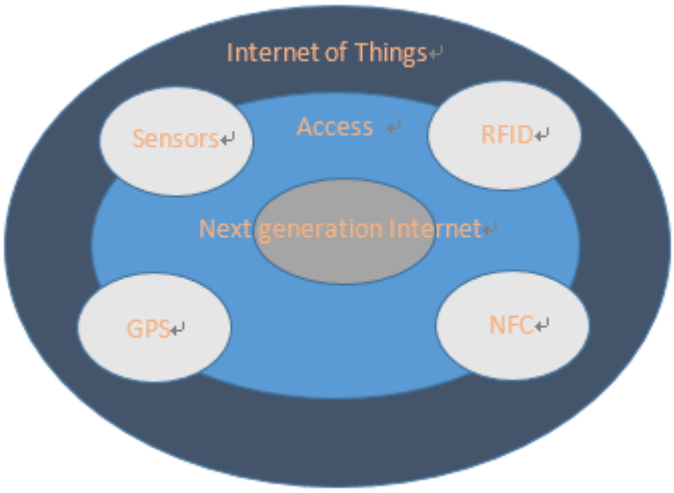

Figure 2-1 Conceptual model of the Internet of Things

Collecting the information about sound, light, heat, electricity, mechanics, chemistry, biology, location, all the information we need, to realize identification and management of items and processes.

The Internet of things is an information carrier based on the traditional Internet network. It enables all physical objects that can be addressed independently to form an interconnected network. Massachusetts Institute of Technology Auto-ID center produce the identification in 1999 by using the RFID and wireless communication technology to connect all of things with the Internet, achieving the intelligent identification and management of things. From this ideas, the Internet of Things is the extension of the Internet.

From the Institute for the Future, Paul Saffo said “Personal computer represented the 1980s, World Wide Web represented the 1990s, and the emergence of cheap sensors will be the next big change”. The internet of things set off the third wave of the global information industry.

2.2.2 The Internet of Things structure

The internet of things organization structure include the sensor layer, network layer and application layer. As the below picture, the sensor layer is the base element as the

resource of information, major in the date collecting and date perception. Sensor layer use the RFID electronic tag, sensors, camera, QR code, etc. information acquisition equipment, to acquire the vibration, force, temperature, humidity, concentration, sound and sport of objective, and convert to identifiable signal resources according to certain laws. Each sensor node and access node transform the information by network, tree and star shape topological mode, they use the sensor node networking technology. For the covered area information collection sensor node, they can connect by the wire or wireless internet, and use the direct or multi-route to transmit information, to form the sensor network connect to the network layer, always apply large scale, low power consumption, low cost short range wireless transmission technology or RFID technology to transmit, to supply information quickly and safely (Zhang,2017).

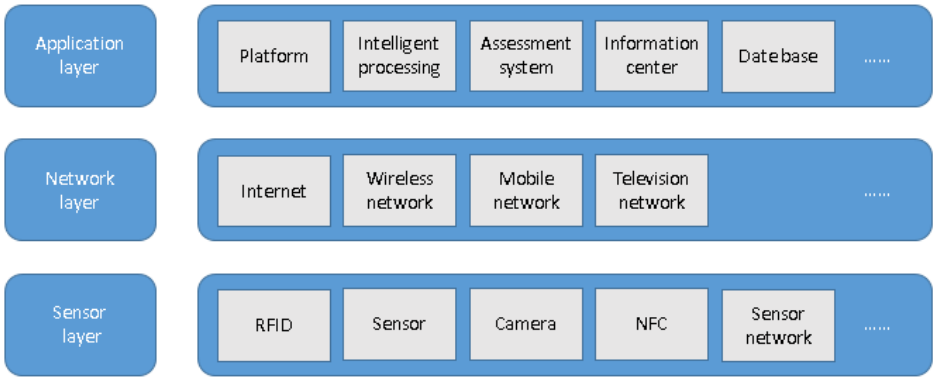

Figure2-2 Organizational structure of the Internet of Things

Network layer between sensor layer and application layer, is like a bridge of two layers. Network layer accord to communication agreement to transmit the information by internet, wireless network, mobile network and television network, and also transmit them to application layer. Meanwhile, when the order from the application layer be achieved, network layer transfer the corresponding action to the sensor layer, to achieve broader connectivity. The main goal of network layer is integration of other two layers, communication network is an important infrastructure to realize the Internet of Things. Whenever the static sensor in area or dynamic label of people, device, animal and botany, they all need transmit the information outside, when achieving wide connecting and sharing and scale application, it is the real internet of things. Now, heterogeneous network is the most of connection of different type, it means they have different communication protocol and transmission characteristic. The mix of heterogeneous networks can expand the coverage, providing diversity needs, reducing the operating costs and enhanced reliability. Moreover, it can remote control by network.

Application layer is the connecting point between Internet of things and users, it is the top level layer of the structure of internet of things, it have the function that face to items by combining industry needs to supply application platform and application service. Application layer analysis, manage and decision the date transmitted by internet of things technology, and combine the industry technology to supply the special application service, for example, building the public safety monitoring platform. The

key goal is information sharing, intelligent processing and information security. The application layer support the different jobs in intelligent logistics, smart transportation and smart electricity.

The common steps for internet of things application is: first mark the things, then read the object properties, translate in the format of the data transmitted over the network, at last transmit to the information processing center, to finish the correlation calculation. The process is like below:

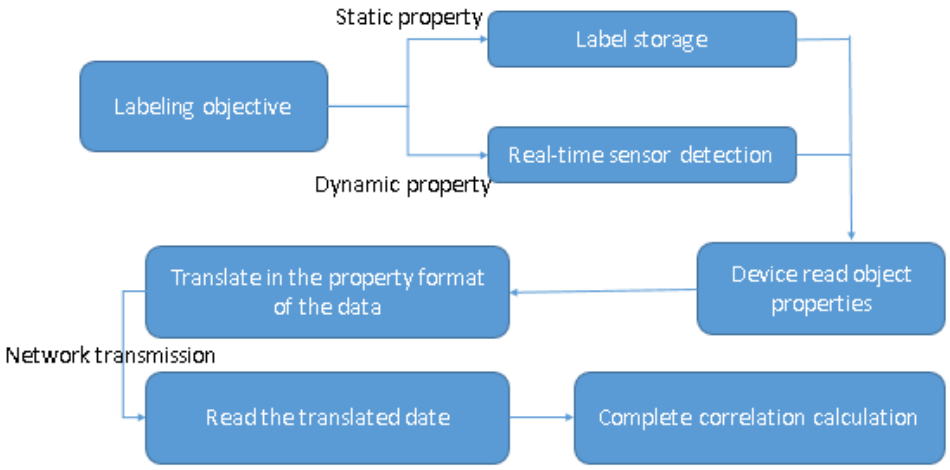

Figure 2-3 Implementation step of the Internet of Things

2.3 The Internet of Things technology

For now the main technologies of Internet of Things are information perception technology, information communication technology, information processing technology and information security technology.

2.3.1 Information perception technology

The main scope of information perception technology include the sensor technology, RFID technology, coordinate positioning technique and near field communication technology.

(1) Sensor technology

Sensor is the base element of the Internet of Things, as the perceptive organ, and in addition to collecting information, it can identify the former state, when the state changed, it also actuation related action and sent the signal to other element. According the Euro standard, the sensor is the perception device that can translate the information collected into electric signal by some defined rules, or other signal that satisfy transmission, processing, storage, display, record and control requirement and information output. Sensor have an extremely important in developing the economy and promoting social progress, its character are digital, smart, miniaturized, and multi-functional, systematize, network. Because of the sensor people could collect widely the information from the nature and production domain, this also provides the

basis for widespread use and development.

(2)RFID technology

RFID (Radio Frequency Identification), be represent as the electric label, electron chip, electronic barcode, induction card and contactless card. As a rule, a complete RFID system divide into tags and reader, the reader responsible for sending a certain frequency of radio wave to the tags, and the tags driver feeds the internal ID code back to the reader. Now, because of good safety and cannot be replicated, it be used widely in the burglar alarm, parking, auto production line, entrance guard control and supermarket.

(3) Coordinate positioning technique

Now the coordinate positioning technique mainly exists in the form of satellite space positioning, as a new method of present positioning, coordinate positioning technique combine with Global Position System satellite positioning and modern communication technology, make surveying and mapping technology, navigation technology have a revolutionary breakthrough, and rely on the high precision, high judgment, high dynamic characteristic applied every aspect of social life.

(4)Near field communication technique

Near-Field-Communication (NFC) is a set of communication protocols for communication between two electronic devices over a distance of 4 cm or less. NFC offers a low-speed connection with simple setup that can be used to bootstrap more-capable wireless connections. NFC devices can act as electronic identity documents and keycards. They are used in contactless payment systems and allow mobile payment replacing or supplementing systems such as credit cards and electronic ticket smart cards. NFC can be used for sharing small files such as contacts, and bootstrapping fast connections to share larger media such as photos, videos, and other files.

2.3.2 Information communication technology

The main technologies of Internet of Things include wire and wireless information transmission technology, switching technology, networking technology and fiber optic communication technology. They have the high reliability and high safety characteristic, information is transmitted through a wide range of interconnected functions (Li, 2016).

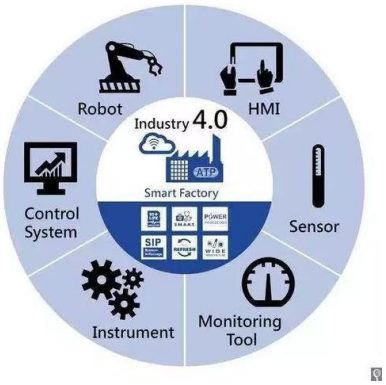

Figure 2-4 Industry 4.0

(1)Wireless transmission technology

Wireless transmission technology divide into wireless mobile transmission and wireless LAN transmission. The different between two technologies is the transmission medium. The wireless mobile transmission use telephone lines and satellites provided by telecommunications offices to support information transmission function to users, and the wireless LAN transmission always use transmitters and receivers built by themselves to transmit signals. Because of their differences, the development of wireless transmission technology is also divided into two main lines: from 2G, 3G to 4G, 5G called cellular communication, and WLAN, WPAN, Bluetooth, WIMAX and RFID development direction. And always moving towards efficient and convenient direction

(2)Switching technology

The switching technology of Internet of Things is different with the common switching technology. In the scope of Internet of Things scope, it means a soft switching technology that face the Next Generation Network, NGN. It support quickly connect control function and business call control function, soft switching technology as the NGN core technology, it is independent of transmission network and has resource allocation, call control, protocol handling, authentication, billing, routing, be able to provide users with all the services that an existing switch can provide, provide programmable capabilities to third parties, and encapsulated network resources, make it connect with application layer, to provide new business. The three key factor are business production interface, equipment access ability, and operational support system. It serves as a solution to the network and business problems related to traditional communication services and new multimedia services to reduce capital and operational input and increase income.

(3)Networking technology

The networking technology of Internet of Things divide into Ethernet network technology and ATM LAN network technology, and the internet of things as the extend of internet, it also can conclude in these two sides. Ethernet is the widely network, it is flexible and easy operation, can use many physical medium, many different topological structure. The rate can be divided into standard Ethernet (10Mbit/s), fast Ethernet (100Mbit/s) and 10G (10Gbit/s). They base on the IEEE802.3 standard, it exists in a typical bus structure, using coaxial cable, twisted pair and optical fiber and other transmission media. The topological structure are bus type and star type. ATM LAN networking technology have the center is ATM switch machine to constitute the local area network, it combine the advantage of packet switching and circuit switching, suit any transmission speed, medium and technology. But because of the complex protocol and expense device, it hard to spread.

(4) Fiber optic communication technology.

Fiber optic technology have the key significance in modern communication technology, it develop from short wave multimode fiber, long wave multimode fiber and long wave single mode fiber. The principle is that the sender point translate the information into electric signal, and then modulation to the beam emitted by the laser, make the intensity of light and the magnitude of the electrical signal are relative, at last it transmit by the fiber optic. On the contrary the receiving terminal translate the optical signal to electric signal, after demodulation back to the original information. Optical fiber technology maximally meets the requirements of high efficiency and accurate real-time data transmission. So far, it has been widely used, which lays a foundation for

the high-performance network environment required by the Internet of Things.

2.3.3 Information processing technology

Information processing technology is the part that ensure the reliable operation of the physical network in all fields, the information transmitted by it must be processed timely and effectively. Information processing technology mainly includes middleware, data mining, data processing, intelligent technology (Luo,2013).

