Introduction of the New Safety Concept "Safety2.0" to Reduce the Risk of Machinery Accidents

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Abstract –

In order to dramatically improve the productivity and safety of tunnel construction, we are developing a new construction production system "Shimizu Smart Tunnel". Based on the concept of "Digital Twin", it utilizes data sensing technology and information communication technology to acquire all kinds of data from people, machines and environment at construction sites. Using the data, we have implemented "Safety 2.0" that realizes collaborative safety technologies between humans and machines and "Safeguard support system" that reduces human error. We introduced a "Human-Machine contact risk reduction system" at actual sites.

Keywords –

Safety2.0; collaborative safety; risk reduction system; Safeguarding Supportive System

1 Introduction

Japan is facing the problem of a declining birthrate and an aging population and a decline in the working-age population. In the construction field, the number of engineers and skilled workers has decreased, and the construction production system has to be changed. In 2017, construction-related casualties accounted for about 30% of all industries, of which more than 70% of fatal accidents were related to falls, construction machinery and dropped loads.[1] The rate of work-related fatalities per 100,000 workers in each country shows that in some countries the rate is lower than in Japan. (Figure 1) [2] Especially in the UK, the rate of decline is very large. We have to learn from the West how to improve occupational safety. [3],[4]

The Ministry of Land, Infrastructure, Transport and Tourism has announced "i-Construction," which utilizes new technologies such as digital data acquisition, ICT, IoT, AI, and robotics. By 2025, it aims to improve productivity by 20% and solve problems in the construction sector. The Ministry of Health, Labor and Welfare aims to realize a society where people can work in good health and peace of mind in a safe environment free from occupational accidents. In 2022, it has set a target to reduce the number of work-related fatalities in the construction industry by more than 15%. [5] The Ministry of Economy, Trade and Industry has announced "New Robot Strategy" in 2015, aiming to strengthen and spread the use of robots, to popularize them, and to acquire international standards.

A robot is defined as a machine that has three elements: sensor, intelligence/control system, and drive system. Construction machinery, like automobiles, is expected to accelerate remote unmanned operation, automatic operation, and robotization.

In this paper, we report the results obtained through the practical introduction and trial of the human-machine contact risk reduction system to the construction site.

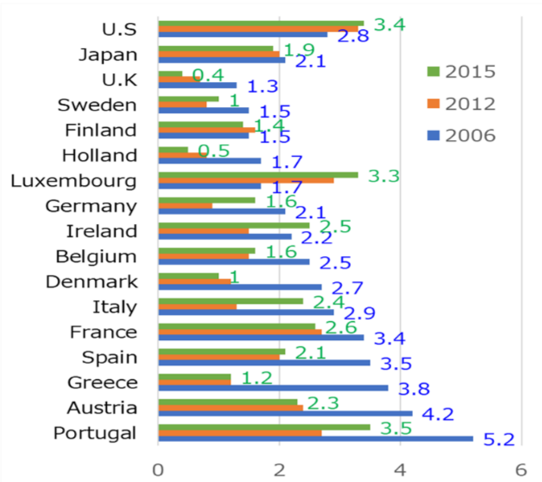

Figure 1. Comparison Occupational Fatality Rate (per 100,000 people). Processing based on [2].

2 Improved safety and productivity

In the construction field, it is required that humans and machines work together to ensure work safety.

2.1 The Concept of Safety 2.0

The human-machine collaborative work consists of a human area, a machine area, and a collaboration area. Here, Safety 2.0 is explained. (Figure 2) [6],[7],[8]

Safety0.0 is a state in which there is no concept of machine safety in the machine domain and it is a hazard to humans, and the collaborative domain is also the hazard domain. A state in which we try to ensure overall safety with only human safety technology. Safety1.0 is a state where the concept of machine safety has been introduced into the machine domain, and together with human safety technology, each ensures safety. The principle of isolation and suspension is established by fool proof and fail safe. Safety 2.0 is a state in which a collaborative safety mechanism that shares information using ICT is incorporated in each area of man and machine, enabling safe work in the area of collaboration.

In the construction field, it is difficult to realize the principle of "Isolation and Suspension" in the construction field, and the avoidance of residual risk is in the state of Safety 0.0, which largely depends on human safety technology.

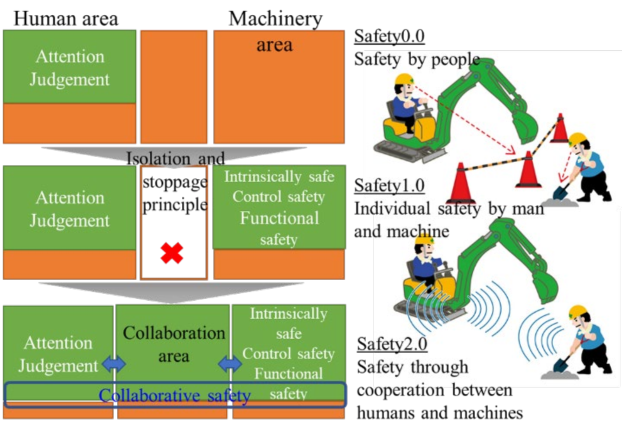

Figure 2. The Concept of Safety 2.0

2.2 Safeguarding Supportive System

In the international standard ISO12100, risk reduction measures for ensuring safety are based on an essentially safe design, safeguarding measures, and a three-step method based on provision of information on use. However, measures to avoid residual risk depend on human safety technology, and human error leads to serious occupational accidents.

There is a misunderstanding that human error can be avoided by attention, education/training/motivation, and multiple checks. The error occurrence rate of a person increases when the consciousness mode is fatigued, strained, or unsteady. Moreover, even if a person understands the work standard and can execute it, there is a case where the improvement of the productivity is prioritized, and the work standard is not intentionally observed. People must be aware that they have the property of causing an error.[9]

Dr.SHIMIZU et al. have reported comprehensive safety management that incorporates a "Safeguarding Supportive system" that prevents human error by combining appropriate ICT equipment.[10],[11]

In contracting duties, construction workers are required to constantly anticipate changes in the surrounding environment and residual risk and implement appropriate protection measures in addition to the original skill implementation.

The relationship between the hazard and the occurrence of harm and the "Safeguarding Supportive system" is shown in Figure 3.

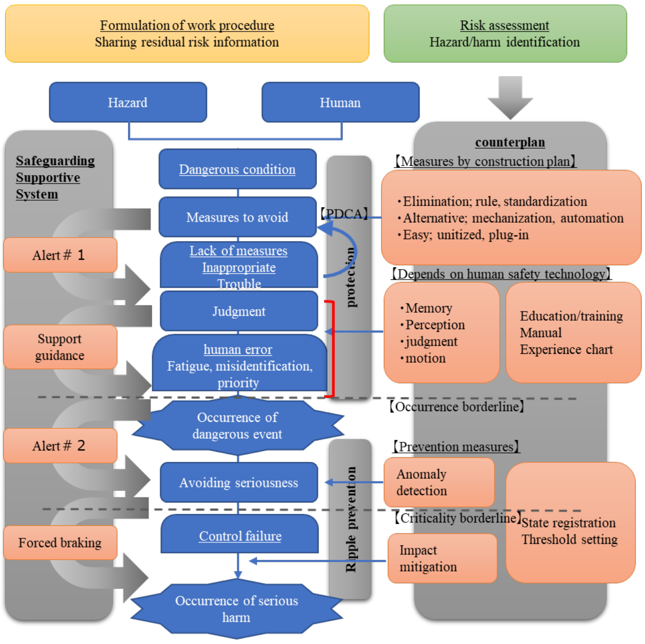

Figure 3. The relationship of harm and the "Safeguarding Supportive system"

2.3 Shimizu Smart Tunnel

Shimizu Corporation is advancing digital reform of its construction production system. In the field of civil engineering, in 2016, we started the development of "Shimizu Smart Tunnel". This system is based on the concept of "Digital Twin". (Figure 4)

In the physical space, various sensors, control devices and communication devices are installed on people and machines, and material supply, position and orientation of people and machines, movement status, condition, work environment, safety and quality, engineers and skilled labor Workers and production process information are aggregated on a digital platform