(1)Middleware

Middleware is a kind of independent system software or application program, which is mainly responsible for providing the connection between system software and application software, including a set of services, which can enable multiple software running on one or more machines to interact through the network. Middleware is located between the operating system and user application software, providing the development and running environment for the application software at the upper level. As a software based on distributed processing, middleware has the function of network communication. Middleware is widely used in modern information technology. Many application servers with different interfaces can exchange information without hindrance because of the existence of middleware.

(2)Data mining

Data mining refers to the process of searching for hidden information from a large amount of data through various algorithms. As a representative concept, data mining can also be regarded as a series of Internet of Things analysis and application technology collectively. These include data mining and data warehousing, business intelligence, decision support, reporting, ETL, Dashboard, and Balanced Scoreboard. Data mining of the Internet of Things mainly refers to taking RFID information data as the main research object and using data mining technology to analyze and find the potentially valuable information of various items connected by the Internet of Things.

(3)Date processing

The Internet of Things collects a lot of data, so the processing of massive data plays an increasingly important role in data analysis and mining. In order to extract valuable information from a large number of data and meet the requirements of accuracy and efficiency, it is necessary to carry out reasonable optimization of the database, timely and effective batch processing of data, optimization of database query statements, establishment of a wide range of labels and indexes, and establishment of data warehouse. Strive to reduce the probability of error, miscellaneous data for reasonable selection and elimination, improve the efficiency of data processing.

(4) Intelligent technology

At present, the intelligent technologies studied mainly include the theoretical research of artificial intelligence, human-computer interaction technology, intelligent control technology and intelligent signal processing technology. All of these technologies are closely related to the development of the Internet of Things. In a broad sense, intelligent technology includes virtual reality technology, multimedia technology, information fusion technology and other Internet of Things technologies, and runs through the whole development process of the Internet of Things.

2.3.4 Information security technology

In order to improve the information security of the Internet of Things, we must pay attention to the development of information security technology of the Internet of Things. The openness and anonymity of the Internet of Things not only improves its convenience, but also brings some security risks. It needs to meet the requirements of authenticity, confidentiality and integrity while improving the trust degree of users and protecting their privacy. The security risks of the Internet of Things mainly focus on RFID system security, Internet of Things business security, core network transmission and information security, hacker intrusion and other aspects. Different from the security independence between the business layer and the network layer of traditional network, the Internet of Things has its particularity. It can learn from part of the Internet security mechanism, but it must be based on its characteristics of encryption mechanism, authentication mechanism to supplement and adjust.

3 IOT application

3.1 Architectural framework

When we try to build an IOT system in the confined space, we need know the simple structure and working mechanism. It's all about device or sensors gathering information about their surroundings and sending it to the internet or the cloud for processing and analysis, so that meaningful results can be derived from it.

The definition tells us that there are few tasks performed by an IOT system: collecting data, sending data, processing and analyzing data, and storage and reporting. We need both hardware and software components. To perform each of these tasks, to come together to form our IOT system.

This chapter we will talk about the actual device that we may need for the confined, the result is we should research the market. To make sure that we can purchase the suitable devices to final the IOT system building in the confined space, this is a feasibility analysis. The devices working range is determines whether it is suitable to use in confined space, and the price determines whether it is suitable to promote small and medium-sized enterprises. Here are some practical products to analyze the feasibility below (Dhameja,2017).

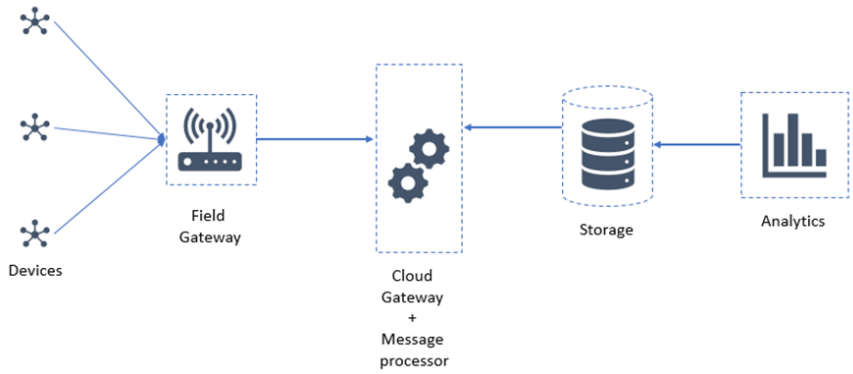

Figure 3-1 Physical framework

Figure 3-2 Device of framework

3.2 Some available equipment

(1)Camera

Wireless camera technology is very developed in the industry market, and different country have different law. The Italy law do not allow to set the camera in the workshop, and the other public zone should apply to the government and put up the signal. So our camera goal is that the operator communicate the hard situation to the supervisor in emergency. The camera should be the portable wireless camera, even the camera in the smartphone.

(2)Gateway

IOT gateway is set out of the confined space, aim to receive the date from the wireless sensors and transfer to the supervisor or the company internet.

For example, we analysis an IOT gateway named BMG500, to verity if it suitable for the confined space.

Figure 3-3 a gateway device used in factory

<table>
<tr><th>Product</th><th colspan="3">Wireless parameter</th><th>VPN</th><th>WIFI</th></tr>
<tr><td>BMG500--LF
LTE/WCDMA Gateway</td><td colspan="3">support FDD-LTE2600/2100/1800/900/800MHz，
support HSPA+/HSDPA/HSUPA/WCDMA/UMTS 900/2100MHz
support EDGE/GPRS/GSM 850/900/1800/1900MHz
support GPRS CLASS 10 EDGE CLASS 12</td><td>Yes</td><td>Yes</td></tr>
<tr><td rowspan="3">Port</td><td rowspan="3">Industrial serial port</td><td rowspan="3">2</td><td colspan="3">6 PIN terminal, 3.5mm distance</td></tr>
<tr><td colspan="3">Terminal type RS-232， RS-485</td></tr>
<tr><td colspan="3">Parameter ： 1200~115200bps，8date bits，1stop bit</td></tr>
</table>

	Ethernet	4 LAN	10/100M RJ45
		1 WAN	10/100M RJ45
	USB	USB2.0	data storage and update
	DI port	2	Input：DC 0~30V
	WIFI port	Frequency band	IEEE802.11b/g/n
		Ideal band	EEE802.11n：max speed 300Mbps
		Secure	WEP、WPA、WPA2
		Output Power	21.5dBm（11g），26dBm（11b）
		Sensitivity	<-72dBm@54Mpbs
	SIM/UIM	1	1.8V/3V SIM/UIM, 15KV ESD
	ANT	1	Standard SMA ANT port, impedance= 50Ω
IP Grade	IP 30	The metal shell is securely isolated from the system	
Working environment	Temperature	-35ºC to 75ºC	
	Humidity	95%, no condensation	

Table 3-1 Gateway usage parameter

Figure 3-4 Conceptual diagram

Comparing the IOT gateway with the confined space environment, we can see that the technology is now set. This example that have wired port, 4 LAN port, 1 WAN port, and could connect the sensors with the standard date line, like RS-232 and RS-485. While, the wireless sensor also connected by 4G or WIFI. The operator can use phone, pad or PC to manager the gateway, and IPsec VPN、L2TP、PPTP、open VPN are used to keep the internet date safety.

These kind of IOT gateway is the key part of our date transformation in the confined space. The sensor date could be transfer to the operator device to alarm, or the

supervisor device to manage. Meanwhile to keep the worker safety and the information safety.

3.3 The Internet of Things application analysis

Advantage of IOT application is the high efficiency. The high efficiency determines its wide application, including industrial, agricultural, environmental, transportation, logistics, security and other infrastructure applications, this technology to allocate resources more efficiently, and more intelligent. In the service sector, IOT application expanded the scope of services, charging the service method and also improved service quality, these service affect every aspect of people's lives, and the final goal is improved human life quality. And IOT application is same applies to the military, from individual combat equipment to warship or missile, IOT application can be found everywhere.

Here are two examples that are relevant to our lives, one is about traffic. The application of IOT technology in public traffic is relatively mature. Road traffic is monitored in real time, this information will give to the driver, and so drivers can choose and adjust the route freely, this action will to relieve traffic pressure. Many smartphone App like google map, it could tell you the fastest route to the destination. People live in Torino, they must know the App named “bus Torino” and “GTT Torino”, these kinds of application give our information of the bus location, bus station location and the timetable. They collect customer location, bus location and traffic situation, to compute the time you should wait, it is a very convenient application of IOT. And also the expressway ETC system, save the time of manual payment. Parking system could tell you how many parking spaces available, the traffic IOT system is very succeed for our life.

Another example is about home life. In recent years, the smart watch is a popular electronics, it goes through the sensor, to get your biological information and analysis to give you a better health advice. The smart watch collect the information of the step daily, heart rate, body temperature, sleep time, sports condition, this information is real time transfer to your smartphone by the Bluetooth, so you can check all your life trace after end of a day and share to the social account. If you want more convenient, you even can monitoring and management all your electric appliance in home, like electric toothbrush, air conditioner, bulb, refrigerator, door lock, pet feeder, these functions are now implemented and the application is spreading widely. You are out of the house in time to check any corner of the home at any time, any security problem could be check. IOT application make household life become easier, better and more beautiful.

3.3.1 IOT feasibility analysis in confined space

Now we focus on the industrial application, especially in confined space. We've talked about the hazards in the confined space last chapter, so our IOT application must deal with these risk.

The main risk need monitored by IOT device are the gas monitoring, the temperature monitoring and the water level height monitoring. The gas include the oxygen, toxic gas and flammable vapor. For keeping the breath, it have two main device to monitor the oxygen concentration: portable oxygen detector and fixed oxygen

detector. They are used in the different situation, for coal mine and underground installation, the worker need long-term operation, we could use the fixed oxygen detector, the benefit is that we can monitor the oxygen concentration before the worker enter the confined space, while the fixed oxygen detector can be connected by wireless network, the control and manage is rapid, the real time date could be monitored. And for the long term using, the cost could be acceptable. Another is the portable oxygen detector, it is suitable for the short term work, and this device function is monitor the oxygen concentration, if the concentration is high or less the human breath range, it will transfer information to worker by voice, light or shake, get the workers out of the danger area as soon as possible, this kind of device is small and cheap, accuracy can be achieved at 0.01% but it cannot be used continued. The worker only know the oxygen concentration before they used the device, if the confined space have changing environment, the worker need monitor the oxygen concentration at intervals to ensure safety. The toxic gas and flammable vapor have the similar device like the oxygen, but with the different working principle. For toxic gas and flammable vapor, we cannot monitor the concentration by portable device, we should monitor the concentration before the worker enter the confined space. So a fixed concentration device is the key device and it must work a long term, and transfer the date fast and precision. Not only we need the sensor for different gas, but also need related information transfer system.

Then the temperature monitoring device, the ambient temperature affect the PPE selected and the working time in the confined space. For the temperature monitor, the different material have different measurement range. It is into two categories, contact and non-contact, for confined space the non-contact is better choice. Our goal is the working temperature, the range is human body can withstand, infrared thermometer is always be used. If we need real time temperature date, the device must have the information transfer function, while we consider the emissivity of the object, the measurement distance, the influence of external factors such as soot and water vapor. This factor will affect the accuracy of the non-contact temperature device. From the human point of view, the humidity, air flow also affect judgment of temperature, further influence the available working time, we should consider more factors in the actual situation. The confined space always exist some liquid, if it is hazardous liquid, we should avoid contact or eliminate them. If not, the water level height monitor would be used, we judge the height before the worker entered the confined space, and equip the related PPE. This kind of device need information transfer function to avoid risk. Above device function analysis is the main problem existed in the confined space, with these device we will get the confined space environment date and analysis the risk. Next we will select some actual equipment to discuss the parameter in the confined space.