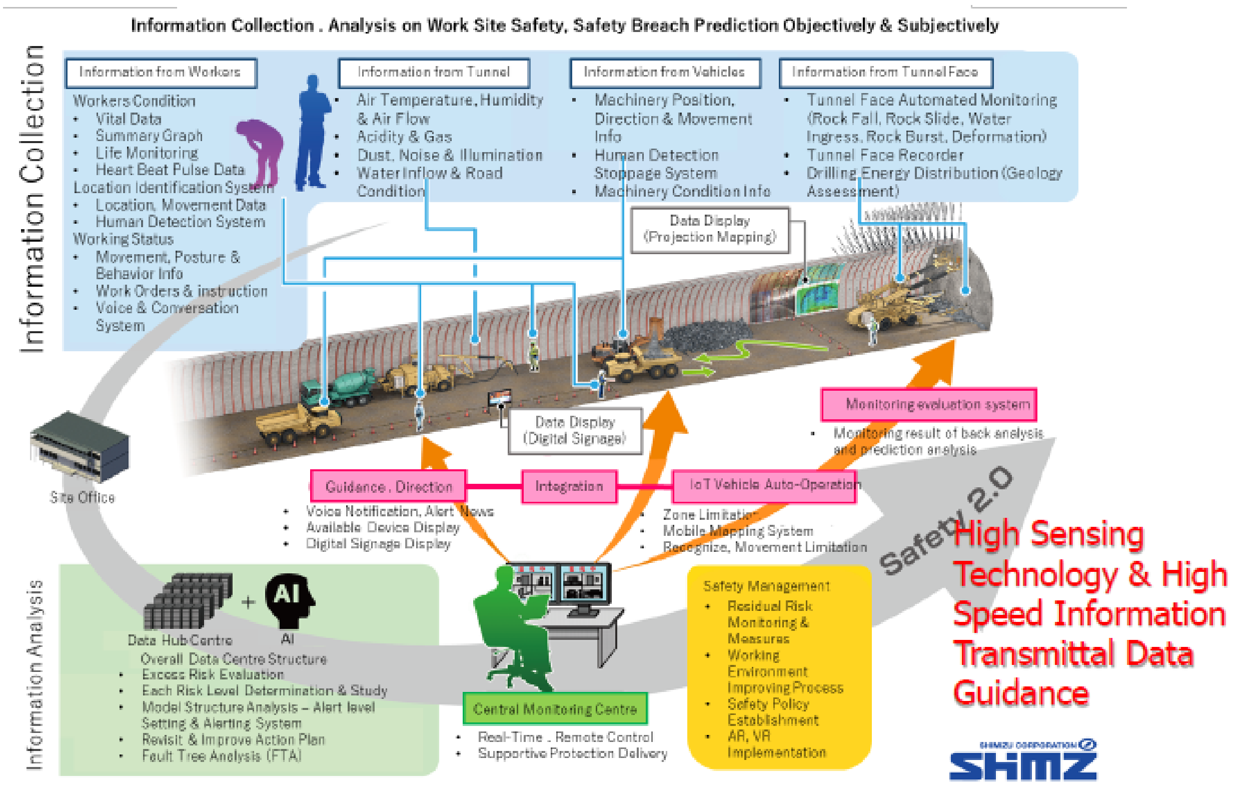

Figure 4. The Concept of Shimizu Smart Tunnel

in cyberspace. It is equipped with a support system that provides feedback to the site in real time through AI analysis and simulation analysis of information that changes moment by moment.

In tunnel construction, the collapse of the face and the contact between people and machines lead to serious disasters. The Shimizu Smart Tunnel will incorporate a safety support system to eliminate these serious disasters.

3 A Practical Approach

The development team of the safety support system selected the actual construction site and tried to introduce Safety2.0 from Safety1.0 by the practical approach.

3.1 Preparation

The safety support system development team held a workshop with experts. In addition, we investigated the safety awareness of the people concerned at all tunnel sites of Shimizu Corporation and reviewed and created safety teaching materials. we learned the following lessons.

- It is important to understand the concept of machine safety and prerequisites.
- It is necessary to rebuild an appropriate safety philosophy through appropriate risk assessment.
- Framework is important to implement and function Safety 2.0.

3.2 Goal Setting

The goals were set as follows.

- Development of a risk assessment method that is compatible with machine safety.
- Site managers and workers understand the concept of safety system.
- Site managers and workers should learn how to operate the safety system and adjustment procedures.
- Obtain "Safety 2.0" certification for the implemented safety system.

3.3 Scope of Development

In general, the construction of mountain tunnels is a cycle work that repeats blasting and mechanical excavation work, mucking work, steel support work, concrete spraying work, and rock bolt installation work. Within 100m from the face (tunnel excavation surface), the machines will be replaced, and the work will continue day and night. The composition of the machines used in the construction is decided at the time of formulating the construction plan, but the risk was extracted by applying a new risk assessment method to the site already in operation.

The development target was set to "mucking work" from the viewpoint of developing "collaborative safety between humans and machines", and we developed the " Human-Machine contact risk reduction system".

3.4 Zoning of Work Areas

The work area for "mucking work" has been divided into a working zone, a moving zone, and a parking zone. The mucking work of excavated soil is performed in a working zone within a range of 100 m from the face.

The tire shovel, which has started from the parking zone about 230 m from the face, travels in the moving zone of about 100 m and enters the working zone. The tire shovel puts the excavated soil scraped by the hydraulic excavator into the hopper near the rear of the working zone. The tire shovel collaborates with the hydraulic excavator to repeat loading into the hopper and finish the mucking work. After that, the tire shovel exits the working zone and retreats to the parking zone to complete the work.

The work area moves forward as the tunnel excavation progresses.

3.5 Risk Extraction

The risks extracted in the mucking work are the following four items that occur irregularly.

- Unauthorized workers enter the working zone and come into contact with operating machines.
- In the work zone, the driver who gets off the machine contacts another machine in operation.
- A machine starting from the parking lot comes into contact with people around
- The retreating machine comes into contact with the person who was in the parking lot.

3.6 Piloting a "Human-Machine contact risk reduction system"

3.6.1 System Component

A directional receiver was placed at the boundary between the working zone and the moving zone, and a normal receiver was placed every 10 m in the moving zone and the parking zone, and the whole was divided into 14 blocks. And a receiver was installed on the ceiling of the machine driver's seat. It receives the BLE (Bluetooth Low Energy) transmitted by the driver and monitors the presence of leaving the machine. Two transmitters are installed for each person and machine. The transmitter transmits a BLE signal that identifies the individual. The receiver installed in the tunnel mine configures a mesh network with multiple units, and the received BLE signal is stored in the cloud server from the Gateway via the on-site network. In the cloud, the positional relationship between the person and the machine is specified from the collected information, and the difference from the set permission state is determined. When an abnormality is detected, an alert signal is transmitted to the warning lighting device. The warning lighting device is arranged at the boundary between the working zone and the moving zone. When the PLC (Programmable Logic Controller) receives an alert signal, it immediately emits a loud alarm and simultaneously projects a blinking red and white LED beam light on the face. (Figure 5,6)