3.4 IOT solutions of work procedure

3.4.1 Traditional operation procedure

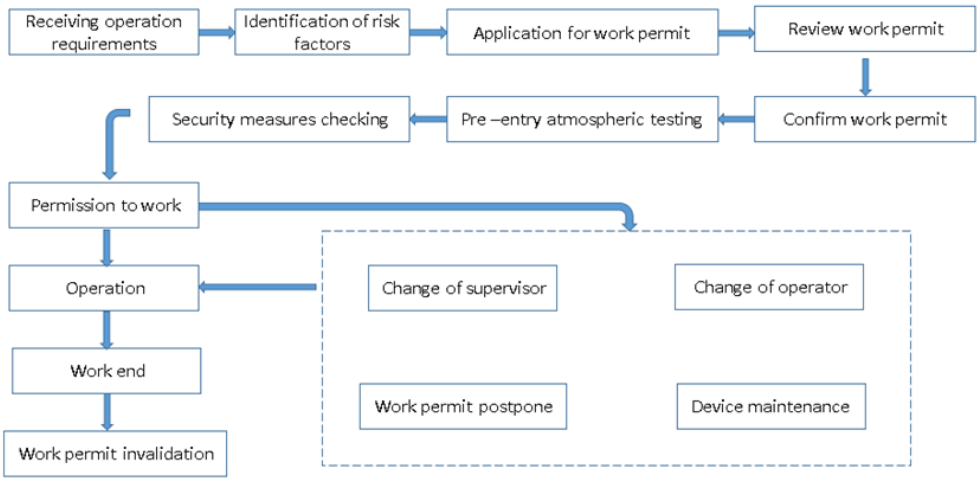

Figure 3-5 work permit application procedure

In the confined space operation process, a traditional working mode have the low efficiency communication of information.

In the information manage situation, the maintenance operator print the register form, going to the equipment storage warehouse, to check the device one by one, writing the device type, device ID code, make sure the legible handwriting and the form clean. If not, the other staff cannot identified the record, and the maintenance operator would rework. The maintenance operator check the label content, when they found the error, they should record this error and go back to change the label. After, when the maintenance operator finish information registration, they should login the internet in the company, and make the excel file to collect all the information by the manual registration, update the excel file. Label updates, collecting the label date that need be changed, than provide the label date to cooperative label production company. Waiting the label production company finish the label, inform the staff, after taking the label, the last step is changing the old label in the device. To calculate this process, if the device number is fifty, one maintenance operator, he need three day to deal with this problem, and the label production cost is fifty euro, all the checking, maintenance and label update is be record in the paper.

Now the operation in the confined space have a regulated procedure to keep operator safe. All entries into permit required confined spaces must be conducted by a minimum of two employees. Employees will be identified as the entry supervisor, attendant, or entrant. When a permit-required confined space must be entered, supervisors must perform and document the pre-entry planning and training with the authorized entrant, standby person, and attendant. When the planning and training have been completed, contact EH&S. Environmental Health & Safety will provide pre-entry atmospheric testing and personal monitoring equipment to the onsite attendant and issue confined space entry permit after the site review. When work is completed or a situation

that violates the terms of the permit arises, then the permit is terminated and EH&S should be notified. A permit is authorized only for the duration of the job. If there is an extended break during the job, the atmosphere must be tested before re-entry. All permit-required spaces must be labeled with a permanent sign that states, “DANGER confined space permit required.”

3.4.2 Digital work permit

Traditional paper work permit is an important operation management, but it have some problem. According to a 500KV transformer substation statistics in 2017 year, the supervisor look for the working location and adjacent device, then confirm the work permit, the work permit procedure spend 100 minutes in the most time (Li,2019).

Month	Work permit number	Time(minutes)	One-time pass rate
April	11	80	81.8%
May	8	60	75%
June	3	60	66.7%

Table 3-2 transformer substation statistics

After using the digital work permit system, the time of work permit writing reduce from 72 minutes to the 34 minutes. In fact the operator write the work permit would forget some content in sometimes, and need supervisor to check the content. People would make mistakes and the work permit should be taken to the different office to signature. This procedure spend many time, and reduce the work efficiency.

In the traditional work permit the staff need write 19 signature by different person in charge, and write 12 form to describe what they use what the situation. If one person make mistakes, the work permit should write again, the pass rate in one time is not high.

3.5 NFC solution of safe access

Near-field communications a set of communication protocols for communication between two electronic devices over a distance of 10cm or less. NFC technology is based on the RFID technology, the different is the RFID reader is single direction, the NFC reader is both way. Every active NFC device can work in one or more of three modes: NFC card emulation, enables NFC-enabled devices such as smartphones to act like smart cards, allowing users to perform transactions such as payment or ticketing. NFC reader/writer, enables NFC-enabled devices to read information stored on inexpensive NFC tags embedded in labels or smart posters. NFC peer-to-peer, enables two NFC-enabled devices to communicate with each other to exchange information in an ad hoc fashion.

NFC is be used in the mobile payment, security protection and label application. In the confined space situation, I think NFC is suitable for the access control system.

After 2017 year, many new edition smartphone have the NFC function, or extending the NFC function by Micro SD card. The staff ID card could be identification and storage in the smartphone, and have the same function as the real one, so the phone

function can replace the physical card (Qi,2017).

The staff ID card is used to clock in, and verify the entry identity. To apply this function in confined space, we can design a safety access management.

In the construction area, geographical environment or man-made environment is complex, the company always set the safety access way to pass, but some staff do not pass this safety access way to save time, this unsafe action cause some accidents. The NFC function can restrict staffs to use safety access way. The NFC reading device can set in the inlet and outlet port, or carry by the security person. The NFC use the frequency 13.56MHz±4kHz short distance high frequency transport, the range is only 10cm, so the inlet and outlet port NFC reader device cannot effect each other in common. This two device can record the operator enter and go out time to judge the operator usage the safety access way. We can allot unique IP address for each NFC reader device, so can remote management effectively.

In the software design, we have two label for the operator, one is the safe access zone label, and another is the operation zone label. The operator is not enter the operation zone and safe access zone, the two label are inactive state. The operator is enter the safe access zone, not enter the operation zone, the safe access label is active. After the operator enter the operation zone, the safe access label is inactive and the operation zone label is active. So the supervisor can check the state to know if the operator use the safety access way correctly. When the operator leave the operation zone, the safe access label is active first and inactive after the operator leave the safe access way. The process is as below:

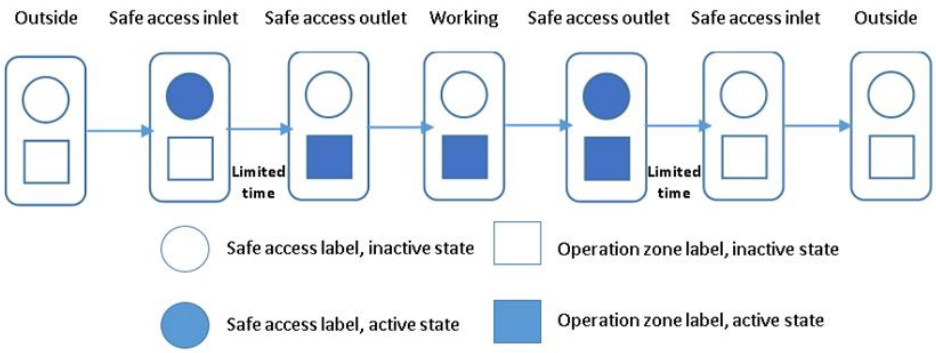

Figure 3-6 Design of NFC safe access

3.6 Two-dimension bar code

3.6.1 Two-dimension bar code introduction

Two- dimensional bar code is according to some of the rules to distribute becomes a black and white geometric image to record the date. It use the computer logic zero and one to edit code, and the text data information is represented by using geometric figures corresponding to the binary, this image is ability to be identified by image input device and photoelectric scanning equipment, to realize automatic processing of information. Two- dimensional bar code have the denominator as other barcode technology, each code have their specific character set, and each character set have a certain width, there

are a certain corrective function. While, it have the function that identify different lines of information and recognition the rotation changes of the image. So two-dimensional bar code could express information in the vertical and horizontal directions at the same time, thus it can express a lot of information in the little area. Two-dimension bar code divided into two categories, linear two-dimension bar code and matrix two-dimension bar code. Common linear two-dimension bar code have the code 16K, code 49, PDF417 and MicroPDF417, and common matrix two-dimension bar code have code one, Maxi Code, QR code, Data Matrix and etc.

3.6.2 Two-dimension bar code features

Two-dimensional bar code have many features that can be applied in confined space:

(1). High density coding information, it could accommodate more than 2710 numbers, or 1850 capital letter, or 500 Chinese character, or 1108 bytes, this volume is a dozen times higher than barcode. (2). Wide range of coding, two-dimensional bar code could express the sound, image, signature, and fingerprint in the coding by digital coding, it also could many kind of languages. (3). Large fault tolerant, with strong error correction function, if the two-dimensional bar code be local coloring and local perforation, it still could be identify accurately. When the damage reached 50 percent of the area, we can still recover it by technical methods. (4). High decoding reliability, the error decoding rate is less than the millionth, the error rate is much lower than normal bar code decoding. (5). Have encryption measures, two-dimensional bar code is good at confidentiality and anti-counterfeiting. (6). Low cost, easy to produce and durability perfect. (7). Size of two-dimensional bar code is could be change by the proportion. (8). Two-dimensional bar code could be identify by the CCD (Charge Couple Device) reader and laser reader.

3.7 Radio frequency identification (RFID)

RFID technology is the shortened form of the Radio Frequency Identification, the system is composed of the target reader, RFID label and computer. The target reader have the function of the date reading and storage by the control unit, high frequency communication module and antenna. The RFID label have the active tag label and passive tag label and semi active tag label because the different modes of power supply. The passive tag label is low cost and low volume to use widely.

4 Risk evolution method

4.1 Risk level evolution

The base risk evolution method (Muré,2019) is the risk level qualitative method, the date transfer by the sensor must be collect and analysis to give a safety advice. From a physiological point of view, the sensor have the low alarm value, it alarm the operator to leave the confined space, and it is the key index. But the confined space is very complex and always have potential hazard and the multiple risk factors together, operators always consider the many safety factors and the working time in the confined space, and leave early before the danger happening, so this chapter we will use the present work to show the methodology for the confined space risk assessment.

The technological risk function R=P×D, it used to calculate the specific feature in the confined space, R=risk index, P=probability of occurrence, D=magnitude of the damage. The probability of occurrence P is defined in two indexes, one is the frequency of exposure in the confined space, writing it in terms of the letter F, another is the contact time I that necessary to final request task, and I is strictly related to the complexity of the intervention.

(1). Risk of contact with fluid or substances or mechanical parts movement in emergency. (2) .Hypoxia risk. (3). Chemical risk. (4). Fire and explosion risk.

Probability	Level	Describe
Very unlikely	1	It is unlikely that the scenario takes place during the lifetime of the plant
Unlikely	2	The scenario could happen during the lifetime of the plant. It happened in similar plants belonging to the Company or external. The personnel is aware of the scenario, but does not have direct experience of it.
Likely	3	The scenario could occur within a year. For a functioning plant, the event probably occurred during the last 5 years
Very likely	4	The scenario can occur several times a year

Table 4-1 Level of probability

The corrective factor assume values in the range 1 to 1.5, but the damage divide into energy damage DE and environment damage DA, so the maximum value could be reached is the 4.

Probability	Level	Describe
Minor	1	Injury or episode or acute exposition with rapidly reversible inability; rapidly reversible minor injuries or physical pathologies
Medium	2	Injury or episode or acute exposition with reversible inability; reversible injuries or physical and psychophysiology

		pathologies
Severe	3	Injury or episode or acute exposition with partial invalidating effects; chronical injuries or physical and psychophysiology pathologies with partial invalidating effects
Major	4	Injury or episode or acute exposition with lethal effects or permanent invalidating effects; chronical injuries or physical and psychophysiology pathologies with invalidating effects

Table 4-2 Level of damage

		Probability of occurrence P			
		Very unlikely	Unlikely	Likely	Very likely
Magnitude of damage D		1	2	3	4
Minor	1	1	2	3	4
Medium	2	2	4	6	8
Severe	3	3	6	9	12
Major	4	4	8	12	16

Table 4-3 risk level R=P×D

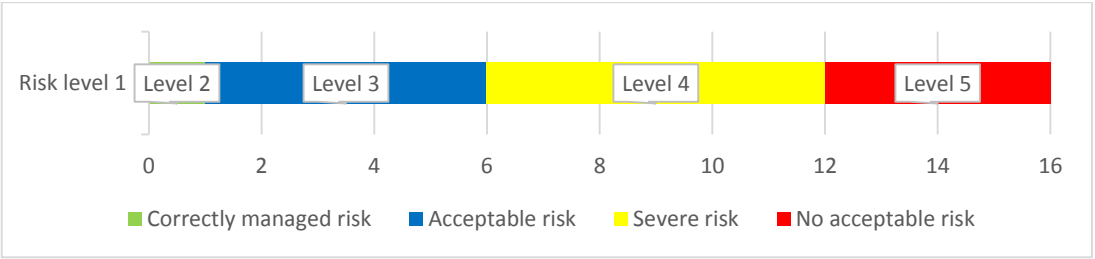

Table 4-4 Level of risk

R=0, the damage is not present;

R=1, correctly managed risk, actions for maintaining the acquired risk level could be implemented.

1<R<6, acceptable risk; technical and/or procedural actions could be carried out.

6⩽R<12, severe risk, urgent actions for risk reductions, in order to obtain a reduction of the risk level EHS 2, working activity can be carried out only under continuous monitoring.

R⩾12, non-acceptable risk, immediate actions for risk reductions, possible suspension of the activity.

Risk level 1 to 5 express the risk situation and it will be used in our digital work

permit form.

4.2 Dow's fire and explosion index

The Dow's fire and explosion index is the widely used risk degree index since 1967. The last edition is the 7th and it was published in 1994. It a quantitative measurements which based on historical date, energy potential and loss prevention practice applied. It is necessary for process designers to evolution the process technology.

F&EI relates process risk factor to process information in term of penalties and credit factors. And it always base on the worst base which means the most hazardous material are evaluated in specific operational state same time. The specific requirement are below (Suardin,2005):

The F&EI has two components, Process Unit Hazards Factor (F3) and Material Factor (MF). F3 consists of General Process Hazards (F1) and Special Process Hazards (F2). The F&EI is determined by the Equations and:

F3=F1*F2; F&EI=MF*F3

The MF value could be determined in the guide.

Liquids&Gases Flammablity or Combustibility	NFPA 325M Or 49	Nr=0	Nr=1	Nr=3	Nr=3	Nr=4
Non-combustible	Nf=0	1	14	24	29	40
F.P>93.3℃	Nf=1	4	14	24	29	40
37.7℃<F.P<93.3℃	Nf=2	10	14	24	29	40
22.7℃<F.P<37.7℃ or F.P<22.7℃ and B.P>37.7℃	Nf=3	16	16	24	29	40
F.P<22.7℃ and BP<37.7℃	Nf=4	21	21	24	29	40

Table 4-5 Nf classifications and material factor determination guide

F.P=flash point, B.P=boiling point

Then, the process unit hazard factor include all factors that are likely to contribute to the occurrence of risk incidents, it is a quantitative method. The numerical value of process unit hazard factor is determined by general process hazards and special process hazard that are described.

In general process hazards, mild exothermic reaction requires a penalty of 0.30. Moderate exothermic reaction requires a penalty of 0.50. Critical-to-control exothermic reaction requires a penalty of 1.00. Particularly sensitive exothermic (i.e., nitration)

require a penalty of 1.25. All endothermic processes in the reactor require a penalty of 0.2 unless the energy for the endothermic processes is provided by combustion of a solid, liquid or gaseous fuel. Warehouse storages or yard storages (not storage tanks) involving chemical with potential fire hazards require a penalty of 0.85, 0.65, 0.40, and 0.25 depend on the flammability of the chemicals handled. Dust collectors located inside an enclosed area requires a penalty of 0.50. Handling flammable fluids at a temperature above their flash point in an enclosed area requires a penalty of 0.30. If more than 1,000 gallons of liquids are handled, the penalty will be 0.45. Liquefied petroleum gas (LPG) or any flammable fluids handled at temperatures above their boiling point in an enclosed area require a penalty of 0.60. However, if more than 10,000 lb of liquids are handled, the penalty will be 0.90. All of the penalties above will be reduced by 50% if mechanical ventilation is properly designed for the fire hazard. Process areas over 1000 m^2 or warehouses over 2500 m^2 with inadequate accesses will have 0.35 as the penalty.

For the special process hazards (F3), they are 12 items listed as process hazards and we would analysis in the case study chapter. The table operate is same as the general process hazards. At last, the credit factor should be determine. In the origin table, the maximum possible property damage (MPPD) should be calculate but in our paper, it is not the content.

5 Case study

5.1 Automobile spray painting workshops introduction

Taking an auto spray painting workshops for example, the specific project content is as follows (Li,2013):

This spray painting workshop build in 2004 by China-Japan joint venture. The location is in Guangzhou, Huangshaqu, motor city. The company produce the passage car, SUV, annual production capacity is 360,000 unit. The spray painting workshop have the steel structure design, building fire resistance grade 2, height 23.6m, area 37020 m^2, and have 500 staffs. The workshop have three layers, it used the non-sparking floor, and the pre-treatment section has the ground required for corrosion protection, it use epoxy anticorrosive paint according to different media and concentration. First layer have the painting mixing room, maintenance room, dying room furnace, warehouse. Second layer have the pre-treatment room, electrophoresis room, painting room. The third floor only have air handing unit. This workshop is the confined space workshop and air change rate is 2 times/h. In the paint mixing room and paint storage room the air changes rates is 12-15 times/h. Painting workshop interior design temperature is 18℃, and the office interior design temperature is also 18℃ by air conditioning unit. The air conditioning units is three modular air conditioner, each air volume is 8500 m3/h.

5.1.1 Spray painting technology

Spray painting technology is the key step of vehicle surface protection and aesthetics, and also the key step of modern automobile manufacturing process. The spray painting process have six production process: pre-treatment Parkerizing, cathode electrophoretic paint, seal vehicle bottom painting, floating coat, finishing coat and after treatment. To sum up, there are three part that include the pre-treatment, painting and after treatment. The pre-treatment include the vehicle surface cleaning, degreasing, washing and Parkerizing. The painting process include the painting and polishing. In this case, the painting technology process is as below:

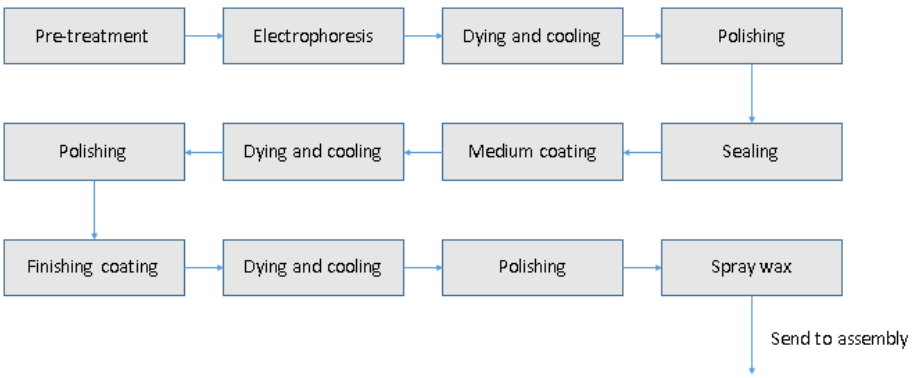

Figure 5-1 spray painting process

The pre-treatment can improve adhesion properties of vehicle surface and improve

the anti-corrosion ability to increase the lifetime. The process technology are organic solvent cleaning, cleanser cleaning, degreasing, washing, Parkerizing and finish cleaning.

The electrophoresis is the technology as the undercoat, the theory is that coating particle move in contrast to charge position under the electric field, the coating particle deposited occurs on the body surface to form coating layer. The electrophoresis is the complex chemical reaction. Cathode electrophoresis is the better choice than anode electrophoresis because it use cheaper device and film layer better than anode electrophoresis. The cathode electrophoresis use the water-soluble paint to reduce the volatile organic compounds pollution and keep safe.

Sealing process use the PVC painting to improve the comfort ability and increase the corrosion resistance in the crevice.

Protective coating process is the base of next step, to protect bottom and top coating, improving the corrosion resistance and durability. The protective coating process include the bottom coating polish, clean, coating, drying and cooling.

Top coating is the last step of spray coating that is very important for complete vehicle coating quality and ability. The process is same as the protective coating, also have the polishing, cleaning, coating, drying and cooling. The workshop use the electrostatic spraying technology that under high voltage electric field, the painting particle is electronegativity, and the vehicle is electro positivity, than the painting particle are attached to the surface of the vehicle. Atomization is achieved by compressed air motor. The motor can change voltage of compressed air to change the injection rate. The high voltage electric field improve the atomization of painting particle and operation efficiency, and then reduce the pollution and keep safe.

After coating process check the coating quality, if the quality is not good then they must be rework and transport to spray painting area again. For good quality vehicle they spray wax and continuous to next step.

5.1.2 Spray painting material

In the spray painting process it will use many chemicals, these chemical have different physicochemical property and risk characteristic. According the spray painting technology process, solvent based coating is the key material for spray painting process and also the powder coating. The solvent based coating is more dangerous, the specific materials are shown in the following diagram. Comparing with solvent based coating the powder coating have lower VOCs pollution. Because of low quality result, the water-based solvent is less use than organic solvent. So the identify of risk factors in workshop is important, and also check the working order and analysis the painting.

Name	Volatility	Main materials
Painting	Nonvolatile part	Natural resin, synthetic resin, vegetable oil
	Volatile part	Solvent, cosolvent, diluent

Table 5-1 solvent based coating component

Step	Material component
Electrophoresis	Pigment, water, solvent(toluene, butyl acetate)
PVC glue	PVC resins, plasticizer, stuffing
Colored paint	Pigment(patent protection)
2K varnish	Diluent(toluene, butyl acetate), curing agent

Table 5-2 painting process material

Material name	Main components
Degreaser	Alkali cleaner
Surface conditioner	Phosphoeptide
Phosphating supplement	phosphoric acid, nickel nitrate
Phosphating accelerator	$NaNO_2$
Passivating agent	Zirconate
Slagging agent	$Fe(NO_3)_2$

Table 5-3 pre-treatment material component

5.2 Workshop risk factors analysis

According to previous chapter, there are two risk factors should be considered in the spray painting workshops, one is the dangerous materials, and another is operation mistakes.

5.2.1 Dangerous chemical analysis

Because of the spray painting technology there are lots of flammable, combustible and volatile solvent. The specific parameters are shown in the table. These solvent have serious risk of combustion and explosion, especially in a confined space workshop. Some of solvent under room temperature (28℃), mixing with air and the concentration is at the explosion limit (1.0%-2.1%), can explosive by open flame, high temperature goods or electric spark. They also gather in the low level ground and poorly ventilated place because of the steam density is bigger than air. So the dangerous chemicals is what we need focus on.

Solvent	Flash point [℃]	Ignition temperature [℃]	Lower explosive limit [%]	High explosive limit [%]	Relative air density
Benzene	-11.1	555	1.2	8.0	2.7
Toluene	4.4	535	1.2	7.0	3.18
Xylene	30	465	1.0	7.6	3.36
Ethyl acetate	-4.4	460	2.1	11.5	3.04
Butyl acetate	22	370	1.2	7.5	4.01

Table 5-4 Physical properties of solvents

In spray painting workshop, the main dangerous chemicals and the influence on human body as below:

(1) Benzene (C_6H_6), the toxicological hazard rating is level Ⅰ (extremely dangerous). Benzene is classified as a carcinogen, which increases the risk of cancer and other illnesses, and is also a notorious cause of bone marrow failure. At the same time, benzene also has strong flammable and explosive properties

(2) Toluene (C_7H_8), the toxicological hazard rating is level Ⅲ(medium dangerous). This substance has irritant to skin and mucous membrane, and has paralytic effect to central nervous system. While it has flammable and explosive properties, it's a volatile substance.

(3) Xylenes (C_8H_{10}), the toxicological hazard rating is level Ⅲ (medium dangerous). Xylene stimulates the eyes and upper respiratory tract and, in high concentration, anesthetizes the central system. Xylenes is flammable, its vapor can form an explosive mixture with air. In case of open fire, high heat causes combustion explosion. It reacts strongly with oxidants.

(4) Ethyl acetate ($C_4H_8O_2$), it belongs to the first grade inflammable. It should be stored in low temperature ventilation and far away from fire sources. It has a stimulating effect on eyes and throat, and can cause paralysis if inhaled in high concentration for a short time. It is a low-toxic substance.

(5) Butyl acetate ($CH_3COO(CH_2)_3CH_3$), acute toxicity is less, but has a strong irritation to the eyes and nose, and in high concentrations will cause anesthesia. Flammable, its vapor and air can form a deflagration mixture. In case of open fire, high temperature can cause combustion explosion. It reacts strongly with oxidants. Its vapor density is higher than air, can diffuse at a lower place to a considerable distance, in the case of open fire will cause combustion

5.2.2 Workshop risks analysis

(1) Fire hazard and explode

Because of the physical property of solvents, the fire hazard and explode is the most important risk factor. In the spray painting operation process, the different chemicals are used in different step, so the each operation area have their own fire risk level.