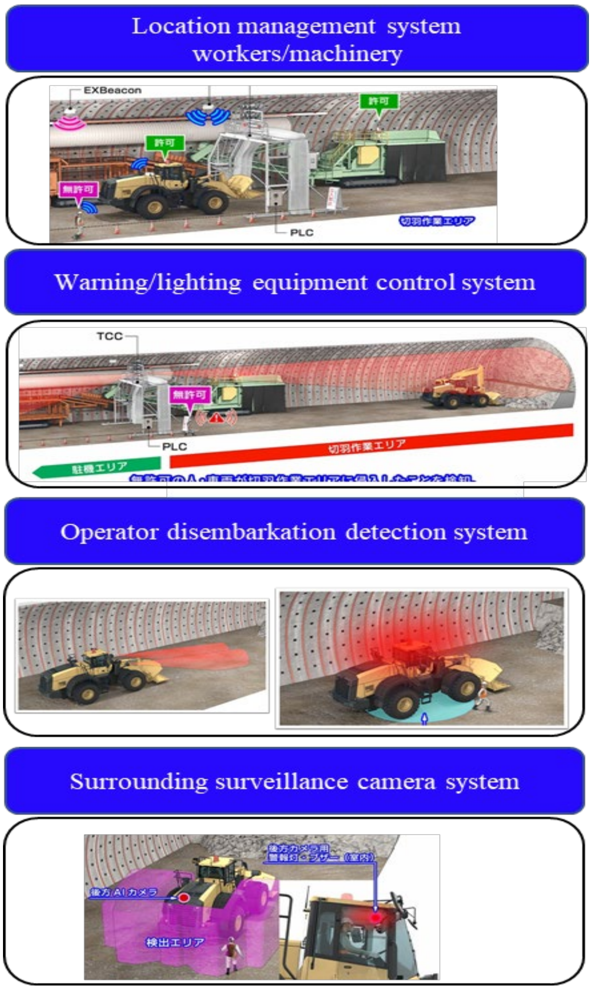

Figure 5. Human-Machine contact risk reduction system

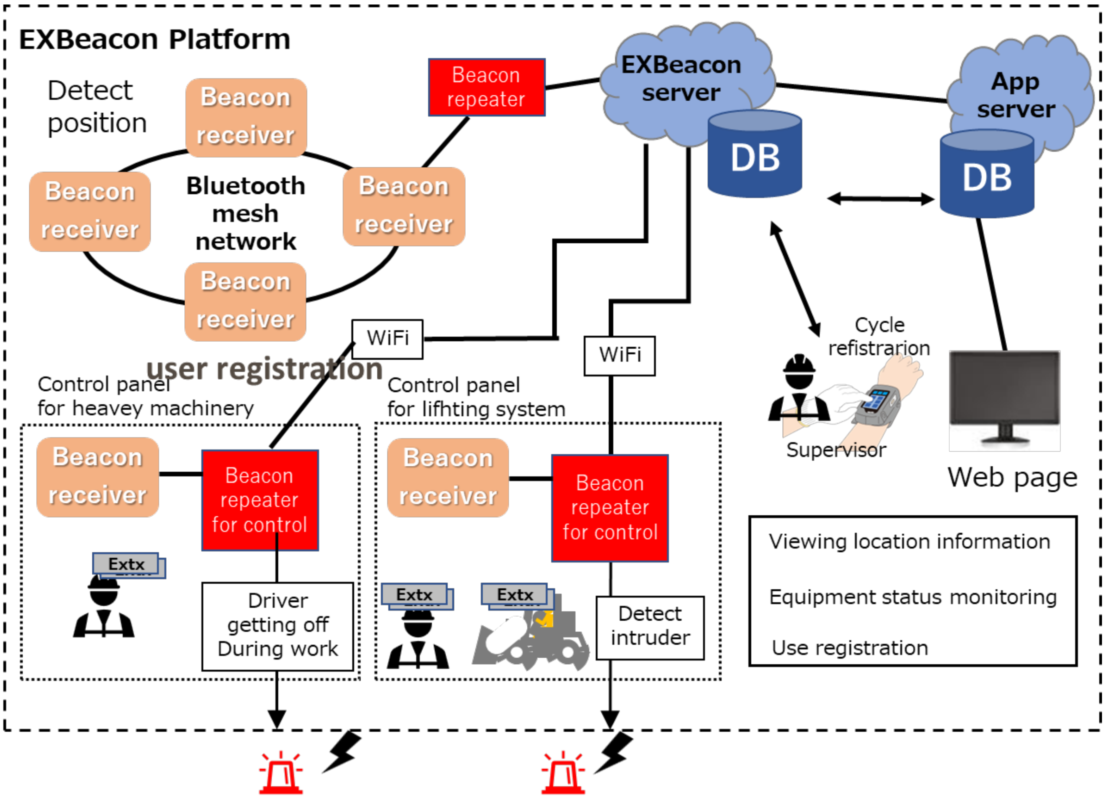

Figure 6. System block diagram

3.6.2 Site of Application

This system was introduced to the construction of the Kumamoto Route 57 TAKIMUROZAKA Tunnel West (first stage) construction (high standard road, construction extension = 2,679m, excavation section = 107m2).