The paint mixing room is the confined space and have the temperature control humidity control device and gas purification device. Even the room satisfy the safety design standards, but is also the typical accidents area.

The painting room is a separated room used confined space design for painting quality and operator safety. If there is a danger, it is easy to control and handle hazardous substances. In the operation process, painting particle form and spread increase the area of contact with air, so is dangerous when the open fire occur.

The drying room is where after electrophoresis, sealing, protective painting and top coating process to dry the vehicle body and fix painting by thermal radiation and hot air convection. It is also the place where organic solvents gather by evaporation, and have risk for fire hazard and explode.

(2) Poisoning and suffocation

In the spray painting workshops, if the toxic chemicals concentration is too high, can cause the acute poisoning accident. In especial toluene and xylene is the main problem. The operator must use the PPE correctly in workshops and choice the good quality PPE. The room ventilate ability must satisfy the international standard. And for the key area they should regularly test for toxic substances.

(3) Electrical accident

The spray painting workshop have many complex device as pervious introduction, so the electrical accident happened some time, and the electrical accident always happen with the fire hazard. The most common accident is electric shock, to cause the local organ injury and death in severe cases. These problem can reduce by risk management and maintenance. Thunder damage is always happened in the rainy area, the building design should consider and check the lightning rod regularly.

(4) Mechanical injury

In the spray painting workshops they have many machines, like the automatic cleaning machine, conveyor. The worker in the workshop should increase the safety awareness and use the PPE correctly. The machine also need check regularly to avoid the failure, and the operator must keep the reasonable distance with machines and keep the well-lit environment to decrease the mistakes.

(5)Noises

The environment noise can cause the risk for operator’s health problem. In the spray painting workshop, many machines working, friction, and collision are reason of environment noise. High intensity, high frequency and long working time under the environment noise, the health of operator get more influence. So the operator in the working area should use earplugs and for severe process isolation measures should be taken.

5.2.3 Operators risk analysis

This spray painting workshop use the advanced automatic robot spraying process, the painting mixing in the confined space, and transfer by the pipeline to reduce the damage for the operators. But even so the operators must contact the different chemicals during different processes as below:

(1) Pre-treatment process: phosphoric acid (H_3PO_4), noise

(2) Electrophoresis process: toluene (C_7H_8), xylene (C_8H_{10}), ethyl acetate ($C_4H_8O_2$), butyl acetate ($CH_3COO(CH_2)_3CH_3$), MIBK ($C_6H_{12}O$), noise

(3)Polishing process: dust, noise

(4)Paint mixing process: toluene (C7H8), xylene (C8H10), ethyl acetate (C4H8O2), butyl acetate (CH3COO(CH2)3CH3), MIBK (C6H12O), noise

(5)Paint spraying process: toluene (C7H8), xylene (C8H10), ethyl acetate (C4H8O2), butyl acetate (CH3COO(CH2)3CH3), MIBK (C6H12O), noise

(6)Paint make-up process: toluene (C7H8), xylene (C8H10), ethyl acetate (C4H8O2), butyl acetate (CH3COO(CH2)3CH3), MIBK (C6H12O), noise

(7)Drying process: high temperature

The specific operating post could exposure to risk factors, method and timetable as below:

Operator post	Risk factor	Method and time
Electrophoresis operator	Chemicals	Work in electrophoresis room 5.5h, add the phosphoric acid 0.5h
Body in white inspector	Noise	Procuring of body welding problems in environment noise 7h
Fixture installer	Noise	Install clamp device, cleaning the car body in environment noise 7h
Sealing worker	Noise	Seal the car body in environment noise 7h
Rubber strip repairer	Chemicals, noise	Procuring of rubber strip and touch toluene (C7H8), xylene (C8H10), ethyl acetate (C4H8O2), butyl acetate (CH3COO(CH2)3CH3), MIBK (C6H12O)
Paint mixing worker	Chemicals, noise	Polling the paint mixing device 7h and touch toluene, xylene, ethyl acetate, butyl acetate, MIBK
Painter	Chemicals, noise	Manual painting 7h and touch toluene, xylene, ethyl acetate, butyl acetate, MIBK

Polishing operator	grinding wheel dust, noise	Manual polishing and touch grinding wheel dust and noise 7h
Minor repair worker	Chemicals	Procuring of minor vehicle problem 7h and touch toluene, xylene, ethyl acetate, butyl acetate, MIBK

Table 5-5 profession operation risk analysis

5.3 Workshop risk level analysis

According the risk factors analysis, the two main risk factor are fire hazard and poisoning. This chapter analysis the risk damage and probability, then decide the specific risk level and related regulatory measure and IOT solution. Because the spray painting workshop have a lot of chemicals materials, so the best analysis is the Dow's fire and explosion index (F&EI), applied in actual factory from Dow Chemical Company in 1964s. The specific function as below:

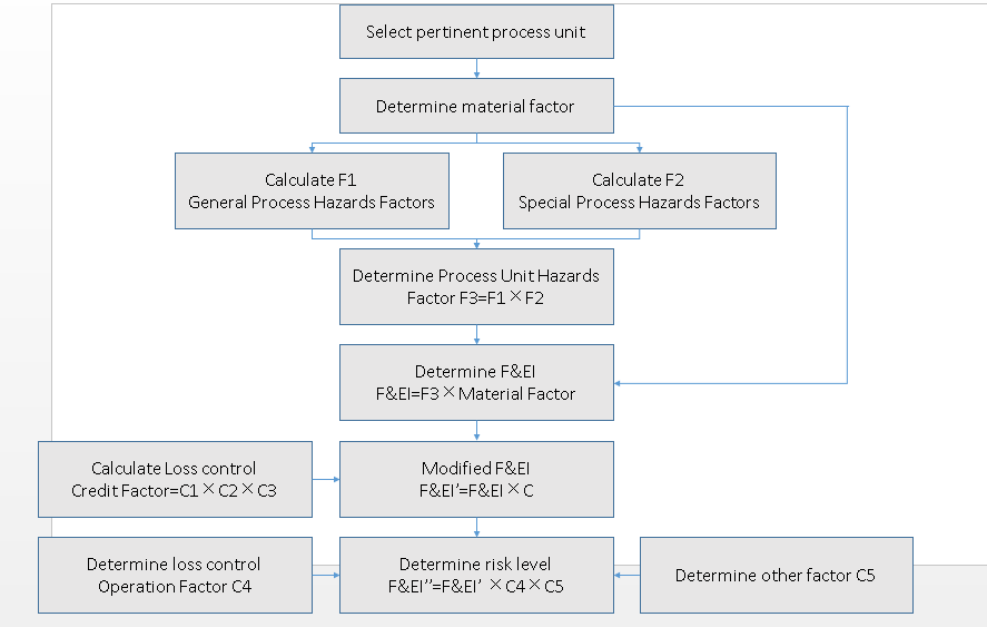

Figure 5-2 Dow's fire and explosion index evolution step

First determining the material factor, from 3.2 the most dangerous materials in spray painting workshop are benzene (C_6H_6), toluene (C_7H_8), xylene (C_8H_{10}), ethyl acetate ($C_4H_8O_2$), butyl acetate ($CH_3COO(CH_2)_3CH_3$), MIBK ($C_6H_{12}O$). According to the DOW's fire and explosion index table: the material factor of benzene (C_6H_6) is 16, toluene (C_7H_8) is 16, xylene (C_8H_{10}) is 16, ethyl acetate ($C_4H_8O_2$) is 16, butyl acetate ($CH_3COO(CH_2)_3CH_3$) is 16, MIBK ($C_6H_{12}O$) is 16. So the material factors of workshop is MF=16.

General process hazards factors have six part of factors, they are base factor, exothermic chemical reaction, endothermic chemical reaction, material handling and transfer, enclosed indoor process units, access, drainage and spill control.

(1) Exothermic chemical reaction. There is no exothermic reaction during process, so the factors is 0.

(2) Endothermic chemical reaction. There is no endothermic reaction during process, so the factor is 0.

(3) Material handling and transfer. The workshop storage solvent and painting at first floor used the storage tanks, so the factor is 0.85.

(4)Enclosed indoor process units. The workshop is a confined space but using the mechanical ventilating device, the room temperature (18℃) higher than benzene, toluene and ethyl acetate, lower than xylene and butyl acetate, and the storage lower than 1000 gallons. So the factor is 0.3*50%=0.15.

(5)Access. The workshop have safety access but the firefighting truck cannot go in the workshop, so the factor is 0.35.

(6)Drainage and spill control. The workshop have no emission pool around, so the factor is 0.5.

Sum up the above, general process hazards factors is F1=1+0+0+0.85+0.15+0.5=2.5.

Special process hazards factor have 12 items to be analysis, the possibility of an accident is decided on special process in most case.

(1)Toxic material. Health factor of benzene is 3, the toluene and xylene are 2, ethyl acetate and butyl acetate are 1. So the factor is 0.2*(3+2+2+1+1)/5=0.36.

(2)Sub-atmospheres pressure. The workshop is positive pressure, so the factor is 0.

(3)Operation in or new flammable range. The workshop have combustible chemical, no inert gas protection, so the factor is 0.5.

(4)Dust explosion. The workshop have no dust risk factor, so the factor is 0.

(5)Relief pressure. The painting pipeline pressure is 500kPa, the formula as below:

$$Y=0.16109+1.61503(500/1000)-1.42879(500/1000)^2+0.5172(500/1000)^3=0.68.$$

(6)Low temperature. The workshop cannot be lower than room temperature, so the factor is 0.

(7)Quantity of flammable/unstable material. Hypothesis the xylene storage weight is 20 tons, the total gross heating value is $(20000kg/0.454)*(17.3*10^3)=0.76*10^9$ Btu, and the xylene flash point is 30℃(curve B), so the factor is 0.38.

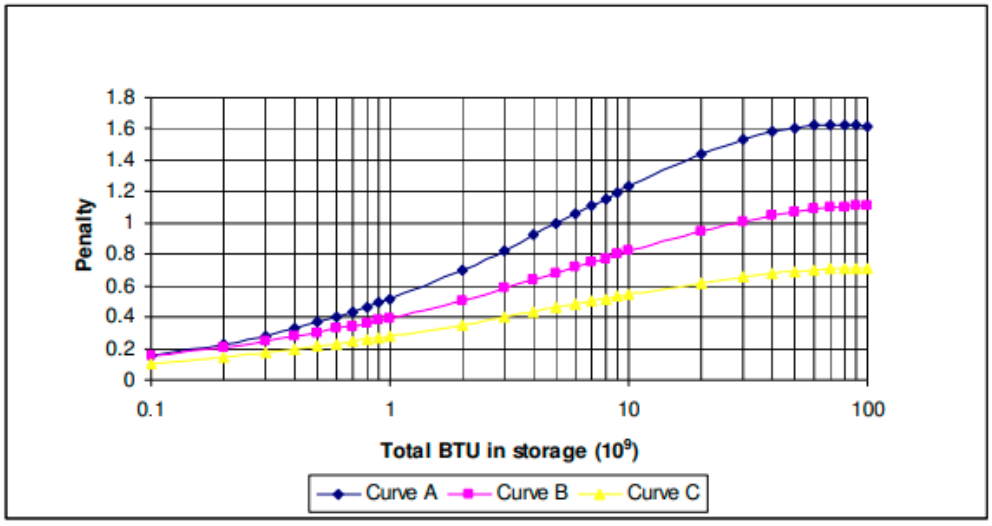

Figure 5-3 Penalty and total BTU in storage

(8)Corrosion and erosion. The chemicals of workshop don't have corrosive, so the factor is 0.

(9)Leakage-joints and packing. The sealing of storage tank may have minor leakage because of technology, so the factor is 0.1.

(10)Use of fired equipment. Ban the fire in the spray painting workshop, so the factor is 0.

(11)Hot oil heat exchange system. The workshop have no system as that so the factor is 0.

(12)Rotating equipment. The workshop have the flow line production, don't rotate the equipment, so the factor is 0.

Sum up the above, the special process hazards factor:

F2=1+0.36+0.5+0.68+0.38+0.1=3.02.

So the process unit hazard factor F3=F1*F2=2.5*3.02=7.55.

The fire and explosion index F&EI=F3*MF=7.55*16=120.8.

F&EI Index Range	Degree of Hazards
1 – 60	Light
61 – 96	Moderate
97 – 127	Intermediate
128 – 158	Heavy
159 – up	Severe

Table 5-6 degree of hazards

So this spray painting workshop risk degree is intermediate level.

Loss control credit factors represent the loss control protective features that have been statistically in preventing serious incidents. Safety control measure can avoid probability of accident and reduce the damage of risk. It divide into process control credit factor C1, material isolation credit factor C2 and fire protection credit factor C3.

For process control credit factor C1, emergency power factor is 1 because of no emergency power, cooling factor is 1 because of no cooling system, explosion control factor is 1 because of no explosion control system, emergency shutdown factor is 1, computer control factor is 1, inert gas factor is 1, operating instruction/procedures factor is 0.95 because that they organize safety exercise every year, reactive chemical review factor is 1, other process hazards analysis factor is 1. So the total C1=0.95.

For material isolation credit factor C2, remote control valves factor is 1 because no control system, dump/blowdown factor is 0.97 because the spare tanks are outside the workshop, drainage factor is 1, and interlock factor is 1. So the total C2=0.97.

For fire protection credit factor C3, leak detection factor is 0.97 because of combustible gas detector in workshops, structural steel factor is 0.96 because of steel structure with fire resistance coating, fire water supply factor is 1, special system factor is 1, sprinkler system factor is 0.9 because of auto sprinkler system, water curtain factor is 1, foam factor is 1, hand extinguisher/monitors factor is 0.9 because they are many hand extinguishers in the workshop, and cable protection factor is 1. So the total C3=0.97*0.96*0.9*0.9=0.75.

C=C1*C2*C3=0.95*0.97*0.75=0.69

Then, the modified F&EI'=F&EI*C=120.8*0.69=83.352.

According the risk degree table, it is the moderate level. The risk degree is not bad, but if we use the IOT solution in the workshop, the risk degree will continue to decline.

5.4 IOT solution in spray painting workshop

In the Dow's fire and explosion index, the factor value just depends on whether this factor is exist or not, but don't consider the people ability and management state in company.

Next we will use the IOT technology for the operational process, to increase the efficiency and safety, and get the related loss control credit factors.

5.4.1 IOT solution in detector

In this spray painting workshop, the detector in the room, also alarm and flash in the room when an accident happens. The supervisor cannot know the situation outside and rescue and maintenance person be a delay in arriving at the room. If we change the detector into the some with a network transmission function. That will save a lot of time and have a better chance of reducing the risk.

For the sensor used in the confined space, we put emphasis on discussing the gas sensors, in especial, the oxygen concentration sensor, toxic gas sensor and flammable sensor. With the development of industry now, these three functional sensors are

integrated together. We found a product that can satisfy our safe requirement in the confined space, it named NA-300 gas sensor (wireless version). Than we could analysis this product parameter to make sure it can use in the confined space. This is not an advertisement, it is a feasibility analysis to IOT solution in the confined space.

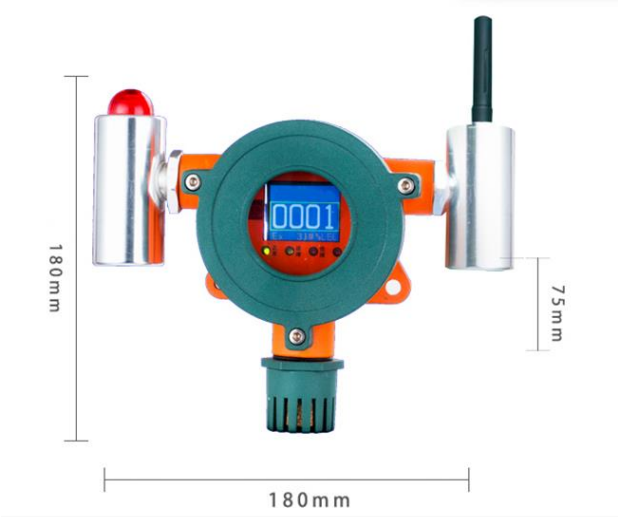

Figure 5-4 NA-300 gas sensor

Signal output	433m wireless signal
Measuring object	toxic gas and flammable sensor
Sample mode	Dispersive
External material	die-casting aluminum
Measurement accuracy	±10%
Protection grade	IP66
Testing principle	Electrochemical/ Catalytic combustion type/ Photoion/ infrared
Display mode	TFT LCD
Dimension	180mm*180mm*75mm
Working voltage	DC 14V-35V
Pressure	86kpa-106kpa
Anti-hazard classification	Ex dll CT6 Gb
Accommodation mode	Infrared and does not open the cover
Usage environment	Temperature:-20℃-70℃ Humidity: 10%-95%

Table 5-7 gas sensor parameter

Gas	Range	Error	Min value	Low alarm value	Response time
O2	0-30%VOL	<±3%FS	0.1%VOL	19.5%VOL	<30s
Ex	0-100%LEL	<±3%FS	1%LEL	20%LEL	<30s
CO	0-1000ppm	<±3%FS	1ppm	50ppm	<30s
H2S	0-100ppm	<±3%FS	1ppm	10ppm	<30s
SO2	0-100ppm	<±3%FS	0.1ppm	10ppm	<30s
NO	0-250ppm	<±3%FS	1ppm	10ppm	<30s
NO2	0-20ppm	<±3%FS	0.1ppm	5ppm	<30s
CL2	0-20ppm	<±3%FS	0.1ppm	5ppm	<30s
NH3	0-100ppm	<±3%FS	1ppm	10ppm	<30s
H2	0-1000ppm	<±3%FS	1ppm	50ppm	<30s
HCN	0-50ppm	<±3%FS	0.1ppm	5ppm	<30s
HCL	0-20ppm	<±3%FS	0.1ppm	5ppm	<30s
PH3	0-1000ppm	<±3%FS	0.1ppm	5-10ppm	<30s
O3	0-20ppm	<±3%FS	0.1ppm	5ppm	<30s
CLO2	0-20ppm	<±3%FS	0.1ppm	5ppm	<30s
C2H4O	0-100ppm	<±3%FS	0.1ppm	10ppm	<30s

Table 5-8 Measuring gas parameter

The sensor data is from their website, it list the common toxic gas and flammable gas. The measurable range, error, the minimum measurable value, the lowest alarm value, and the response time. And next table will show the main toxic gas requirement in the law.

Toxic gas	TWA	STEL	IDLH	MAC
NH3	25	35	500	30
CO	25	-	1500	30
CL2	0.5	1	30	1
HCL	10	4.7	50	0.3
H2S	10	15	300	10
NO	25	-	100	-
SO2	2	5	100	15
VOC	50	100	-	-

Table 5-9 Gas safety requirements

VOC= volatile organic compounds;

TWA= the eight-hour statistical weighted average;

STEL= short-term exposure concentration in 15 minutes;

IDLH= immediately dangerous to life or health;

MAC= Maximum allowable concentration of workshop (mg/m3);

The sensor have a low alarm value that inform operator the risk situation. While, the wireless function could transfer the signal out of the confined space, so the supervisor could know the gas concentration too, and take action when the operator do not pay attention to the alarm. The unit used in the law is the [mg/m3], the NH3 MAC=30 [mg/m3], after the conversion, 22.4×30/17=39.53 [ppm], so it mean the workshop, that is the confined space, the maximum allowable concentration is 39.53 [ppm], and the sensor low alarm value is 10 [ppm], it work fine and satisfy our goal to keep safe. Other data is the same conversion.

At the same time, using the QR code in the sensor maintenance management, maintenance personnel will be able to view the instrument maintenance record at any time. Instead of going to the workshop to check the maintenance hangar above the sensor. The operation method is as follows:

To improve the working efficiency in confined space, we should make the two-dimensional bar code for each device or PPE, and sum the information that include the device information, checking record, maintenance record and etc. To realize paperless management, operator can check the device information in any time, update the working record, and the superior can monitor the device running state at any time.

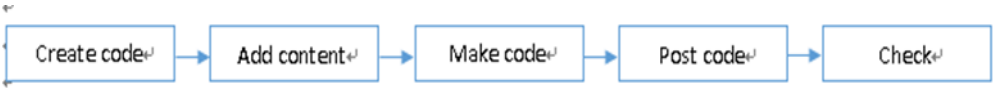

Figure 5-5 Usage process of two-dimension bar code

The two- dimensional bar code usage process is:

(1). Create two- dimensional bar code for each device

There are many two- dimensional bar code management platform and generators. We write the device information in the form and update the file relative the device. For example, we write the NA-300 gas sensor information into the QR code generators, and we get the QR code below:

Figure 5-6 QR code for our gas sensor

This QR code include the information as below:

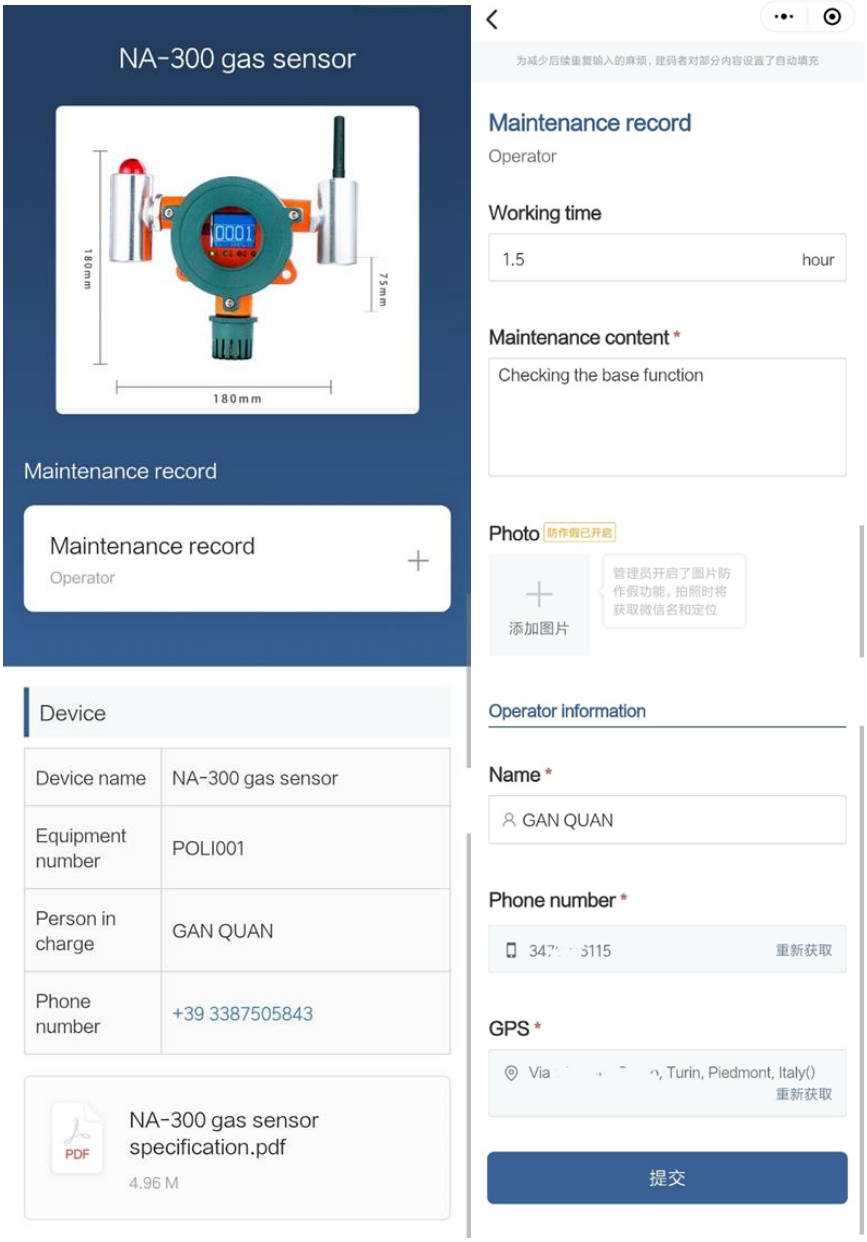

Figure 5-7 Content in our QR code and maintenance record

When the operator scan the QR code of the gas sensor, he could check the device information and write his testing result in it. The supervisor can check the operator record at the same time in the office, and judge whether the operator are correct or not. The supervisor view is below, he have additional judgment function.