3.6.3 Rules of Operation

- The site manager should register the mucking work permission ID and combination conditions before the work.
- Daily inspection of the system should be carried out by all supervisors and workers before starting work.
- The person in charge of monitoring carries the control tablet.
- The person in charge of monitoring switches the safety system to the "mucking mode" during mucking work.
- When the warning lighting system is activated, the machine operator makes an emergency stop.
- The person in charge of monitoring cannot cancel the alarm until the cause of the alarm is eliminated.
- The site manager collects the number of reports, IDs, and logs to inform workers and improve work.

3.6.4 Procedure for Adjusting the Safety System

Since a large machine is installed inside the tunnel mine under construction and the machine operates in a narrow work zone, the radio wave system tends to be unstable. Even in this introduction, several malfunctions occurred. There was a big difference between the ID position reproduced in the cyber space on the cloud and the position in the actual physical space, causing the ID position to move confusion in the tunnel in the cyber space. Further, at the boundary between the work zone and the moving zone, there was a false detection that a worker in the moving zone was in the working zone.

BLE transmission/reception in a tunnel mine is apt to cause multipath due to the reflection of the machines located in the mine and the moving machines. Even if the reception strength is weak, if the number of BLE transmission receptions fluctuates, it may be erroneously determined that there is a transmitter in the vicinity. The safety system adjustment procedure was established for these problems.

Step1. Divide the adjustment scene into whether the machine is operating or not.

Step2. In a static environment where there is no machine operation, repeat the receiver placement verification at intervals of 50 cm, analyze the radio wave intensity characteristics, and determine the optimal installation position.

Step3. In a dynamic environment with machine operation, analyze the radio wave strength characteristics and determine the optimum combination of reception strength thresholds.

3.6.5 Implementation Process Framework

Generally, when introducing a new system to the field, it is important to understand the theory, foster appropriate operation methods and improvement consciousness, and share consciousness with the development team. If the site manager and workers have a voluntary intention, they will succeed. is there. The education of safety concept and the new system by the development team was repeated using animated videos. A dedicated instructor was assigned to the site to practice the operation confirmation and inspection methods of the new system equipment at "On Job Training (OJT) ". OJT was repeatedly carried out for the mechanical and electrical engineering staff because the procedure for eliminating false positives requires specialized technical knowledge to analytical the radio characteristics and reset thresholds.

3.6.6 Effects of Introduction

Here, the introduction effects are summarized.

- Unauthorized entry into the work zone and disembarking from the driver's machine could be quickly shared as a risk.
- The warning from the warning lighting device surely guided the stoppage of the machine operation, and the risk of being overlooked became zero
- The loud alarm and the intense red and white flashing projection caused psychological strain on the machine driver, and the initial action of the machine stop for the risk occurrence was accelerated.
- Workers began efforts to prevent short-circuiting work violations. This is because warning issuance leads to a reduction in work efficiency. Intentional disembarkation from the machine in the work zone was reduced.
- The frequency of cleaning and checking not only the equipment that constitutes the safety system but also the machine itself has been improved. In addition, they became more sensitive to machine failures and reduced the frequency of repairs.
- The safety system operation at the installation site has received level 1 certification from IGSAP (Safety Global Promotion Organization) as a technical measure that complies with Safety 2.0. [12]

4 Conclusion

This paper has seen a trial example of a safety system for collaborative safety for human-machine collaboration. The risk assessment in the construction field was reviewed based on the flow of machine safety.

The concept of coordinated safety (Safety 2.0) and Safeguarding Supportive system was highly evaluated by workers and field managers who work on the front lines of the field. “We understand the need, and I feel that productivity will be improved by the support system.” (Figure 7)

Figure 7. Warning by blinking LED light

It is expected that robot technology will continue to evolve in the future, and a more advanced production system will be constructed in which humans, machines, and the environment will be firmly connected by IoT and IoP (Internet of Process). Standards, standards, rules and frameworks are important for maximizing the Safety 2.0 effect with a Safeguarding Supportive system.

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