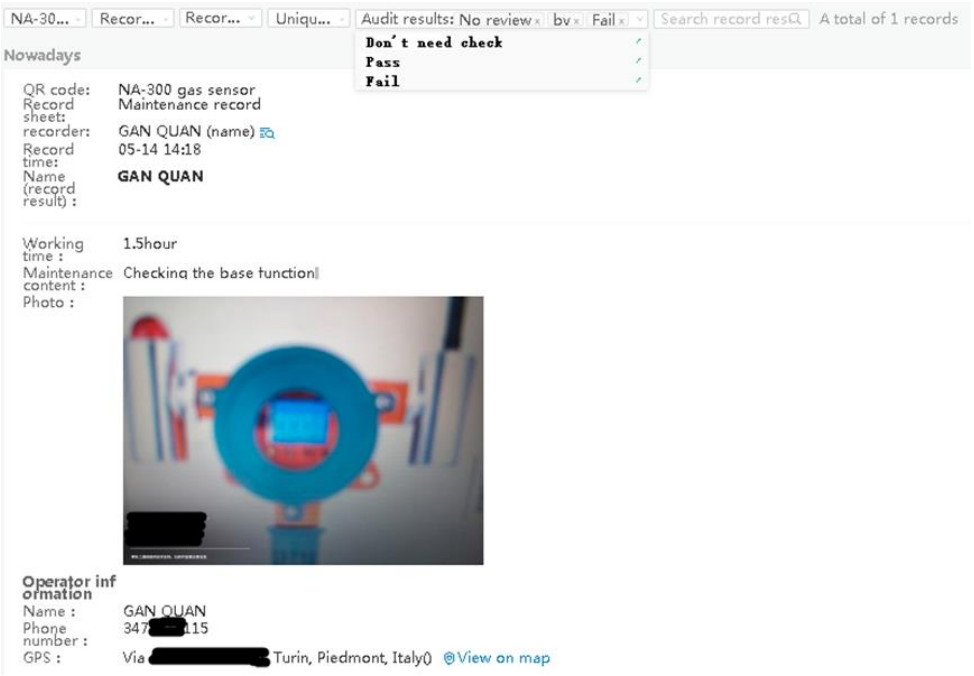

Figure 5-8 Administrator interface

This operation record could use smartphone, pad or PC to do, and the supervisor can check the working process whenever and wherever. The maintenance form finished, the QR code do not need change. The form in the QR code can be replaced in different type, like usage record, then the QR code can use as the PPE usage record. When the operator need use the PPE, he can scan the QR code, and system remember the time and user, it is very convenience.

(2). Make two- dimensional bar code

In the common environment, we can use the office printer to produce the two-dimensional bar code as paper editor. But if we use the device with two- dimensional bar code in the confined space, there are always have a dark, wet and instability environment. So we will need to adopt a laminated film and adhesive sticker method, to ensure that you can use it in an extreme environment. Here is a comparison of the different options below:

Method	A4 paper	A4+ adhesive sticker	Label machine	Advertising agency
Compose type	A4 label compose	A4 label compose	Pack to download	Agency compose
Cost	0.02/unit	0.04-0.3/unit	0.02-0.1/unit	>0.5/unit
Device	Printer	Printer	Label printer (about 200€)	No
Material	Paper	Art paper/ Self-adhesive	Art paper/	PVC/ Acrylic/Metal

		paper	Self-adhesive paper	

Table 5-10 Different type of QR code

If the company need specific design, they can have their layout design in PC. And if the using environment is extreme, the two- dimensional bar code still could be made by other material. The A4 paper and adhesive sticker+A4 paper is suitable for small and medium number device, the cost is low and production is fast.

(3). Post and check two- dimensional bar code

The location of posting cannot effect the operation of the device, and the size of the code also cannot effect the normal working. After posting, the operator should check the code could be used and test it.

If we have a lot of number of same type device, there are a module form to done, then we can import the date in the excel file to get a quick production of large number QR code, reducing the workload.

Maintenance staff and operator staff scan a same code can enter in different form to reach the division of labor. Because the authentication, the writing form is only open to the staff, and the staff log in the account by their working ID number. The strange only can see the device information, but not the operation form, it is a safe protection method. Now we use the QR code system online, this function can be realize by different social account. In the company application, the account can be change with their specific staff account in the internal network. And to avoid the staff counterfeit date, the code could be set, only scanning in specified time and location by GPS function to make sure the date correct.

By using a remote measuring sensor and QR code management, we change the fire protection credit factor C3, original leak detection factor is 0.97, now it can be reduced at 0.94. Because remote manage reduce risk that patrols enter the danger zone, while more related person in charge can check the sensor value in the same, it increases the probability that the danger will be discovered.

5.4.2 IOT solution in PPE management

At first, according the previous analysis, the PPE requirements of painting workers as follow:

Post	PPE
Electrophoresis loading worker	Gas mask, Rubber gloves, Chemical protective clothing
Body in white inspector	Earplugs3M110(SNR=27dB), Protective gloves
Fixture installer	Earplugs3M110(SNR=27dB), Protective gloves
Sealing worker	Earplugs3M110(SNR=27dB), Protective gloves

Rubber strip repairer	Earplugs3M110(SNR=27dB), Protective gloves
Paint mixing worker	Gas mask, Rubber gloves, Chemical protective clothing, Earplugs3M110(SNR=27dB)
Painter	Gas mask, Rubber gloves, Chemical protective clothing, Earplugs3M110(SNR=27dB)
Polishing operator	Earplugs3M110(SNR=27dB), N90 face mask, Anti-smashing shoes, Anti-mechanical damage gloves
Minor repair worker	Gas mask, Rubber gloves, Chemical protective clothing

Table 5-11 PPE requirement

For gas mask and chemical protective clothing, the mask needs to be replaced with a filter element, they take a long time to use and are relatively large items. The RFID technology can use in them.

RFID is used in the production process, transport & logistics, and commercial sales. Because the people can track the job step, goods location, personal identity verification and payment. Many function of the RFID is very useful in the confined space operation, like the personal identity verification and tracking the device. The RFID could be set in the cash, passport, clothes and other items. I think this technology could be used in the device management like the QR code, when the environment is not good to scan the QR code, the RFID is still work to track the device, its range of recognition from 1cm to 100m depend on the type.

The PPE is suitable to use the RFID technology. The PPE is divide of protection suit, protective glasses and mask, ear protector, protective gloves and protective cream. This kind of item is not suitable to post the QR code, and before if the operator would use the PPE, they need to write the form to describe what they used and how the situation of the PPE, the time and the location is not always correct, because they write the form after the working time. So if the RFID is set in the PPE, the operator just need get the PPE and close to the RFID reader in the room, then wearing the PPE to work. This process will save time, and the time is remembered by the RFID reader, the supervisor can check the record any time and have a better management of the PPE usage to keep the operator safe.

Regulations	Band	Range	Remarks	Cost
Unregulated	120-150kHz	10cm	Animal identification, factory data collection	1€
ISM band	13.56 MHz	10cm-1m	Smart cards. ISO-non-compliant memory cards. ISO-compatible microprocessor cards.	0.5-5€
ISM band	865-868 MHz	1m-12m	EAN, various standards; used by railroads	0.15€
ISM band	2450-5800	1m-2m	802.11 WLAN, Bluetooth standards	25€

	MHz			

Table 5-12 Type of RFID technology

The company can according the usage range and cost to select the RFID label band, the PPE always need be cleaned after use, so the RFID label must waterproof, resistant to corrosion and reliability. In the market there are some company to produce the RFID label to satisfy our requirement, like RF-HDTDVBB-N1 and RF-HDT-DVBE-N0. This RFID label is used in the fire department of Krefeld, Germany, they sew the label into the fire suit, RFID label can sustain many time cleaning and disinfection until the fire suit be replaced. In the confined space, the operator working environment is similar as the fireman, so this example have a very good reference significance.

Name	RF-HDTDVBB-N1
Categories	RFID tags
Style	Encapsulated
Technology	Passive
Frequency	13.56MHz
Memory Type	Read/Write
Writable Memory	2kb (User)
Standards	ISO 15693, ISO 18000-3
Size / Dimension	22.00mm Dia x 3.00mm
Operating Temperature	-25°C ~ 90°C

Table 5-13 RF-HDTDVBB-N1 parameter

Because of the RFID technology, it will reduce the probability that without PPE will enter the work area, or using expired PPE. The safety of the factory is guaranteed. While the process control credit factor C1, related factor that operating instruction/procedures factor will be reduce, original value is 0.95, now the value could be 0.92.

5.4.3 IOT solutions in work permit

When we using the IOT management, to use the digital work permit. The operation environment date can get from the sensor, the safe situation can update after the test in time, according the update date the system can recommend PPE for the operator. And the operator just need to read the all the date provided in the digital work permit and verify his staff card on the smartphone. Because the work permit on the internet, the supervisor and operator can check, write and confirm anytime and anywhere, it would

save a lot of time, staffs don't need to learn anything skills extra.

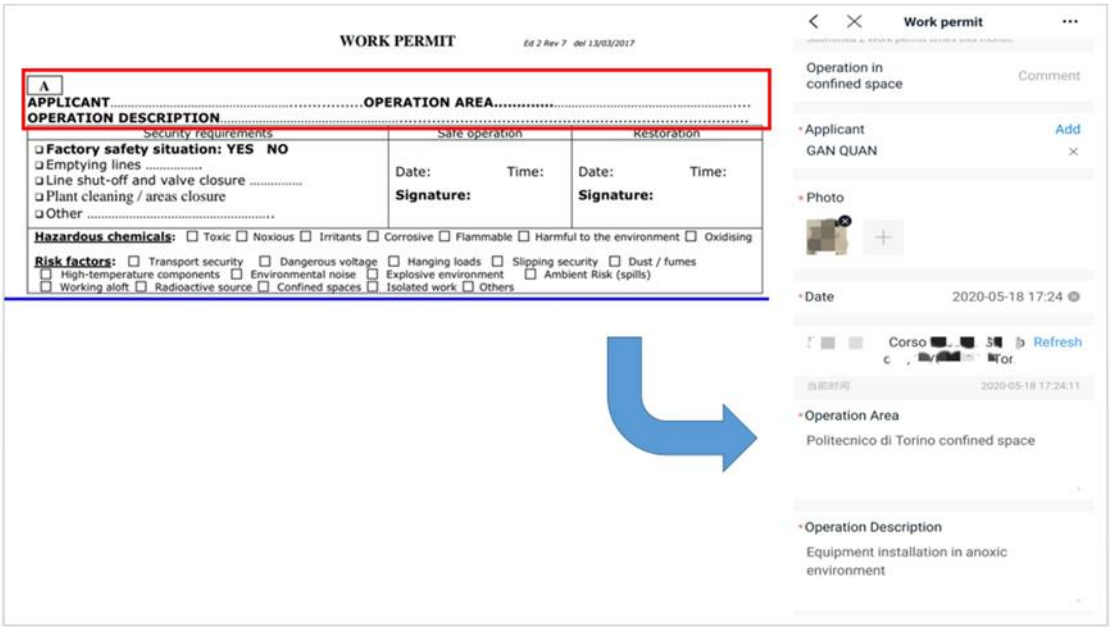

Figure 5-9 Application information in smartphone App

We transform the paper work permit to the digital work permit in the smartphone App. The first step of using digital work permit is build a work team with all of the staffs in the company, it could use the staff ID number, phone number and photo to identify each staff. In the digital work permit, the applicant must in the company group, and take a photo when they write this work permit, it is the method to secure staff identity and company data. While the location (GPS) and date also be updated in the work permit, the supervisor can check this information. Then the applicant write the operation area information and operation description in the form.

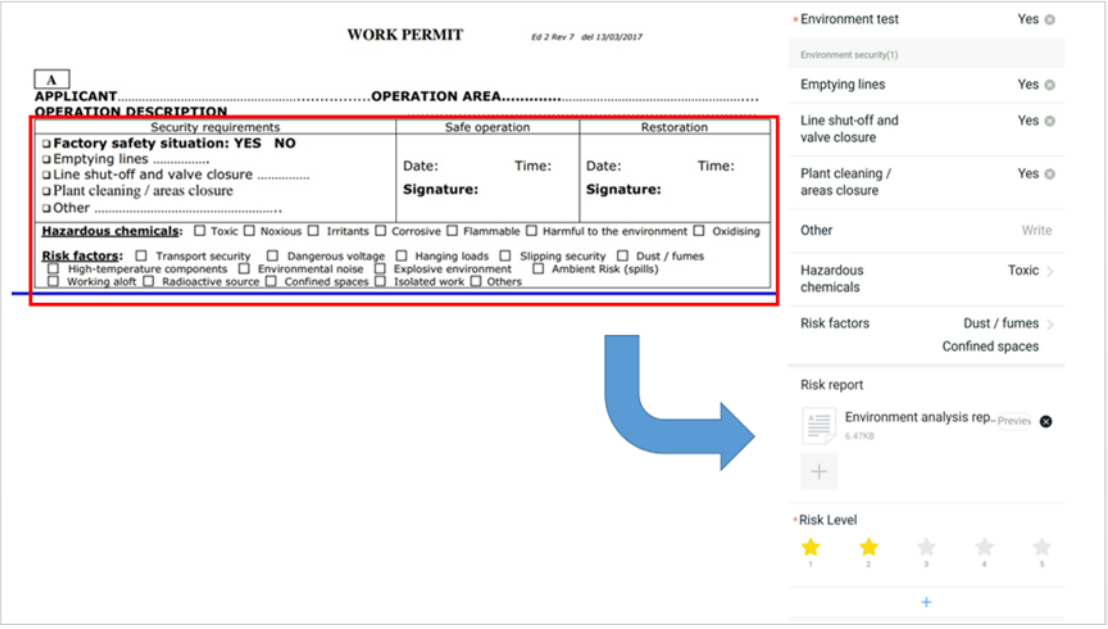

Figure 5-10 Environment test information in smartphone App

In the second part, the test person should input the options about the environment in the confined space. And update the risk analysis result already done before and according to the risk assessment to give the level. It is very easy to show the risk for the operator. For hazardous chemicals and risk factors, they are multi-choice.

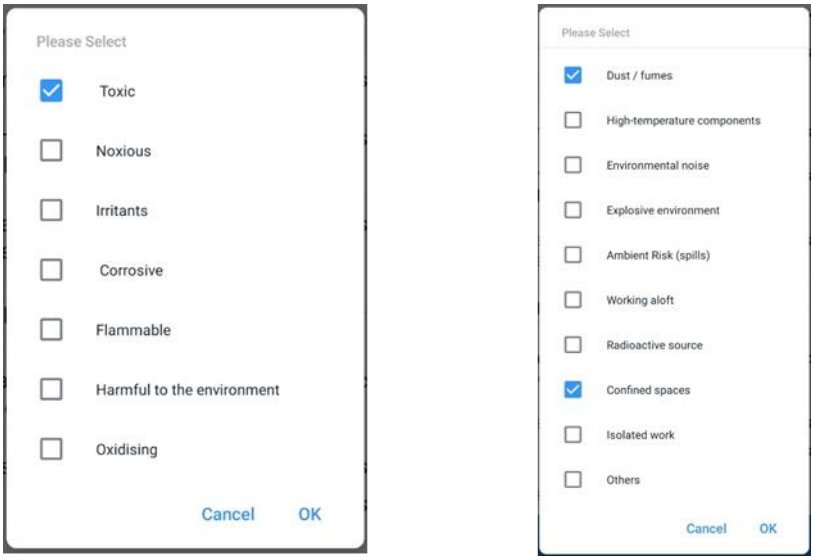

Figure 5-11 Multi-choice interface

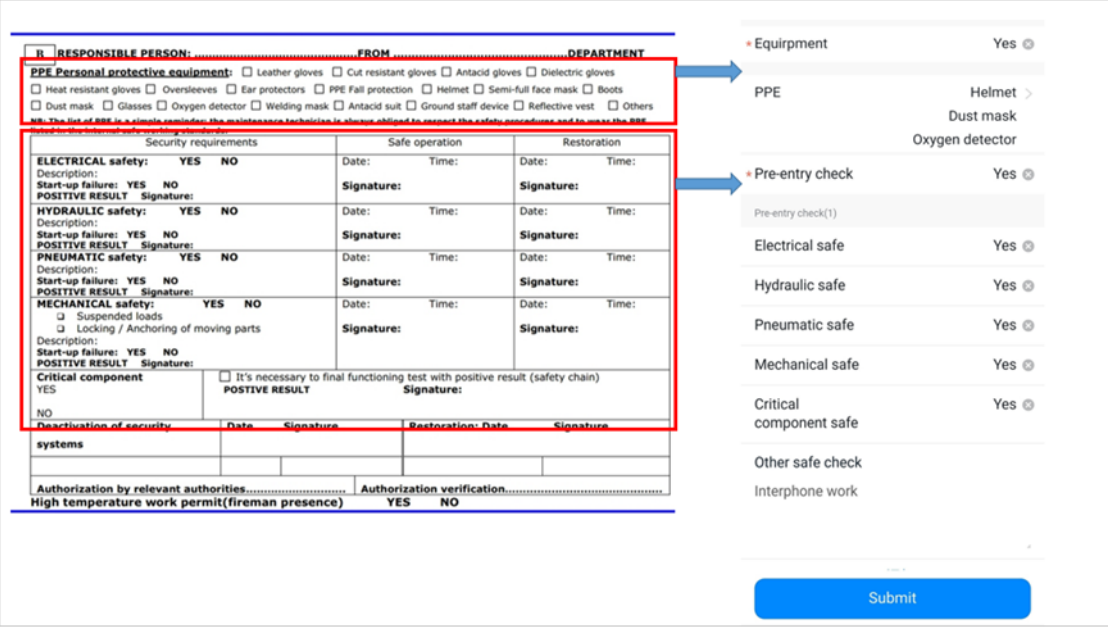

Figure 5-12 Equipment and pre-entry check in smartphone App

The PPE is the same function as environment test, the staff choice the suitable PPE according the risk assessment situation. It is also a multi-choice options.

Before the operator enter in the confined space, the team leader or supervisor in the field must check the all the situation again to keep safe. They can write information in this part and submit this work permit.

After writing the work permit, it would be send to the different manager. If the application do not finish environment test, this work permit would be fail. If the option is yes, this work permit would be sent to the HSE apartment manager, he check the work permit and pass. This work permit would be sent to second manager of equipment apartment, they will consider the equipment application, and give their advices, they can write the equipment situation and change the options of PPE, then would confirm this work permit. After, the third supervisor receive the work permit, he would check the operator equipment and any risk factor in the field, and confirm. Finally, the manager of all the project could confirm this operation after three manager confirm and the work permit could make a copy to others to supervise this operation.

This process divide confirmation to different supervisor, if the operation work start, many manager would check the work permit and signature. At least three person to confirm can reduce the error by person.

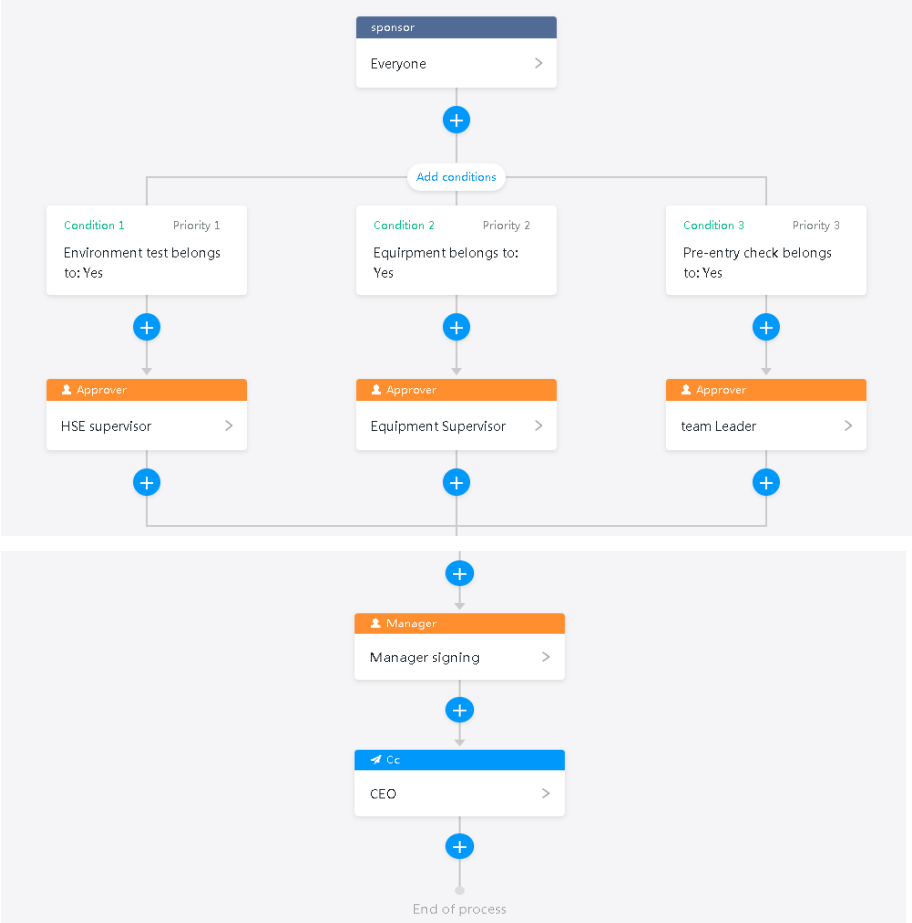

Figure 5-13 Approval process

In the approval process, the manager must signature to keep the authenticity of information. Because the work permit on the internet, the file will be arrived as soon as possible, the manager can approval the work permit in the PC or phone. And if they find some problem in the work permit, they can talk to the application in the software or change the information by themselves.

After operation is finished, the team leader or other checking person can write the comment for this work permit. They would write the operation result and signature.

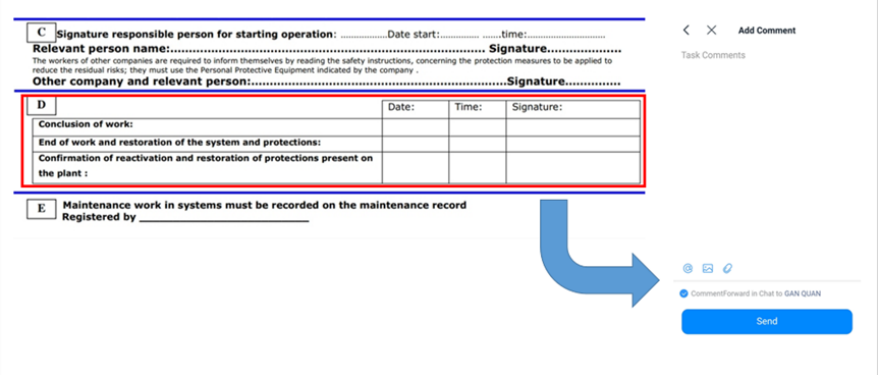

Figure 5-14 Comment for working results

The digital work permit increased work efficiency, while ensures that problems in the factory can be eliminated more quickly, then reducing the risk problems. This can be categorized as C5, giving a 0.98 value for contribution.

5.5 Updated F&EI" value calculation

On the basis of the original value, considering the IOT solution factor, the final index as below:

F&EI''=F&EI'*C4*C5=83.352*0.94*0.92*0.98=70.64

From the table, the risk degree is moderate but has been a significantly reduction.

6 Conclusion

This paper analysis the spray painting workshop risk management state, then build the evaluation of risk degree, at last giving some solution based on IOT. The effectiveness of the program is evaluated and demonstrated, and the following results are obtained. Through the analysis of the current situation of personnel safety management in painting workshop, the paper studies the existing risks and the main causes of safety accidents, and then analyzes the main causes of personnel safety accidents in the workshop.

Based on the current situation of safety management of construction personnel in painting workshop, this paper adopts Dow's chemical fire and explosion index to analyze personnel, machine, environment and management. Using the Internet of things technology, the security management system solution is proposed, including remote monitoring of equipment, monitoring of wearing PPE and the idea of electronic permit form. The risk degree decrease from 83.35 to 70.64. The safety factor has been significantly improved. Meanwhile, the work efficiency and modernization of the painting workshop have also been improved, which is more in line with the design concept of Industry 4.0.

In further study, also need to go into details of the following ways, first of all, this article only on the personnel factors of safety management was improved, because the factory project has oneness, researchers have greater liquidity, making the Internet of things technology solutions has certain limitation, especially the circuit for plant safety related research, after worth further research. At the same time, the Internet of things technology is a huge system, in addition this paper mentioned a few core technology, there are many other technology didn't use to, and IOT renovation to the factory, is in itself a huge funding needs of tasks, many companies can't afford, this makes the actual factory, managers often choose the sidelines, so for the cheaper more convenient Internet solutions, still need to try in practice.

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